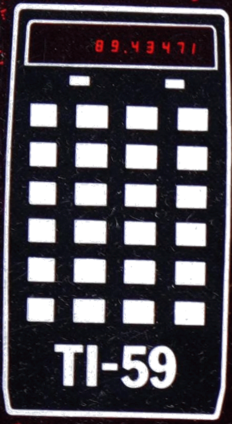
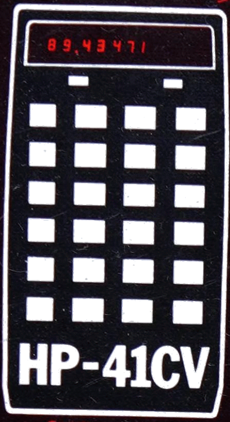




Instrument Engineering Programs

Proven, interactive programs for quickly and easily determining instrumentation requirements

Stanley W. Thrift

TI-59 and HP-41CV Instrument Engineering Programs

Gulf Publishing Company
Book Division
Houston, London, Paris, Tokyo

TI-59 and HP-41CV Instrument Engineering Programs

Stanley W. Thrift

Catalytic Enterprises Limited
Sarnia, Ontario, Canada

TI-59 and HP-41CV Instrument Engineering Programs

Library of Congress Cataloging in Publication Data

Thrift, Stanley W., 1926–

TI-59 and HP-41CV instrument engineering programs.

Includes index.

1. Engineering instruments—Data processing. 2. TI Programmable 59 (Calculating–machine) 3. HP–41 (Calculating–machine) I. Title.

TA165.T45 1983 620'.0028'5425 82-20920

ISBN 0-87201-387-1

Contents

Preface

The primary purpose of this book is to present a complete and coordinated set of instrument engineering programs for use on the TI-59 and the HP 41CV programmable calculators. By using these programs, the instrument engineer can eliminate the mathematical chores that would be necessary to determine instrument requirements and instead concentrate on the real engineering problems. This book also provides a single source of formulas and data associated with instrument selection.

The programs are self prompting, making user instructions unnecessary after a few basic ground rules are understood. Every effort has been made to simplify program use. They are all loaded, initiated, and used in the same manner. All input and outputs are identified and units specified to avoid confusion.

Programs are included to calculate specific weight and compressibility factors, which are required in many instrument calculations, but which are not readily available from other sources. Charts and tables of standard and typical data are also included for many common liquids and gases.

The programs have been developed over the past ten years and have been in constant use by the instrument engineering personnel at Catalytic Enterprises Limited, Sarnia, Ontario.

Personal calculators have always been the first choice for calculations, even though a time-shared computer has been available. The immediate access, the instant answers, and the ease of recalculation to optimize selections have always given the programmable calculator the edge.

I am indebted to Ralph Lee and George Royer for invaluable assistance in editing the text, to the many associates who provided feedback over the years, to the manufacturers and publishers who permitted their material to be included, to the typists who had to cope with those ghastly formulas, and finally to Catalytic Enterprises Limited, which made it all possible.

Stanley W. Thrift
Catalytic Enterprises Limited

TI-59 Features and Functions

Keyboard And Instruction Key Codes

Key	Key Code	Key	Key Code	Key	Key Code	Key	Key Code	Key	Key Code
A'	16	B'	17	C'	18	D'	19	E'	10
A	11	B	12	C	13	D	14	E	15
		INV	27	log	28	CP	29	CLR	20
2nd	Merged	INV	22	$\ln x$	23	CE	24	CLR	25
Pgm	36*	P→R	37	sin	38	cos	39	tan	30
LRN	None	$x \rightleftarrows t$	32	x^2	33	$\sqrt{x}$	34	$1/x$	35
Ins	None	CMs	47	Exc	48*	Prd	49*	Ind	40 (or merged)
SST	None	STO	42*	RCL	43*	SUM	44*	y^x	45
Del	None	Eng	57	Fix	58*	Int	59	$\|x\|$	50
BST	None	EE	52	(	53	)	54	÷	55
Pause	66	$x=t$	67*	Nop	68	Op	69*	Deg	60
GTO	61*	7	07	8	08	9	09	×	65
Lbl	76*	$x \geq t$	77*	$\Sigma+$	78	$\bar{x}$	79	Rad	70
SBR	71*	4	04	5	05	6	06	−	75
St flg	86*	If flg	87*	D.MS	88	π	89	Grad	80
RST	81	1	01	2	02	3	03	+	85
Write	96	Dsz	97*	Adv	98	Prt	99	List	90
R/S	91	0	00	.	93	+/−	94	=	95

*Keys requiring instructions or addresses to be complete.

Note: The Ind instruction is sometimes numerically merged with the code of the key it is used with.

There is a MYLAR** polyester film sheet called a "Key Code Overlay" that comes with your calculator. When placed over the keys, it shows the key code associated with each key.

**A registered trademark of DuPont.

TI-59 Printer Listing and Key Sequence

Printer Listing	Key Sequence
A – E	A – E
A' – E'	2nd A' – 2nd E'
ADV	2nd Adv
BST	See Note Below
CE	CE
CLR	CLR
CP	2nd CP
CMS	2nd CMs
COS	2nd cos
DEG	2nd Deg
DEL	See Note Below
DMS	2nd D.MS
DSZ	2nd Dsz
EE	EE
ENG	2nd Eng
EQ	2nd $x=t$ ■
EX*	2nd Exc 2nd Ind
EXC	2nd Exc
FIX	2nd Fix
GE	2nd $x \geq t$
GO*	GTO 2nd Ind
GRD	2nd Grad
GTO	GTO
I EQ	INV 2nd $x=t$ † ■
I GE	INV 2nd $x \geq t$ † ■
I Σ+	INV 2nd Σ+ †
ICOS	INV 2nd cos †
IDMS	INV 2nd D.MS †
IDSZ	INV 2nd Dsz †
IFF	2nd If flg ■
IFIX	INV 2nd Fix †
IIFF	INV 2nd If flg † ■
IINT	INV 2nd Int †
ILNX	INV ln$x$ †

Printer Listing	Key Sequence
ILOG	INV 2nd log †
IND	2nd Ind
INS	See Note Below
INT	2nd Int
INV	INV
IPD*	INV 2nd Prd 2nd Ind †
IP/R	INV 2nd P→R †
IPRD	INV 2nd Prd †
ISBR	INV SBR †
ISIN	INV 2nd sin †
ISM*	INV SUM 2nd Ind †
ISTF	INV 2nd St flg †
ISUM	INV SUM †
ITAN	INV 2nd tan †
Ix̄	INV 2nd $\bar{x}$ †
IXI	2nd $\lvert x \rvert$
IY^X	INV y^x †
LBL	2nd Lbl
LNX	ln$x$
LOG	2nd log
LRN	See Note Below
LST	2nd List
NOP	2nd Nop
OP	2nd Op
OP*	2nd Op 2nd Ind
PAU	2nd Pause
PD*	2nd Prd 2nd Ind
PG*	2nd Pgm 2nd Ind
PGM	2nd Pgm
P/R	2nd P→R
PRD	2nd Prd
PRT	2nd Prt
RAD	2nd Rad
RC*	RCL 2nd Ind

Printer Listing	Key Sequence
RCL	RCL
R/S	R/S
RST	RST
RTN	INV SBR
SBR	SBR
SIN	2nd sin
SM*	SUM 2nd Ind
SST	See Note Below
ST*	STO 2nd Ind
STF	2nd St flg
STO	STO
SUM	SUM
TAN	2nd tan
WRT	2nd Write
X ≷ T	$x \rightleftarrows t$
X^2	x^2
$\bar{x}$	2nd $\bar{x}$
IXI	2nd $\lvert x \rvert$
1/X	$1/x$
$\sqrt{x}$	$\sqrt{x}$
Y^X	y^x

SYMBOLS

Σ+
π
)
(
−
+
×
÷
=
.
+/−

NOTE: This instruction is only seen when its key is encountered while listing a program. Because the key code cannot be placed in program memory by pressing the key, the key code can only be a remnant from the edit of some other instruction and should be corrected.

† Printed in trace mode only.

■ TI Programmable 58C only: The symbol "▲" prints during trace when a branch is taken.

HP 41CV Function Index

All HP-41C functions can be recorded as instructions in program memory except those indicated. Functions with one name for keyboard execution and a second name for display execution are shown adjacent to each other in the columns below (e.g., [√x] on the keyboard and SQRT in the display). Unless otherwise noted, all of the following functions can be executed from the display and reassigned. Functions unique to the ALPHA mode keyboard are marked with *. Note that only the functions on the normal or ALPHA mode keyboard are shown as key functions, even though all HP-41C functions may be assigned to the keyboard (except those indicated). To execute a function from the display, press [XEQ] [ALPHA], key in the alpha characters shown, then press [ALPHA].

Function: Display Execution	Function: Keyboard Execution	Description
	[■]	Shift key Not programmable or assignable.
+	[+]	Addition operator
−	[−]	Subtraction operator
×	[×]	Multiplication operator
/	[÷]	Division operator
1/X	[1/x]	Reciprocal
10↑X	[10^x]	Common antilogarithm
ABS		Absolute value
ACOS	[COS⁻¹]	Arc cosine
ADV		Advance paper if printer is in system
AOFF	[ALPHA] mode key	ALPHA mode off The ALPHA mode *key* is not programmable or assignable.
AON	[ALPHA] mode key	ALPHA mode on The ALPHA mode *key* is not programmable or assignable.
	[APPEND] *	Append ALPHA display Not assignable, not executable.
ARCL	[ARCL] *	ALPHA recall. Requires 2-digit, stack, indirect 2-digit, or indirect stack address
ASHF		ALPHA shift left
ASIN	[SIN⁻¹]	Arc sine
ASN	[ASN]	Assign. Requires function name and key location input Not programmable.
ASTO	[ASTO] *	ALPHA store. Requires 2-digit, stack, indirect 2-digit, or indirect stack address
ATAN	[TAN⁻¹]	Arc tangent

AVIEW	[AVIEW] *	ALPHA view
BEEP	[BEEP]	Beeper
BST	[BST]	Back step Not programmable.
CAT	[CATALOG]	Catalog list. Requires 1-number input. or indirect address Not programmable.
CF	[CF]	Clear program flag. Requires 2-digit, indirect 2-digit, or indirect stack address
CHS	[CHS]	Change sign
CLA	[CLA] *	Clear ALPHA register
CLD		Clear display
CLP		Clear program. Requires program name input Not programmable.
CLRG		Clear all storage registers
CLΣ	[CLΣ]	Clear statistics registers
CLST		Clear automatic memory stack
CLX	[CLX/A]	Clear X-register
COPY		Copy (download or copy). Requires ALPHA program name input Not programmable.
	[←] *	Correction key Not assignable, not programmable.
COS	[COS]	Cosine
D - R		Degrees to radians conversion
DEC		Octal to decimal conversion
DEG		Degrees mode
DEL		Delete program memory lines. Requires 3-number input Not programmable.
DSE		Decrement and skip if equal. Requires 2-digit, stack, indirect 2-digit, or indirect stack address
	[EEX]	Enter exponent
END		End of program
ENG	[ENG]	Engineering notation display. Requires 1-digit, indirect 2-digit, or indirect stack address
ENTER↑	[ENTER↑]	Enter number in X-register into Y-register
E↑X	[e^x]	Natural antilogarithm
E↑X-1		Natural antilogarithm for arguments close to zero
FACT		Factorial
FC?		"Flag clear" test. Requires 2-digit, indirect 2-digit, or indirect stack address
FC?C		"Flag clear" test and clear. Requires 2-digit, indirect 2-digit, or indirect stack address

FIX	[FIX]	Fixed point display. Requires 1-digit, indirect 2-digit, or indirect stack address
FRC		Fractional portion of number
FS?		"Flag set" test. Requires 2-digit, indirect 2-digit, or indirect stack address
FS?C		"Flag set" test and clear. Requires 2-digit, indirect 2-digit, or indirect stack address
GRAD		Grads mode
GTO	[GTO]	Go to. Requires 2-digit label, ALPHA program name, indirect 2-digit, or indirect stack address
GTO.	[GTO] [•]	Go to line number. Requires 3-number input or ALPHA label Not assignable, not programmable.
GTO..	[GTO] [•] [•]	Go to end of program memory and prepare calculator for new program Not programmable, not assignable.
HMS		Decimal hours to hours, minutes, seconds conversion
HMS+		Hours, minutes, seconds addition
HMS−		Hours, minutes, seconds subtraction
HR		Hours, minutes, seconds to decimal hours conversion
INT		Integer portion of number
ISG	[ISG]	Increment and skip if greater. Requires 2-digit, stack, indirect 2-digit, or indirect stack address
LASTX	[LASTX]	Recalls LAST X register contents to X-register
LBL	[LBL]	Label program. Requires 2-number label or ALPHA program name
LN	[LN]	Natural logarithm
LN1+X		Natural logarithm for arguments close to one
LOG	[LOG]	Common logarithm
MEAN		Mean
MOD		Modulo (remainder) operator
OCT		Decimal to octal conversion
OFF		Power off
	[ON]	Power on/off key Not programmable or assignable. Refer to ON and OFF.
ON		Power on (continuous) function Not programmable.
P - R	[P-R]	Polar to rectangular conversion
PACK		Pack program memory Not programmable.
%	[%]	Percent

%CH		Percent of change
PI	[π]	Pi
	[PRGM] mode key	Program mode key Not programmable.
PROMPT		Prompt
PSE		Pause
R↑		Roll up
R - D		Radians to degrees conversion
R - P	[R-P]	Rectangular to polar conversion
	[R/S]	Run/stop. Stops running program or starts a stopped program
RAD		Radians mode
RCL	[RCL]	Recall. Requires 2-digit, stack, indirect 2-digit, or indirect stack address
RDN	[R↓]	Roll down
RND		Round
RTN	[RTN]	Return
SCI	[SCI]	Scientific notation display. Requires 1-digit, indirect 2-digit, or indirect stack address
SDEV		Standard deviation
SF	[SF]	Set program flag. Requires 2-digit, indirect 2-digit, or indirect stack address
Σ+	[Σ+]	Accumulations for statistics
Σ−	[Σ-]	Accumulation correction
ΣREG		Statistical register block specification. Requires 2-digit, indirect 2-digit, or indirect stack address
SIGN		Sign, unary of *x*
SIN	[SIN]	Sine
SIZE		Size of register configuration (allocation). Requires 3-number input Not programmable.
SQRT	[√x]	Square root
SST	[SST]	Single step Not programmable.
ST+	[STO] [+]	Storage register addition. Requires 2-digit, stack, indirect 2-digit, or indirect stack address
ST−	[STO] [−]	Storage register division. Requires 2-digit, stack, indirect 2-digit, or indirect stack address
ST*	[STO] [×]	Storage register multiplication. Requires 2-digit, stack, indirect 2-digit, or indirect stack address
ST/	[STO] [÷]	Storage register division. Requires 2-digit, stack, indirect 2-digit, or indirect stack address

STO	[STO]	Store. Requires 2-digit, stack, indirect 2-digit, or indirect stack address
STOP	([R/S])	Stops program execution
TAN	[TAN]	Tangent
TONE		Tone of beeper. Requires 2-digit, indirect 2-digit, or indirect stack address
	[USER]	USER mode key. Not programmable or assignable.
VIEW	[VIEW]	View register contents. Requires 2-digit, stack, indirect 2-digit, or indirect stack address
X=0?	[x=0?]	X equal to 0 conditional test
X≠0?		X not equal to 0 conditional test
X<0?		X less than 0 conditional test
X<=0?		X less than or equal to 0 conditional test
X>0?		X greater than 0 conditional test
X=Y?	[x=y?]	X equal to Y conditional test
X≠Y?		X not equal to Y conditional test
X<Y?		X less than Y conditional test
X<=Y?	[x≤y?]	X less than or equal to Y conditional test
X>Y?	[x>y?]	X greater than Y conditional test
X<>		Exchange contents of X-register with any other register. Requires 2-digit, stack, indirect 2-digit, or indirect stack address
X<>Y	[x⇄y]	Exchange X- and Y-registers
XEQ	[XEQ]	Execute. Requires program or function name, label number or indirect address
X↑2	[x^2]	Square
Y↑X	[y^x]	Exponential

CHAPTER ONE

Use of the Programmable Calculator for Instrument Calculations

Instrument Engineering Calculations

There have been many schemes over the years to simplify instrument calculations. An instrument engineer's back drawer is full of flow slide rules, valve-sizing slide rules, nomographs, charts, and calculation sheets. All have been good in their time but have required practice and patience to use. Two people could never arrive at identical answers, and in many cases the answers were provisional only. Black Art was legend—it was well known that butterfly valves had a cavitation problem, but how big was it? Either the question was avoided or an answer found by bitter experience.

As computing power became readily available, complex equations to predict cavitation, noise, etc. were developed, and it became possible to select instruments scientifically. Computer availability then became a problem. Many instrument calculations require optimization, necessitating that the calculation be rerun until the best selection is found. Most time-sharing computers simply do not have the flexibility to do this economically.

Enter the programmable calculator. It is inexpensive, portable, accurate, and reliable, and has adequate computational and printing power. It is the answer to the instrument engineer's dilemma. With the programs listed in the following pages, and in the luxury of sitting at your own desk surrounded by your reference books, manufacturers' catalogs, and telephone, it is possible to do a complete mathematical analysis using any combination of input data and obtain the answers immediately.

As with any computer program, it is not necessary that you understand the program before you use it. You should be aware of the formulas used and should try a few calculations with known answers in order to gain confidence in the program. However, there is not too much to be gained by trying to understand the program. Programming skills and engineering skills are not particularly related; after all, everyone drives cars, but few appreciate what goes on under the hood.

Programmable Calculators

There are two programmable calculators available today powerful enough to perform the calculations required:

1. The Texas Instruments TI 59
2. The Hewlett Packard HP 41CV

They should be obtained with the printer accessory so that a permanent record can be retained. The card reader and rechargeable battery pack should also be purchased for the HP 41CV (it is included with the TI 59).

The selection is very much a personal choice. The following comments may be helpful.

1. The largest program listed uses all of the TI 59 capability yet less than half that of the HP 41CV.
2. The TI 59 plus printer has been advertised for less than $400.00. The HP 41CV may cost at least three times as much (at this printing).
3. The TI 59 uses an AOS (Algebraic Operating System); the HP 41CV uses RPN (Reverse Polish Notation). Both arrive at the same result in the same time, and the program user will never know the difference.

Program Storage

The ideal way to store the programs would be to have them all permanently in memory, for they would all then be instantly available for use and updating. It would take approximately 30K bytes to store this set of programs. Unfortunately, this is not yet available. The best compromise is still the magnetic cards.

The TI 59 calculator works best on programs that have been recorded on the particular calculator using the cards. Cards recorded on other machines have occasionally been rejected, and it has then been necessary to read the program, ignoring the rejection signs, print the program, correct the errors, and then re-record the card. This is considerably faster than punching the complete program in from the beginning. Our experience has indicated only one or two errors needing to be corrected.

Both machines have the capability of recording protected cards. These cards can be read and executed any number of times but cannot be copied, viewed, or altered. It is recommended that cards for general service be recorded this way so that the program cannot be changed inadvertently and a wrong answer obtained.

The cards appear to have an indefinite life. Dirt and fingerprints will occasionally cause a misread. However, in our experience a cleanup of the card and head has always rectified the problem.

The TI 59 takes two cards for each program. The HP 41CV requires between five and seven, depending on the length of the program.

The HP 41CV wand and barcode system has not been found to be practical. The programs would take approximately eight pages of barcode each. They are difficult to produce and change and require considerable concentration to read into the machine.

User Instructions

Each calculator is provided with an excellent instruction book. It describes in considerable detail all of the functions and capabilities of the machine. It is, however, a ponderous document, and while the reader is encouraged to ultimately read and understand it, only the following instructions are necessary to use the programs.

Texas Instruments TI 59 and Printer

1. Plug in the power cord.
2. Energize the printer with the slide switch on the side.
3. Switch the calculator on.
4. For programs 10, 11, and 12, special memory partitioning is required. Press 5, 2nd OP, and 17. The display will show 559.49. For all other programs do nothing.
5. Press the CLR button.
6. Load the first side of the magnetic card by inserting the card into the lower slot on the right-hand side of the calculator. The motor will start and drive the card through to the left side.
7. Repeat steps 5 and 6 until both sides of both cards are entered. Note that the sequence of entry is unimportant and that a side entered more than once will be ignored.
8. Go to the operating instructions for the selected program.

Note: It is wise to switch the calculator off momentarily before entering a new program to ensure that all flags and return instructions are reset.

Hewlett Packard HP 41CV and Printer

1. Plug in and clip the card reader to the top of the calculator.
2. Connect the printer cord.

3. Check that the BAT annunciator on the calculator and printer is not on. If it is, recharge the batteries.
4. Switch the calculator on.
5. Switch the printer on.
6. Set the printer MODE switch to MAN, and INTENSITY as desired.
7. PRGM and ALPHA must be off. Press USER button on calculator.
8. Eighty storage registers are used for all programs. If the calculator is not set, press XEQ, ALPHA, SIZE, ALPHA, and 080.
9. Load program-card side one by inserting the card into the slot on the right-hand side of the card reader. The motor will start and drive the card through to the left-hand side.
10. Load both sides of the program cards as prompted by the display.
11. Load the data cards similarly.
12. Store a magnetic card in the groove above the calculator display to identify the user-defined keys A–J.
13. Go to the operating instructions for the selected program.

General Notes

1. Handle the magnetic cards by their edges to keep them clean.
2. The printing functions on both calculators work best if the decimal point is set at nine. Common sense is used to round out the answers.
3. Periodically test the calculator by using the diagnostic card and a sample calculation.
4. Use good-quality thermal paper. Poor-quality paper can gum the printing head, resulting in poor printing. After a few months, print on thermal paper will fade, so it is recommended that programs be photocopied.
5. Read the instruction manual. The programs will allow for manual calculations of input data. This makes for a very powerful combination of manual intermediate calculation capability.
6. Some invalid input data will cause calculator error conditions when running a program (e.g., dividing by zero, taking the square root of a negative number). Analyze the data and re-enter.
7. The E subroutine is a simplifed way of re-entering data and recalculating results without repeating the print routine. It is contained in most of the programs. To use it, all data must first be entered in the normal way and an answer obtained. To change an entry (e.g., entry 2), press 2, then E. The original value will be displayed. The new value is now entered; press R/S and the new value is stored and the old one discarded.

There are three choices from here.

- Change other entries in the same way.
- Press R/S again and recalculate the answer with minimum printing.
- Initiate the program for a complete automatic print of all data.

Note that once an entry is changed, a complete reprint must be made before the calculator is cleared for another calculation. On multiple choice programs it remembers which calculation was made and reprints that one, regardless of which initiation button is depressed.

8. A calculator printout for a typical calculation is provided for each program, along with charts and tables of process data for many common liquids and gases.

CHAPTER TWO

Control Valves

The control valve is a vital part of any control system, and it is still the most widely used final control element. Until recently, its sizing and selection was almost a Black Art. Many control problems can be traced to having the wrong valve installed.

There is a tendency to oversize a control valve by taking the largest flow it will have to pass, doubling it to make it operate at the mid-point, and then picking the next available larger size. This can lead to a rangeability problem on low flows, with the control valve trying to regulate flow and bouncing on its seat.

The undersized-valve problem is usually caused by increased plant throughput. It can be solved by cracking open the bypass valve, but with variable flowrates this is likely to lead to control problems. A far better solution is to purchase the valve with a larger body and a reduced trim if future increased flowrates are anticipated.

Cavitation occurs more often than one would expect. It is surprising how many plants have valves making that peculiar crackling noise. They only control successfully for a short period of time before requiring maintenance.

Valves in gas and vapor service experiencing large pressure drops can be the noisiest pieces of equipment in a plant (even while performing well and lasting a long time). It might be possible to reduce the noise with extra insulation, but in most cases a special low-noise valve is needed to solve the problem.

The cost of not selecting the right valve for the job can be very high (typical control valves and their characteristics are shown in Figure 2-1). Anti-cavitation and low-noise control valves may seem expensive compared to standard valves, but when correctly applied they can result in significant cost savings.

Mathematical methods of calculating estimated noise are available. The calculations are very onerous to perform manually. However, the following programs for the programmable calculator will solve the equations easily and accurately.

The formulas used are those in ANSI/ISA-S75.01 and in ISA "Handbook for Control Valves" by J. W. Hutchison, and the Masoneilan noise prediction formula.

The materials of construction for a control valve are determined by the process fluid; the body style by the opinions and practice of the user. From this point, the knowledge gained from the programs can be used.

Liquid Flow

The internal contours of some valve bodies are such that because of the relationship between velocity and pressure, the velocity of the liquid at one place in the body may have risen so high that the pressure falls below the vapor pressure of the liquid and pockets of vapor form. Farther along in the valve body the velocity may have decreased enough for the pressure to increase above the liquid vapor pressure. The vapor pockets implode with considerable noise and energy and can be extremely erosive. This is cavitation.

To avoid this, manufacturers publish a liquid recovery coefficient (F_L) to quantify the characteristic. A low F_L number (e.g., 0.5 for an angle valve) signifies a valve which will cavitate quicker than a valve with a higher F_L will (e.g., 0.9 for a globe valve). The lower the F_L, the greater the tendency to cavitate.

The program will calculate a minimum F_L from the process conditions. To avoid cavitation, a valve with a larger F_L must be selected. If this is not possible, an anti-cavitation trim should be selected. This is a special hard trim designed to keep the implosions away from the softer metal in the body. If this is not possible, a heavier valve body should be selected to avoid premature failure because of metal erosion.

Cavitation chokes the valve and reduces its capacity. The program recognizes this condition and compensates for it. In addition, if cavitation is occurring, its noise value (dBA) will be calculated and printed.

When the discharge pressure is lower than the liquid vapor pressure, the liquid will flash into a vapor as it passes through the valve. This is not as erosive on the valve as cavitation, but a hardened trim is usually justified. Flashing also affects valve capacity and is compensated for by this calculation.

Control valves are usually smaller than line size. It is a rule of thumb that in a properly designed system the control valve size should be one size less

(text continued on page 10)

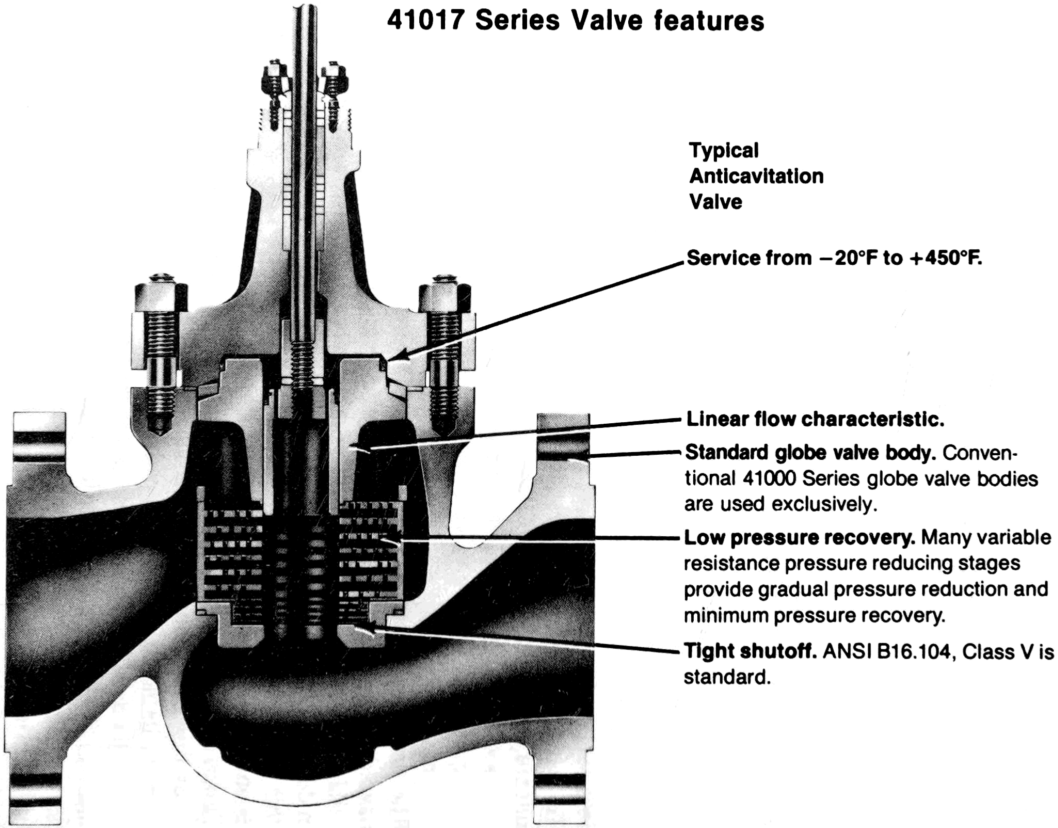
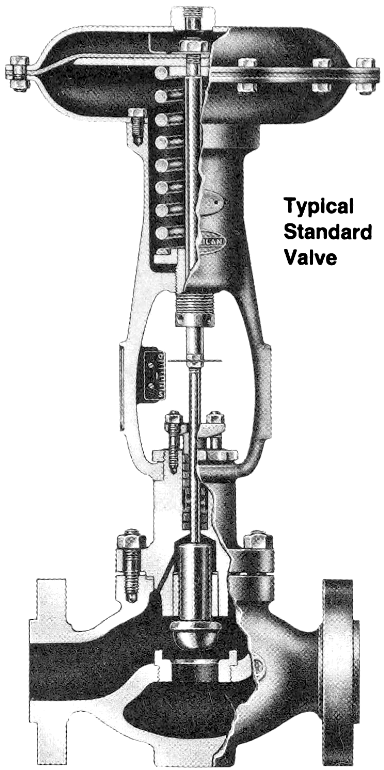
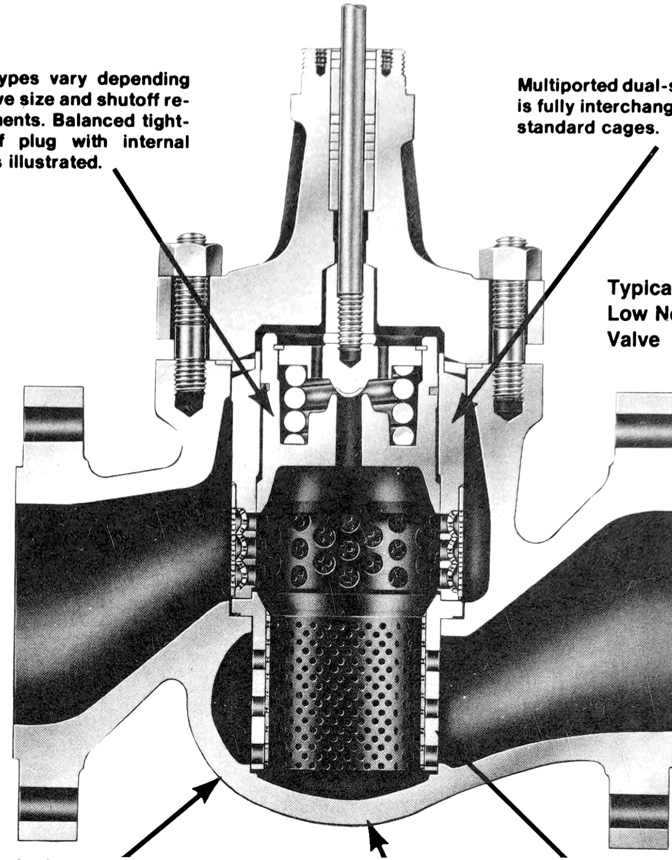


Figure 2-1. Typical control valves and their characteristics. (Courtesy Masoneilan International, Inc.) (Figure continued on next page.)

Fig. 2–1 continued



20000 Series Control Valve
with Direct Spring Diaphragm Actuator



than the line size. Spot checks over the years for deviations from this rule have shown that either the line is too small or that some special circumstances apply, such as an unusually high pressure drop. However, it should be noted that published control-valve capacities are based on line-size valves, and a piping geometry correction factor where required is provided in the program.

The viscosity of the liquid must be compensated for if the Reynolds number is less than 3000. For this, the valve-style modifier (F_d) is required.

The final calculated C_v includes correction factors for all the preceding if necessary.

Gas and Steam Flows

The first problem the program considers is the minimum size valve for sonic velocity. It is very often possible to select a valve having an adequate C_v yet still have sonic velocity at the outlet port. This creates a noise problem which cannot be overcome with a low-decibel trim if the noise level of the valve is too high (and it most likely will be for all but the smallest valves). A valve larger than the sonic size must be selected.

The final C_v has corrections for the gas expansion factor and for piping geometry similar to those for the liquid calculation.

The program will next ask for data to calculate the noise level. When this exceeds 80 dBA, select a special low-noise trim, extra pipe wall thickness, or a special valve. Extreme cases may require extra insulation on the pipe and auxiliary devices to take part of the pressure drop.

Noise is normally calculated at actual operating conditions. Therefore, run a calculation for the operating flowrate and F_L value. It is not normally necessary to consider worst conditions because they are usually short-term, and noise will usually be tolerated for that time period.

Two-Phase Flow

This program is a combination of the two previous programs and calculates C_v based on the effective specific weight. Cavitation is checked for and should be handled as for liquid flow.

Rangeability

By this time the body style, the trim style, and the valve size have been selected. The question now is will the valve control for the range of flowrates and pressure drops that will be encountered in service.

Valve manufacturers list the rangeability of various types of valves, which can be as high as 50:1. This means that if a valve has a rated C_v of 20, then it could be expected to control at a C_v of 0.4.

Determine the minimum flowrate and the maximum pressure drop that is expected and re-enter these values. Is the C_v more than the minimum value? Now determine the maximum flowrate and the minimum pressure drop. Is the C_v less than the maximum? If either is exceeded, try different valve sizes until the optimum is reached.

At this stage you can be very well assured that you have a valve ideally sized for the service.

Reliability of the Calculation System

If care is taken to ensure that the input process data are representative of the actual flowing conditions, then the formulas, which are essentially empirical, will predict the results with acceptable accuracy.

After several years experience sizing valves for LPG plants with liquids that cavitate and flash easily, and sizing noisy valves for vents and centrifugal compressor surge control, it has been found that problems can generally be traced to inaccurate input information. One exception was that the noise prediction program was not accurate for a 24-inch butterfly valve. The large C_v produced an unrealistically high sound pressure level.

Program 1
Liquid Flow

Program 1: User Instructions

a) Initiate program, press A.

b) Enter:

1. Flowrate, pounds per hour	Press R/S
2. Inlet pressure, PSIG	Press R/S
3. Pressure drop across the valve, PSI	Press R/S
4. Specific gravity at flow temperature, dimensionless	Press R/S
5. Absolute viscosity, centipoises	Press R/S
6. Liquid vapor pressure, PSIA	Press R/S
7. Liquid critical pressure, PSIA	Press R/S

c) Program calculates minimum liquid recovery factor F_L.

d) Enter:

8. Selected valve F_L, dimensionless	Press R/S

e) Program calculates preliminary C_v.
f) Using preliminary C_v, enter:

9. Valve size, inches, based on preliminary C_v	Press R/S
10. Pipe size, inches	Press R/S
11. Valve-style factor F_d, dimensionless	Press R/S

g) Program calculates final C_v.
h) If cavitation occurs, program calculates sound pressure level dBA.

Note: If final C_v is too small for the selected valve size, press entry number 9, press E, re-enter new valve size, press R/S, then press A for a new printout. The E subroutine can be used to change all input data in the same way.

Program 1: TI 59 Data Sheet

```
********************

  CV CALC LIQD

********************

ENTR  FLOW   PPH
    1135000.
ENTR  PRSS PSIG
        185.3
ENTR     ΔP  PSI
          75.
ENTR  FLOW    SG
          0.9
ENTR  VISC    CP
          0.6
ENTR VAPOR PRSS PSIA
          58.
ENTR  CRIT PRSS PSIA
        3206.
CALC    MIN    FL
 .7154930199
ENTR VALVE    FL
         0.85
CALC PRELM   CV
 276.2956012
ENTR VALVE SIZE    IN
           6.
ENTR  PIPE SIZE    IN
           8.
ENTR STYLE FACT    FD
           1.
CALC    CV
 278.9083383

********************
```

Program 1: TI 59 Register Loading

PARTITIONING
479.59

```
0.    00        0.    06
0.    01        0.    07
0.    02        0.    08
0.    03        0.    09
0.    04        0.    10
0.    05        0.    11
                0.    12
                0.    13
                0.    14
```

0.	15	302431.	38
0.	16	56.3845	39
0.	17	0.2945	40
0.	18	15352437.	41
0.	19	56.4632	42
.0718094234	20	1533.292837	43
.0001539571	21	7533.272837	44
.3084233398	22	2127.262536	45
.1289633805	23	3335172730.	46
33362413.	24	56.32	47
21131537.	25	56.31	48
3637452717.	26	33362422.	49
33243317.	27	4213333235.	50
36244617.	28	42243615.	51
4213274217.	29	33353636.	52
32.5654	30	21273243.	53
161413.5335	31	2724341600.	54
154200.5249	32	5151515151.	55
333624.4433	33	1513271500.	56
3622.5334	34	1731373500.	57
333323.5143	35	0.	58
2116.505224	36	0.	59
2431.415224	37		

Program 1: TI 59 Listing

SUBROUTINES

RESET FLAGS

```
000  16 A'
001  98 ADV
002  98 ADV
003  43 RCL
004  17  17
005  91 R/S
```

PRINT & STORE VARIABLES

```
006  76 LBL
007  10 E'
008  29 CP
009  01  1
010  44 SUM
011  58  58
012  73 RC*
013  58  58
014  22 INV
015  59 INT
016  52 EE
017  22 INV
018  52 EE
019  67  EQ
020  19 D'
021  85  +
022  05  5
023  07  7
024  95  =
025  17 B'
026  69 OP
027  21  21
028  73 RC*
029  01  01
030  87 IFF
031  00  00
032  00  00
033  37  37
034  91 R/S
035  72 ST*
036  01  01
037  73 RC*
038  01  01
039  99 PRT
040  61 GTO
041  10 E'
```

PRINT LINES

```
042  76 LBL
043  19 D'
044  01  1
045  44 SUM
046  58  58
047  73 RC*
048  58  58
049  76 LBL
050  17 B'
051  42 STO
052  59  59
053  73 RC*
054  59  59
055  69 OP
056  01  01
057  18 C'
058  69 OP
059  02  02
060  18 C'
061  69 OP
062  03  03
063  18 C'
064  69 OP
065  04  04
066  69 OP
067  05  05
068  92 RTN
```

DECODE LINES

```
069  76 LBL
070  18 C'
071  01  1
072  00  0
073  00  0
074  48 EXC
```

```
075  59  59
076  22  INV
077  59  INT
078  49  PRD
079  59  59
080  73  RC*
081  59  59
082  92  RTN
```

PRINT LINE OF STARS

```
083  76  LBL
084  16  A'
085  93  .
086  00  0
087  01  1
088  08  8
089  35  1/X
090  98  ADV
091  17  B'
092  98  ADV
093  92  RTN
```

RE-ENTER VARIABLES

```
094  76  LBL
095  15  E
096  99  PRT
097  85  +
098  01  1
099  95  =
100  42  STO
101  01  01
102  73  RC*
103  01  01
104  91  R/S
105  72  ST*
106  01  01
107  99  PRT
108  98  ADV
109  86  STF
110  00  00
111  86  STF
112  02  02
113  91  R/S
114  12  B
```

CALC P_1-F_FP_v

```
115  76  LBL
116  22  INV
117  53  (
118  71  SBR
119  23  LNX
120  75  -
121  43  RCL
122  07  07
123  65  ×
124  53  (
125  93  .
126  09  9
127  06  6
128  75  -
129  93  .
130  02  2
131  08  8
132  65  ×
133  53  (
134  43  RCL
135  07  07
136  55  ÷
137  43  RCL
138  08  08
139  54  )
140  34  √X
141  54  )
142  54  )
143  92  RTN
```

CALC P_1

```
144  76  LBL
145  23  LNX
146  53  (
147  43  RCL
148  03  03
149  85  +
150  01  1
151  04  4
152  93  .
153  07  7
154  54  )
155  92  RTN
```

MAIN PROGRAM ENTER DATA

```
156  76  LBL
157  11  A
158  22  INV
159  86  STF
160  02  02
161  01  1
162  42  STO
163  01  01
164  02  2
165  09  9
166  42  STO
167  58  58
168  16  A'
169  19  D'
170  16  A'
171  10  E'
```

CALC MIN F_L

```
172  76  LBL
173  12  B
174  43  RCL
175  04  04
176  55  ÷
177  71  SBR
178  22  INV
179  95  =
180  34  √X
181  42  STO
182  14  14
183  87  IFF
184  02  02
185  01  01
186  89  89
187  99  PRT
```

CALC PRELIM C_v

```
188  10  E'
189  43  RCL
190  02  02
191  55  ÷
192  05  5
193  00  0
194  00  0
195  55  ÷
196  53  (
197  43  RCL
198  04  04
199  65  ×
200  43  RCL
201  05  05
202  54  )
203  34  √X
204  95  =
205  42  STO
206  17  17
207  87  IFF
208  02  02
209  02  02
210  13  13
211  99  PRT
```

CALC F_{LP}

```
212  10  E'
213  53  (
214  53  (
```

```
215  01   1
216  75   -
217  53   (
218  43  RCL
219  10   10
220  55   ÷
221  43  RCL
222  11   11
223  54   )
224  33  X²
225  42  STO
226  01   01
227  54   )
228  33  X²
229  42  STO
230  59   59
231  65   ×
232  93   .
233  05   5
234  85   +
235  01   1
236  75   -
237  43  RCL
238  01   01
239  33  X²
240  95   =
241  65   ×
242  53   (
243  53   (
244  43  RCL
245  17   17
246  55   ÷
247  43  RCL
248  10   10
249  33  X²
250  54   )
251  33  X²
252  55   ÷
253  08   8
254  09   9
255  00   0
256  54   )
257  42  STO
258  01   01
259  85   +
260  43  RCL
261  09   09
262  33  X²
263  35  1/X
264  95   =
265  34  √X
266  35  1/X
267  42  STO
268  15   15
269  43  RCL
270  59   59
271  65   ×
272  01   1
273  93   .
274  05   5
275  65   ×
276  43  RCL
277  01   01
278  85   +
279  01   1
280  95   =
281  34  √X
282  49  PRD
283  17   17
284  35  1/X
285  42  STO
286  16   16
```

CALC F_y

```
287  65   ×
288  43  RCL
289  14   14
290  55   ÷
291  43  RCL
292  15   15
293  95   =
294  35  1/X
295  32  X:T
296  22  INV
297  86  STF
298  01   01
299  01   1
300  22  INV
301  77   GE
302  43  RCL
303  86  STF
304  01   01
305  32  X:T
306  76  LBL
307  43  RCL
308  42  STO
309  13   13
310  22  INV
311  49  PRD
312  17   17
```

CALC F_R

```
313  43  RCL
314  37   37
315  32  X:T
316  03   3
317  04   4
318  93   .
319  06   6
320  65   ×
321  43  RCL
322  12   12
323  65   ×
324  43  RCL
325  02   02
326  55   ÷
327  43  RCL
328  06   06
329  55   ÷
330  43  RCL
331  15   15
332  34  √X
333  55   ÷
334  43  RCL
335  17   17
336  34  √X
337  65   ×
338  53   (
339  53   (
340  43  RCL
341  15   15
342  65   ×
343  43  RCL
344  17   17
345  55   ÷
346  08   8
347  09   9
348  00   0
349  55   ÷
350  43  RCL
351  11   11
352  33  X²
353  54   )
354  33  X²
355  85   +
356  01   1
357  54   )
358  45  YX
359  93   .
360  02   2
361  05   5
362  95   =
363  42  STO
364  18   18
365  77   GE
366  24  CE
367  32  X:T
368  93   .
369  01   1
370  77   GE
371  44  SUM
372  32  X:T
373  45  YX
374  43  RCL
```

```
375   22   22
376   65   ×
377   43  RCL
378   23   23
379   75   -
380   43  RCL
381   21   21
382   65   ×
383   43  RCL
384   18   18
385   75   -
386   43  RCL
387   20   20
388   95   =
389   42  STO
390   19   19
391   22  INV
392   49  PRD
393   17   17
```

PRINT C_v

```
394   76  LBL
395   24  CE
396   43  RCL
397   17   17
398   99  PRT
```

DETERMINE CAVITATION

```
399   22  INV
400   87  IFF
401   01   01
402   25  CLR
403   71  SBR
404   23  LNX
405   32  X:T
406   43  RCL
407   07   07
408   85   +
409   43  RCL
410   04   04
411   95   =
412   77   GE
413   25  CLR
```

CALC dBA

```
414   43  RCL
415   48   48
416   17  B'
417   29  CP
418   43  RCL
419   17   17
420   65   ×
421   43  RCL
422   09   09
423   95   =
424   28  LOG
425   65   ×
426   01   1
427   00   0
428   85   +
429   53   (
430   43  RCL
431   04   04
432   75   -
433   43  RCL
434   14   14
435   33  X²
436   65   ×
437   71  SBR
438   22  INV
439   65   ×
440   43  RCL
441   13   13
442   54   )
443   28  LOG
444   65   ×
445   08   8
446   85   +
447   53   (
448   71  SBR
449   23  LNX
450   75   -
451   43  RCL
452   04   04
453   75   -
454   43  RCL
455   07   07
456   54   )
457   28  LOG
458   65   ×
459   02   2
460   00   0
461   85   +
462   03   3
463   03   3
464   95   =
465   99  PRT
466   76  LBL
467   25  CLR
468   22  INV
469   87  IFF
470   02   02
471   42  STO
472   91  R/S
473   76  LBL
474   42  STO
475   81  RST
```

Program 1: HP 41CV Data Sheet

```
************

*CV LIQUID*

************

ENTER  FLOW PPH
     1,135,000.00     ***
ENTER  PRSS PSIG
           185.30     ***
ENTER dP PSI
            75.00     ***
ENTER  FLOW SG
             0.90     ***
ENTER  VISC cP
             0.60     ***
ENTER VAPOUR PRSS PSIA
            58.00     ***
ENTER   CRIT PRSS PSIA
         3,206.00     ***
CALC  MIN  FL
             0.72     ***
ENTER VALVE  FL
             0.85     ***
CALC  PRELIM
CV
           276.30     ***
ENTER VALV SIZE IN
             6.00     ***
ENTER PIPE SIZE IN
             8.00     ***
ENTER STYLE FACT FD
             1.00     ***
CALC   CV
           327.17     ***
CALC  dBA
           100.87     ***

************

           327.17
```

```
************

*CV LIQUID*

************

ENTER  FLOW PPH
    1,135,000.00    ***
ENTER  PRSS PSIG
          185.30    ***
ENTER dP PSI
           75.00    ***
```

```
ENTER  FLOW SG
            0.90    ***
ENTER  VISC cP
            0.60    ***
ENTER VAPOUR PRSS PSIA
           58.00    ***
ENTER   CRIT PRSS PSIA
        3,206.00    ***
CALC  MIN  FL
            0.72    ***
ENTER VALVE  FL
            0.85    ***
```

```
CALC  PRELIM
CV
          276.30    ***
ENTER VALV SIZE IN
            6.00    ***
ENTER PIPE SIZE IN
            8.00    ***
ENTER STYLE FACT FD
            1.00    ***
CALC   CV
          278.91    ***
************
```

Program 1: HP 41CV Register Loading

SIZE 080

```
R00=  0.000000
R01=  0.000000
R02=  0.000000
R03=  0.000000
R04=  0.000000
R05=  0.000000
R06=  0.000000
R07=  0.000000
R08=  0.000000
R09=  0.000000
R10=  0.000000
R11=  0.000000
R12=  0.000000
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  0.000000
R17=  0.000000
R18=  0.000000
R19=  0.000000
R20=  0.071809
R21=  0.000154
R22=  0.308423
R23=  0.128963
R24=  0.562500
R25=  0.191406
R26= "*CV LI"
R27= "QUID* "
R28=  0.000000
R29=  0.000000
R30=  26.270000
R31=  57.495000
R32=  57.515200
R33=  57.530000
R34=  57.495400
R35=  57.606100
R36=  57.625164
R37=  57.655164
R38=  0.000000
R39=  56.660000
R40=  57.676300
R41=  0.000000
R42=  56.686900
R43=  57.707100
R44=  57.727100
R45=  57.737475
R46=  0.000000
R47=  56.690000
R48=  56.760000
R49= " FLOW "
R50= "PPH   "
R51= " PRSS "
R52= "PSIG  "
R53= "dP PSI"
R54= "SG    "
R55= "******"
R56= "CALC "
R57= "ENTER "
R58=  47.000000
R59=  0.000000
R60= " VISC "
R61= "cP    "
R62= "VAPOUR"
R63= " FL   "
R64= "PSIA  "
R65= "  CRIT"
R66= "MIN FL"
R67= "VALVE "
R68= "PRELIM"
R69= " CV   "
R70= "VALV S"
R71= "IZE IN"
R72= "PIPE S"
R73= "STYLE "
R74= "FACT F"
R75= "D     "
R76= "dBA   "
R77=  0.066184
R78=  0.000000
R79=  0.000000
```

Program 1: HP 41CV Listing

SUBROUTINES

```
01♦LBL "CV LIQ"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
```

```
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 GTO d
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53♦LBL 01
54 XEQ J
55 GTO e
```

RE-ENTER VARIABLES

```
56♦LBL "REENTER"
57 ADV
58 1
59 +
60 STO 01
61 RCL IND 01
62 XEQ J
63 STOP
64 XEQ J
65 STO IND 01
66 ADV
67 SF 00
68 SF 02
69 STOP
70 GTO 02
```

BYPASS PRINTER

```
71♦LBL J
72 FC? 55
73 GTO 01
74 PRX
75 RTN
76♦LBL 01
77 VIEW X
78 RTN
```

CALC P_1-F_FP_V

```
79♦LBL B
80 .96
81 RCL 07
82 RCL 08
83 /
84 SQRT
85 .28
86 *
87 -
88 RCL 07
89 *
90 CHS
91 XEQ C
92 +
93 RTN
```

CALC P_1

```
94♦LBL C
95 RCL 03
96 14.7
97 +
98 RTN
```

MAIN PROGRAM ENTER DATA

```
99♦LBL A
100 CF 02
101 1
102 STO 01
103 29
104 STO 58
105 XEQ a
106 XEQ d
107 XEQ a
108 XEQ e
```

CALC MIN F_L

```
109♦LBL 02
110 0
111 STO 00
112 RCL 04
113 XEQ B
114 /
115 SQRT
116 STO 14
117 FS? 02
118 GTO 01
119 XEQ J
```

CALC PRELIM C_V

```
120 XEQ e
121♦LBL 01
122 RCL 04
123 RCL 05
124 *
125 SQRT
126 500
127 *
128 1/X
129 RCL 02
130 *
131 STO 17
132 FS? 02
133 GTO 01
134 XEQ J
```

CALC F_{LP}

```
135 XEQ e
136♦LBL 01
137 1
138 RCL 10
139 RCL 11
140 /
141 X↑2
142 STO 24
143 -
144 X↑2
145 STO 25
146 .5
147 *
148 1
149 +
150 RCL 24
151 X↑2
152 -
153 RCL 17
154 RCL 10
155 X↑2
156 /
157 X↑2
158 890
159 /
160 STO 77
161 *
162 RCL 09
163 X↑2
164 1/X
165 +
166 SQRT
167 1/X
168 STO 15
```

CALC F_P

```
169 RCL 25
170 1.5
171 *
172 RCL 77
173 *
```

```
174 1
175 +
176 SQRT
177 ST* 17
178 1/X
179 STO 16
```

CALC F_y

```
180 RCL 14
181 *
182 RCL 15
183 /
184 1/X
185 CF 01
186 1
187 X<=Y?
188 GTO 03
189 SF 01
190 RDN
191◆LBL 03
192 STO 13
193 ST/ 17
```

CALC F_R

```
194 34.6
195 RCL 12
196 *
197 RCL 02
198 *
199 RCL 06
200 /
201 RCL 15
202 SQRT
203 /
204 RCL 17
205 SQRT
206 /
207 RCL 15
208 RCL 17
209 *
210 890
211 /
212 RCL 11
213 X↑2
214 /
215 X↑2
216 1
217 +
218 ENTER↑
219 .25
220 Y↑X
221 *
222 STO 18
223 3000
224 X<=Y?
225 GTO 04
226 RDN
227 .1
228 X>Y?
229 GTO 07
230 RCL 18
231 ENTER↑
232 RCL 22
233 Y↑X
234 RCL 23
235 *
236 RCL 21
237 RCL 18
238 *
239 -
240 RCL 20
241 -
242 STO 19
243 ST/ 17
```

PRINT C_v

```
244◆LBL 04
245 RCL 17
246 XEQ J
```

DETERMINE CAVITATION

```
247 FC? 01
248 GTO 05
249 XEQ C
250 RCL 07
251 RCL 04
252 +
253 X>Y?
254 GTO 05
```

CALC dBA

```
255 RCL 17
256 RCL 09
257 *
258 LOG
259 10
260 *
261 XEQ B
262 RCL 14
263 X↑2
264 *
265 RCL 13
266 *
267 CHS
268 RCL 04
269 +
270 LOG
271 8
272 *
273 +
274 XEQ C
275 RCL 04
276 -
277 RCL 07
278 -
279 LOG
280 20
281 *
282 +
283 33
284 +
285 STO 00
286 SF 12
287 RCL 48
288 XEQ b
289 RCL 00
290 XEQ J
291◆LBL 05
292 FS? 02
293 GTO 06
294 CF 00
295 CF 01
296 XEQ a
297◆LBL 06
298 RCL 00
299 RCL 17
300 VIEW X
301 BEEP
302 STOP
303◆LBL 07
304 0
305 1/X
306 STOP
307 END
```

("Program 1: Sequence of Calculations" begins on next page)

Program 1: Sequence of Calculations

1. Calculate minimum pressure recovery factor from process conditions.

$$F_L = \sqrt{\frac{\Delta P}{P_1 - P_v\left(.96 - .28\sqrt{\frac{P_v}{P_c}}\right)}}$$

2. Calculate preliminary valve size.

$$C_v = \frac{W}{500\sqrt{\Delta P G_f}}$$

3. Calculate contained pressure recovery factor and piping geometry factor.

$$F_{LP} = \left[\frac{.5\left(\left(1 - \left(\frac{d}{D}\right)^2\right)^2 + \left(1 - \left(\frac{d}{D}\right)^4\right)\right)}{890} \cdot \left(\frac{C_v}{d^2}\right)^2 + \frac{1}{F_L^2}\right]^{-1/2}$$

4. Calculate piping geometry factor.

$$F_P = \left[1 + \left(\frac{1.5\left(1 - \left(\frac{d}{D}\right)^2\right)^2}{890}\left(\frac{C_v}{d^2}\right)^2\right)\right]^{-1/2}$$

5. Calculate choked flow factor.

$$F_y = \frac{F_{LP}}{F_P}\sqrt{\frac{P_1 - P_v\left(.96 - .28\sqrt{\frac{P_v}{P_c}}\right)}{\Delta P}}$$

Limit $F_y < 1$

6. Calculate valve Reynolds number.

$$R_{ev} = \frac{34.6\, F_d W}{\mu_{cp} \sqrt{F_{LP} C_v}} \left[\left(\frac{F_{LP} C_v}{890 d^2} \right)^2 + 1 \right]^{1/4}$$

7. Calculate Reynolds number factor.

$$F_R = .12896 R_{ev}^{-.30842} - .0001596\, R_{ev} - .07181$$

Limit $F_R < 1$

8. Calculate final valve size.

$$C_v = \frac{\text{preliminary } C_v}{F_P F_y F_R}$$

9. If the valve is cavitating, the noise value will be calculated.

$$\begin{aligned} \text{dBA} &= 10 \log C_v F_L + 8 \log (P_2 \text{ CRIT} - P_2) \\ &\quad + 20 \log (P_2 - P_v) + 33 \end{aligned}$$

where

$$\begin{aligned} P_2 \text{ CRIT} &= P_1 - F_L^2 (P_1 - P_v) \\ (P_2 \text{ CRIT} - P_2) &= \Delta P - F_L^2 (P_1 - P_v) \end{aligned}$$

Program 1: Nomenclature

- C_v Valve sizing coefficient, dimensionless
- d Nominal valve size, inches
- D Internal diameter of the piping, inches
- F_d Valve-style modifier, dimensionless
- F_k Ratio of specific heats factor, dimensionless
- F_L Rated liquid pressure recovery factor, dimensionless
- F_{LP} Combined liquid pressure recovery factor and geometry factor of valve with reducers (when there are no reducers, $F_{LP} = F_L$), dimensionless
- F_P Piping geometry factor, dimensionless
- F_R Reynolds number factor, dimensionless
- F_y Liquid choked flow factor, dimensionless
- G_f Specific gravity (ratio of densities) of the liquid at flowing temperature compared to water at base conditions, dimensionless

P_1 Upstream absolute static pressure, PSIA
P_2 Downstream absolute static pressure, PSIA
P_c Critical pressure, PSIA
P_v Vapor pressure (absolute) of liquid at inlet temperature, PSIA
ΔP Pressure drop, $(P_1 - P_2)$ across the valve, PSI
R_{ev} Valve Reynolds number, dimensionless
W Weight rate of flow, pounds per hour
μ_{cp} Absolute viscosity, centipoises

References

ANSI/ISA-S75.01, 1977, "Control Valve Sizing Equations."

J. W. Hutchison, *ISA Handbook of Control Valves,* 2nd Edition, ISA (specifically p. 245).

Masoneilan Noise Control Manual, 1st Edition, Masoneilan International, Inc.

Program 2
Gas or Vapor Flow

Program 2: User Instructions

a) Initiate program, press A.
b) Enter:
   1. Flowrate, pounds per hour — Press R/S
   2. Inlet pressure, PSIG — Press R/S
   3. Discharge pressure, PSIG — Press R/S
   4. Flowing temperature, °F — Press R/S
   5. Gas molecular weight, dimensionless — Press R/S
   6. Gas compressibility factor, dimensionless — Press R/S
   7. Ratio of specific heats, dimensionless — Press R/S
   8. Selected valve recovery factor F_L, dimensionless — Press R/S
c) Program calculates minimum size for sonic velocity (inches) and preliminary valve C_v.
d) Using this data, enter:
   9. Valve size, inches — Press R/S
   10. Discharge pipe size, inches — Press R/S
e) Program calculates final C_v. If a noise check is required, continue.
f) Enter:
   11. Discharge pipe wall thickness, inches — Press R/S

12. Gas property factor, dimensionless — Press R/S
13. Valve acoustic efficiency, dimensionless — Press R/S

g) Program calculates sound pressure level, dBA.

Note: All data can be changed using the E subroutine.

Program 2: TI 59 Data Sheet

```
******************

 ISA CALC   GAS   CV

******************

ENTR  FLOW  PPH
        68794.
ENTR INLET PRSS PSIG
          235.
ENTR  DSCH PRSS PSIG
           35.
ENTR  TEMP    °F
           60.
ENTR    MW
         28.97
ENTR      Z
            1.
ENTR CP/CV
           1.4
ENTR     FL
          0.94

CALC SONIC SIZE   IN
 3.466249691
CALC PRELM    CV
 70.11536061
ENTR VALVE SIZE   IN
            4.
ENTR  DSCH PIPE SIZE
            4.
CALC     CV
 105.1730409

******************

ENTR  DSCH PIPE WALL
         0.237
ENTR   GAS PROP FACT
            0.
ENTR   ACOUSTIC EFFY
       0.00002
CALC    DBA
 89.49489464

******************
```

Program 2: TI 59 Register Loading

```
PARTITIONING
   459.59
         0.   00
         0.   01
         0.   02
         0.   03
         0.   04
         0.   05
         0.   06
         0.   07
         0.   08
         0.   09
         0.   10
         0.   11
         0.   12
         0.   13
         0.   14
         0.   15
         0.   16
         0.   17
         0.   18
         0.   19
         0.   20
  17212145.   21
4136372415.   22
  21131537.   23
  33353233.   24
  43132727.   25
3632312415.   26
  33243317.   27
  36244617.   28
4213274217.   29
```

0.3231	30	56.32	45
221336.3834	31	2127.352725	46
1542.543736	32	3043.312423	47
46.353736	33	7321.492221	48
333323.5248	34	131532.	49
16361523.47	35	56.39	50
33362422.33	36	1533631542.	51
33353636.51	37	37173033.	52
21273243.46	38	24361300.	53
161413.	39	2431271737.	54
56.262843	40	5151515151.	55
56.4432	41	1513271500.	56
2416.292843	42	1731373500.	57
2431.352728	43	0.	58
3335172730.	44	0.	59

Program 2: TI 59 Listing

SUBROUTINES

PRINT & STORE VARIABLES

```
000  76 LBL
001  10 E'
002  29 CP
003  01  1
004  44 SUM
005  58  58
006  73 RC*
007  58  58
008  22 INV
009  59 INT
010  52 EE
011  22 INV
012  52 EE
013  67  EQ
014  19 D'
015  85  +
016  05  5
017  07  7
018  95  =
019  17 B'
020  69 OP
021  21  21
022  73 RC*
023  01  01
024  87 IFF
025  00  00
026  00  00
027  31  31
028  91 R/S
029  72 ST*
030  01  01
031  73 RC*
032  01  01
033  99 PRT
034  61 GTO
035  10 E'
```

PRINT LINES

```
036  76 LBL
037  19 D'
038  01  1
039  44 SUM
040  58  58
041  73 RC*
042  58  58
043  76 LBL
044  17 B'
045  42 STO
046  59  59
047  73 RC*
048  59  59
049  69 OP
050  01  01
051  18 C'
052  69 OP
053  02  02
054  18 C'
055  69 OP
056  03  03
057  18 C'
058  69 OP
059  04  04
060  69 OP
061  05  05
062  92 RTN
```

DECODE LINES

```
063  76 LBL
064  18 C'
065  01  1
066  00  0
067  00  0
068  48 EXC
069  59  59
070  22 INV
071  59 INT
072  49 PRD
073  59  59
074  73 RC*
075  59  59
076  92 RTN
```

PRINT LINE OF STARS

```
077  76 LBL
078  16 A'
079  93  .
080  00  0
081  01  1
082  08  8
083  35 1/X
084  98 ADV
085  17 B'
086  98 ADV
087  92 RTN
```

RE-ENTER VARIABLES

```
088  76 LBL
089  15  E
090  99 PRT
091  85  +
092  01  1
093  95  =
094  42 STO
095  01  01
096  73 RC*
```

```
097   01   01
098   91  R/S
099   72  ST*
100   01   01
101   99  PRT
102   98  ADV
103   86  STF
104   02   02
105   86  STF
106   00   00
107   91  R/S
108   12   B
```

CALC X_T

```
109   76  LBL
110   24  CE
111   53   (
112   43  RCL
113   06   06
114   33  X²
115   65   ×
116   93   .
117   08   8
118   04   4
119   54   )
120   92  RTN
```

CALC F_k

```
121   76  LBL
122   34  √X
123   53   (
124   43  RCL
125   03   03
126   85   +
127   01   1
128   05   5
129   54   )
130   92  RTN
```

CALC P_1

```
132   76  LBL
133   34  √X
134   53   (
135   43  RCL
136   03   03
137   85   +
138   01   1
139   05   5
140   54   )
141   92  RTN
```

CALC T_1

```
142   76  LBL
143   13   C
144   53   (
145   43  RCL
146   05   05
147   85   +
148   04   4
149   06   6
150   00   0
151   54   )
152   92  RTN
```

CALC $\frac{\Delta P}{P_1}$

```
153   76  LBL
154   35  1/X
155   53   (
156   53   (
157   43  RCL
158   03   03
159   75   -
160   43  RCL
161   04   04
162   54   )
163   55   ÷
164   71  SBR
165   34  √X
166   54   )
167   92  RTN
```

CALC P_2

```
168   76  LBL
169   44  SUM
170   53   (
171   43  RCL
172   04   04
173   85   +
174   01   1
175   05   5
176   54   )
177   92  RTN
```

MAIN PROGRAM

ENTER DATA

```
178   76  LBL
179   11   A
180   22  INV
181   86  STF
182   02   02
183   01   1
184   42  STO
185   01   01
186   02   2
187   09   9
188   42  STO
189   58   58
190   16  A'
191   19  D'
192   16  A'
193   10  E'
```

CALC SONIC SIZE

```
194   76  LBL
195   12   B
196   13   C
197   55   ÷
198   43  RCL
199   06   06
200   95   =
201   34  √X
202   65   ×
203   43  RCL
204   02   02
205   55   ÷
206   71  SBR
207   44  SUM
208   95   =
209   34  √X
210   65   ×
211   93   .
212   00   0
213   04   4
214   05   5
215   04   4
216   95   =
217   42  STO
218   19   19
```

CALC C_v

```
219   71  SBR
220   24  CE
221   65   ×
222   71  SBR
223   25  CLR
224   95   =
225   32  X:T
226   71  SBR
227   35  1/X
228   22  INV
229   77   GE
230   22  INV
231   32  X:T
232   76  LBL
```

```
233  22 INV
234  42 STO
235  20  20
236  13  C
237  65  ×
238  43 RCL
239  07  07
240  55  ÷
241  43 RCL
242  20  20
243  55  ÷
244  43 RCL
245  06  06
246  95  =
247  34 √X
248  65  ×
249  43 RCL
250  02  02
251  55  ÷
252  71 SBR
253  34 √X
254  55  ÷
255  01  1
256  09  9
257  93  .
258  03  3
259  95  =
260  42 STO
261  16  16
```

CALC F_P

```
262  87 IFF
263  02  02
264  23 LNX
265  43 RCL
266  19  19
267  99 PRT
268  19 D'
269  43 RCL
270  16  16
271  99 PRT
272  10 E'
273  76 LBL
274  23 LNX
275  43 RCL
276  10  10
277  55  ÷
278  43 RCL
279  11  11
280  95  =
281  33 X²
282  42 STO
283  00  00
284  94 +/-
285  85  +
286  01  1
287  95  =
288  33 X²
289  42 STO
290  18  18
291  55  ÷
292  05  5
293  09  9
294  03  3
295  65  ×
296  53  (
297  43 RCL
298  16  16
299  55  ÷
300  43 RCL
301  10  10
302  33 X²
303  54  )
304  33 X²
305  42 STO
306  59  59
307  85  +
308  01  1
309  95  =
310  34 √X
311  35 1/X
312  42 STO
313  17  17
```

CALC X_{TP}

```
314  71 SBR
315  24 CE
316  55  ÷
317  43 RCL
318  17  17
319  33 X²
320  55  ÷
321  53  (
322  01  1
323  85  +
324  71 SBR
325  24 CE
326  55  ÷
327  01  1
328  00  0
329  00  0
330  00  0
331  65  ×
332  53  (
333  93  .
334  05  5
335  65  ×
336  43 RCL
337  18  18
338  85  +
339  01  1
340  75  -
341  43 RCL
342  00  00
343  33 X²
344  54  )
345  65  ×
346  43 RCL
347  59  59
348  54  )
349  95  =
350  42 STO
351  18  18
352  00  0
353  42 STO
354  00  00
355  01  1
356  75  -
357  43 RCL
358  20  20
359  55  ÷
360  03  3
361  55  ÷
362  71 SBR
363  25 CLR
364  55  ÷
365  43 RCL
366  18  18
367  95  =
368  42 STO
369  18  18
```

CALC C_v

```
370  43 RCL
371  16  16
372  55  ÷
373  43 RCL
374  17  17
375  55  ÷
376  43 RCL
377  18  18
378  95  =
379  42 STO
380  15  15
381  99 PRT
382  16 A'
```

CALC dBA

```
383  87 IFF
384  02  02
385  14  D
386  10 E'
387  22 INV
388  86 STF
```

```
389  00  00      416  14  14      443  45  YX
390  76  LBL     417  65  ×       444  01  1
391  14  D       418  13  C       445  06  6
392  53  (       419  85  +       446  65  ×
393  02  2       420  93  .       447  13  C
394  08  8       421  01  1       448  54  )
395  65  ×       422  08  8       449  55  ÷
396  43  RCL     423  65  ×       450  43  RCL
397  15  15      424  71  SBR     451  12  12
398  65  ×       425  44  SUM     452  45  YX
399  43  RCL     426  33  X²      453  03  3
400  09  09      427  65  ×       454  95  =
401  45  YX      428  43  RCL     455  28  LOG
402  93  .       429  10  10      456  65  ×
403  09  9       430  33  X²      457  01  1
404  65  ×       431  65  ×       458  00  0
405  71  SBR     432  43  RCL     459  85  +
406  34  √X      433  11  11      460  43  RCL
407  65  ×       434  33  X²      461  13  13
408  71  SBR     435  65  ×       462  95  =
409  44  SUM     436  53  (       463  99  PRT
410  65  ×       437  43  RCL     464  32  X:T
411  43  RCL     438  19  19      465  16  A'
412  11  11      439  55  ÷       466  98  ADV
413  33  X²      440  43  RCL     467  98  ADV
414  65  ×       441  10  10      468  32  X:T
415  43  RCL     442  54  )       469  91  R/S
```

Program 2: HP 41CV Data Sheet

```
************

 * CV GAS *

************

ENTER  FLOW PPH
      68,794.000    ***
ENTER INLET PRSS PSIG
         235.000    ***
ENTER DISCH PRSS PSIG
          35.000    ***
ENTER TEMP DEG F
          60.000    ***
ENTER MOL WT
          28.970    ***

ENTER Z
           1.000    ***
ENTER CP/CV
           1.400    ***
ENTER VALVE FL
           0.940    ***
CALC SONIC
SIZE IN
           3.466    ***
CALC PRELIM
CV
          70.115    ***
ENTER VALV SIZE IN
           4.000    ***
ENTER DISCH PIPE SIZE IN
           4.000    ***

CALC   CV
         105.173    ***

************

ENTER DISCH PIPE WALL IN
           0.237    ***
ENTER GAS PROPERTY FACT
           0.000    ***
ENTER ACOUSTIC EFFICENCY
       2.000-05     ***
CALC dBA
          89.495    ***

************
```

Program 2: HP 41CV Register Loading

SIZE 080

```
                      R03=  0.000000      R08=  0.000000
                      R04=  0.000000      R09=  0.000000
R00=  0.000000        R05=  0.000000      R10=  0.000000
R01=  0.000000        R06=  0.000000      R11=  0.000000
R02=  0.000000        R07=  0.000000      R12=  0.000000
```

```
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  0.000000
R17=  0.000000
R18=  0.000000
R19=  0.000000
R20=  0.000000
R21=  0.000000
R22=  0.000000
R23=  0.000000
R24=  0.945714
R25=  0.000000
R26= " *CV S"
R27= "TEAM "
R28= " FLOW "
R29= "PPH  "
R30=  26.270000
R31=  57.282900
R32=  57.515253
R33=  57.545253
R34=  57.606100
R35=  57.626300
R36=  0.000000
R37=  56.646566
R38=  56.676800
R39=  57.697700
R40=  56.686967
R41=  56.707100
R42=  57.727300
R43=  57.547473
R44=  0.000000
R45=  56.710000
R46=  57.547576
R47=  57.777879
R48=  57.222324
R49=  0.000000
R50=  56.250000
R51= "INLET "
R52= "PRSS P"
R53= "SIG  "
R54= "DISCH "
R55= "******"
R56= "CALC "
R57= "ENTER "
R58=  50.000000
R59=  0.000000
R60= "TEMP D"
R61= "EG F  "
R62= "MOL WT"
R63= "Z     "
R64= "CP/CV "
R65= "VALVE "
R66= "FL    "
R67= "IN  "
R68= "SONIC "
R69= " SIZE "
R70= "PRELIM"
R71= " CV   "
R72= "VALV S"
R73= "IZE IN"
R74= "PIPE S"
R75= "PIPE W"
R76= "ALL IN"
R77= "GAS PR"
R78= "OPERTY"
R79= " FACT "
```

Program 2: HP 41CV Listing

SUBROUTINES

```
01♦LBL "CV GAS"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 GTO d
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53♦LBL 01
54 XEQ J
55 GTO e
```

RE-ENTER VARIABLES

```
56♦LBL "REENTER"
57 ADV
58 1
59 +
60 STO 01
61 RCL IND 01
62 XEQ J
63 STOP
64 XEQ J
65 STO IND 01
66 ADV
67 SF 00
68 SF 02
69 STOP
70 GTO 02
```

BYPASS PRINTER

```
71♦LBL J
72 FC? 55
73 GTO 01
74 PRX
75 RTN
76♦LBL 01
77 VIEW X
78 RTN
```

CALC X_T

```
79♦LBL B
80 RCL 09
81 X↑2
82 .84
83 *
84 RTN
```

CALC F_k

```
85♦LBL C
86 RCL 08
87 1.4
88 /
89 RTN
```

CALC P_1

```
90♦LBL F
91 RCL 03
92 15
93 +
94 RTN
```

CALC T_1

```
95♦LBL H
96 RCL 05
97 460
98 +
99 RTN
```

CALC $\frac{\Delta P}{P_1}$

```
100♦LBL D
101 RCL 03
102 RCL 04
103 -
104 XEQ F
105 /
106 RTN
```

CALC P_2

```
107♦LBL G
108 RCL 04
109 15
110 +
111 RTN
```

MAIN PROGRAM ENTER DATA

```
112♦LBL A
113 CF 02
114 1
115 STO 01
116 29
117 STO 58
118 XEQ a
119 XEQ d
120 XEQ a
121 XEQ e
```

CALC SONIC SIZE

```
122♦LBL 02
123 0
124 STO 00
125 XEQ H
126 RCL 06
127 /
128 SQRT
129 RCL 02
130 *
131 XEQ G
132 /
133 SQRT
134 .0454
135 *
136 STO 19
```

CALC PRELIM C_v

```
137 XEQ B
138 XEQ C
139 *
140 XEQ D
141 X<=Y?
142 GTO 01
143 RDN
144♦LBL 01
145 STO 20
146 XEQ H
147 RCL 07
148 *
149 RCL 20
150 /
151 RCL 06
152 /
153 SQRT
154 RCL 02
155 *
156 XEQ F
157 /
158 19.3
159 /
160 STO 16
```

CALC F_P

```
161 FS? 02
162 GTO 03
163 RCL 19
164 XEQ J
165 XEQ d
166 RCL 16
167 XEQ J
168 XEQ e
169♦LBL 03
170 RCL 10
171 RCL 11
172 /
173 X↑2
174 STO 00
175 CHS
176 1
177 +
178 X↑2
179 STO 18
180 593
181 /
182 RCL 16
183 RCL 10
184 X↑2
185 /
186 X↑2
187 STO 59
188 *
189 1
190 +
191 SQRT
192 1/X
193 STO 17
```

CALC X_{TP}

```
194 .5
195 RCL 18
196 *
197 1
198 +
199 RCL 00
200 X↑2
201 -
202 RCL 59
203 *
204 XEQ B
205 *
206 1000
207 /
208 1
209 +
210 1/X
211 XEQ B
212 *
213 RCL 17
214 X↑2
215 /
216 STO 18
217 0
218 STO 00
219 1
220 RCL 20
```

```
221 3
222 /
223 XEQ C
224 /
225 RCL 18
226 /
227 -
228 STO 18
```

CALC C_v

```
229 RCL 16
230 RCL 17
231 /
232 RCL 18
233 /
234 STO 15
235 XEQ J
```

CALC dBA

```
236 FS? 02
237 GTO 01
238 XEQ a
239 XEQ e
240 CF 00
241♦LBL 01
242 28
243 RCL 15
244 *
245 RCL 09
246 .9
247 Y↑X
248 *
249 XEQ F
250 *
251 XEQ G
252 *
253 RCL 11
254 X↑2
255 *
256 RCL 14
257 *
258 XEQ H
259 *
260 .18
261 XEQ G
262 X↑2
263 *
264 RCL 10
265 X↑2
266 *
267 RCL 11
268 X↑2
269 *
270 RCL 19
271 RCL 10
272 /
273 16
274 Y↑X
275 *
276 XEQ H
277 *
278 +
279 RCL 12
280 3
281 Y↑X
282 /
283 LOG
284 10
285 *
286 RCL 13
287 +
288 STO 21
289 XEQ J
290 FS? 00
291 STOP
292 XEQ a
293 RCL 21
294 RCL 15
295 VIEW X
296 BEEP
297 ADV
298 STOP
299 .END.
```

Program 2: Sequence of Calculations

1. Calculate minimum valve size for sonic velocity.[1]

$$= .0454\sqrt{\frac{W}{P_2}\sqrt{\frac{T_1}{M}}}\quad \text{inches}$$

2. Calculate pressure drop ratio factor.

$$X = \frac{\Delta P}{P_1}\quad \text{limited to a minimum of } F_k X_T$$

where

$$F_k = \frac{k}{1.4}$$

$$X_T = .84\,F_L^2$$

3. Calculate preliminary valve size.

$$C_v = \frac{W}{19.3\, P_1} \sqrt{\frac{T_1 Z}{XM}}$$

4. Calculate piping geometry factor.

$$F_P = \left[1 + \left(\frac{1.5\left(1 - \left(\frac{d}{D}\right)^2\right)^2}{890} \left(\frac{C_v}{d^2}\right)^2 \right) \right]^{-1/2}$$

5. Calculate pressure drop ratio factor for piping geometry.

$$X_{TP} = \frac{X_T}{F_P^2} \left[1 + \frac{X_T}{1000} \left(.5 \left(1 - \left(\frac{d}{D}\right)^2\right)^2 + \left(1 - \left(\frac{d}{D}\right)^4\right) \right) \left(\frac{C_v}{d^2}\right)^2 \right]^{-1}$$

6. Calculate expansion factor.

$$Y = 1 - \left(\frac{X}{2.14\, k\, X_{TP}} \right)$$

7. Calculate final valve size.

$$\text{final } C_v = \frac{\text{preliminary } C_v}{F_P Y}$$

8. Calculate sound pressure level.[1]

$$\text{dBA} = 10 \log \left(\frac{28 C_v F_L P_1 P_2 \eta T_1 + .18\, P_2^2 d^2 D^2 \left(\frac{\text{sonic size}}{d}\right)^{16} T_1}{t^3} \right) + S_{lg}$$

Program 2: Nomenclature

C_v Valve sizing coefficient, dimensionless
d Nominal valve size, inches

D	Internal diameter of the piping, inches
F_k	Ratio of specific heats factor, dimensionless
F_L	Rated liquid pressure recovery factor, dimensionless
F_P	Piping geometry factor, dimensionless
k	Ratio of specific heats, dimensionless
M	Molecular weight, dimensionless
P_1	Upstream absolute static pressure, PSIA
P_2	Downstream absolute static pressure, PSIA
ΔP	Pressure drop $(P_1 - P_2)$ across the valve, PSI
S_{lg}	Gas property factor, dimensionless
t	Pipe wall thickness, inches
T_1	Absolute upstream temperature, °R
W	Weight rate of flow, pounds per hour
X	Ratio of pressure drop to absolute inlet static pressure $(\Delta P/P_1)$, dimensionless
X_T	Rated pressure drop ratio factor, dimensionless
X_{TP}	Value of X_T for valve/fitting assembly, dimensionless
Y	Expansion factor, ratio of flow coefficient for a gas to that for a liquid at the same Reynolds number, dimensionless
Z	Compressibility factor, dimensionless
η	Acoustical efficiency

Literature Cited

1. Masoneilan Noise Control Manual, 1st Edition, Masoneilan International, Inc.

All other sizing equations are from ISA S75.01, 2nd Edition.

Program 3
Steam Flow

Program 3: User Instructions

a) Initiate program, press A.
b) Enter:

1. Flowrate, pounds per hour	Press R/S
2. Inlet pressure, PSIG	Press R/S
3. Discharge pressure, PSIG	Press R/S
4. Flowing temperature, °F	Press R/S
5. Selected valve recovery factor F_L, dimensionless	Press R/S

c) Program calculates minimum size for sonic velocity (inches) and preliminary C_v.

d) Using this data, enter:

6. Valve size, inches	Press R/S
7. Discharge pipe size, inches	Press R/S

e) Program calculates final C_v. If a noise check is required, continue.

f) Enter:

8. Discharge pipe wall thickness, inches	Press R/S
9. Valve acoustic efficiency, dimensionless	Press R/S

Note: All data can be changed using the E subroutine.

Program 3: TI 59 Data Sheet

```
********************

CALC STEAM    CV

********************

ENTR  FLOW  PPH
          62000.
ENTR INLET PRSS PSIG
           2485.
ENTR  DSCH PRSS PSIG
            385.
ENTR  TEMP    °F
            660.
ENTR     FL
              1.
CALC SONIC SIZE    IN
 1.587479338
```

```
CALC PRELM    CV
 11.37227918
ENTR VALVE SIZE    IN
          3.
ENTR  DSCH PIPE SIZE
          4.
CALC     CV
 17.06733282

********************
ENTR  DSCH PIPE WALL
          0.531
ENTR   ACOUSTIC EFFY
        0.00011
CALC    DBA
 94.98851735

********************
```

Program 3: TI 59 Register Loading

PARTITIONING
479.59

0.	00
0.	01
0.	02
0.	03
0.	04
0.	05
0.	06
0.	07
0.	08
0.	09
0.	10
0.	11
0.	12
0.	13
0.	14

```
          0.      15         56.5332      38
          0.      16        0.292834      39
          0.      17        0.352728      40
          0.      18              0.      41
          0.      19           56.32      42
          0.      20        0.352725      43
   17212145.      21     7321.492221      44
 4136372415.      22       33353636.      45
          0.      23           56.48      46
.9457142857       24     3637171330.      47
   43132727.      25         161413.      48
 3632312415.      26         131532.      49
   33243317.      27     2317133700.      50
   36244617.      28       37173033.      51
 4213274217.      29       21273243.      52
     56.4732      30     3335172730.      53
 333323.5231      31     2431271737.      54
 1542.544536      32     5151515151.      55
 2127.354536      33     1513271500.      56
   2431.5144      34     1731373500.      57
 16361523.33      35              0.      58
   33362422.      36              0.      59
   56.262834      37
```

Program 3: TI 59 Listing

SUBROUTINES PRINT & STORE VARIABLES

```
000  76  LBL
001  10  E'
002  29  CP
003  01   1
004  44  SUM
005  58   58
006  73  RC*
007  58   58
008  22  INV
009  59  INT
010  52  EE
011  22  INV
012  52  EE
013  67   EQ
014  19  D'
015  85   +
016  05   5
017  07   7
018  95   =
019  17  B'
020  69  OP
021  21   21
022  73  RC*
023  01   01
024  87  IFF
025  00   00
026  00   00
027  31   31
028  91  R/S
029  72  ST*
030  01   01
031  73  RC*
032  01   01
033  99  PRT
034  61  GTO
035  10  E'
```

PRINT LINES

```
036  76  LBL
037  19  D'
038  01   1
039  44  SUM
040  58   58
041  73  RC*
042  58   58
043  76  LBL
044  17  B'
045  42  STO
046  59   59
047  73  RC*
048  59   59
049  69  OP
050  01   01
051  18  C'
052  69  OP
053  02   02
054  18  C'
055  69  OP
056  03   03
057  18  C'
058  69  OP
059  04   04
060  69  OP
061  05   05
062  92  RTN
```

DECODE LINES

```
063  76  LBL
064  18  C'
065  01   1
066  00   0
067  00   0
068  48  EXC
069  59   59
070  22  INV
071  59  INT
072  49  PRD
073  59   59
074  73  RC*
075  59   59
076  92  RTN
```

PRINT LINE OF STARS

```
077  76  LBL
078  16  A'
079  93  .
080  00  0
081  01  1
082  08  8
083  35  1/X
084  98  ADV
085  17  B'
086  98  ADV
087  92  RTN
```

RE-ENTER VARIABLES

```
088  76  LBL
089  15  E
090  99  PRT
091  85  +
092  01  1
093  95  =
094  42  STO
095  01  01
096  73  RC*
097  01  01
098  91  R/S
099  72  ST*
100  01  01
101  99  PRT
102  98  ADV
103  86  STF
104  02  02
105  86  STF
106  00  00
107  91  R/S
108  12  B
```

CALC X_T

```
109  76  LBL
110  24  CE
111  53  (
112  43  RCL
113  06  06
114  33  X²
115  65  ×
116  93  .
117  08  8
118  04  4
119  54  )
120  92  RTN
```

CALC P_1

```
121  76  LBL
122  34  ΓX
123  53  (
124  43  RCL
125  03  03
126  85  +
127  01  1
128  05  5
129  54  )
130  92  RTN
```

SUBROUTINES

```
131  76  LBL
132  13  C
133  53  (
134  43  RCL
135  05  05
136  85  +
137  04  4
138  06  6
139  00  0
140  54  )
141  92  RTN
```

CALC $\frac{\Delta P}{P_1}$

```
142  76  LBL
143  35  1/X
144  53  (
145  53  (
146  43  RCL
147  03  03
148  75  -
149  43  RCL
150  04  04
151  54  )
152  55  ÷
153  71  SBR
154  34  ΓX
155  54  )
156  92  RTN
```

CALC PRELIM C_v

```
157  76  LBL
158  44  SUM
159  53  (
160  43  RCL
161  04  04
162  85  +
163  01  1
164  05  5
165  54  )
166  92  RTN
```

MAIN PROGRAM ENTER DATA

```
167  76  LBL
168  11  A
169  22  INV
170  86  STF
171  02  02
172  01  1
173  42  STO
174  01  01
175  02  2
176  09  9
177  42  STO
178  58  58
179  16  A'
180  19  D'
181  16  A'
182  10  E'
```

CALC SONIC SIZE

```
183  76  LBL
184  12  B
185  13  C
186  55  ÷
187  01  1
188  08  8
189  95  =
190  34  ΓX
191  65  ×
192  43  RCL
193  02  02
194  55  ÷
195  71  SBR
196  44  SUM
197  95  =
198  34  ΓX
199  65  ×
200  93  .
201  00  0
202  04  4
203  05  5
204  04  4
205  95  =
206  42  STO
207  19  19
```

CALC PRELIM C_v

```
208  71  SBR
209  24  CE
210  65  ×
211  43  RCL
212  24  24
213  95  =
214  32  X:T
```

```
215   71  SBR
216   35  1/X
217   22  INV
218   77   GE
219   22  INV
220   32  X:T
221   76  LBL
222   22  INV
223   42  STO
224   20   20
225   13   C
226   55   ÷
227   43  RCL
228   20   20
229   55   ÷
230   01   1
231   08   8
232   95   =
233   34  √X
234   65   ×
235   43  RCL
236   02   02
237   55   ÷
238   71  SBR
239   34  √X
240   55   ÷
241   01   1
242   09   9
243   93   .
244   03   3
245   95   =
246   42  STO
247   16   16
```

CALC F_P

```
248   87  IFF
249   02   02
250   23  LNX
251   43  RCL
252   19   19
253   99  PRT
254   19  D'
255   43  RCL
256   16   16
257   99  PRT
258   10  E'
259   76  LBL
260   23  LNX
261   43  RCL
262   07   07
263   55   ÷
264   43  RCL
265   08   08
266   95   =
267   33  X²
268   42  STO
269   00   00
270   94  +/-
271   85   +
272   01   1
273   95   =
274   33  X²
275   42  STO
276   18   18
277   55   ÷
278   05   5
279   09   9
280   03   3
281   65   ×
282   53   (
283   43  RCL
284   16   16
285   55   ÷
286   43  RCL
287   07   07
288   33  X²
289   54   )
290   33  X²
291   42  STO
292   59   59
293   85   +
294   01   1
295   95   =
296   34  √X
297   35  1/X
298   42  STO
299   17   17
```

CALC X_{TP}

```
300   71  SBR
301   24  CE
302   55   ÷
303   43  RCL
304   17   17
305   33  X²
306   55   ÷
307   53   (
308   01   1
309   85   +
310   71  SBR
311   24  CE
312   55   ÷
313   01   1
314   00   0
315   00   0
316   00   0
317   65   ×
318   53   (
319   93   .
320   05   5
321   65   ×
322   43  RCL
323   18   18
324   85   +
325   01   1
326   75   -
327   43  RCL
328   00   00
329   33  X²
330   54   )
331   65   ×
332   43  RCL
333   59   59
334   54   )
335   95   =
336   42  STO
337   18   18
338   00   0
339   42  STO
340   00   00
341   01   1
342   75   -
343   43  RCL
344   20   20
345   55   ÷
346   03   3
347   55   ÷
348   43  RCL
349   24   24
350   55   ÷
351   43  RCL
352   18   18
353   95   =
354   42  STO
355   18   18
```

CALC C_v

```
356   43  RCL
357   16   16
358   55   ÷
359   43  RCL
360   17   17
361   55   ÷
362   43  RCL
363   18   18
364   95   =
365   42  STO
366   15   15
367   99  PRT
368   16  A'
```

CALC dBA

```
369   87  IFF
370   02   02
```

371	14	D
372	10	E'
373	22	INV
374	86	STF
375	00	00
376	76	LBL
377	14	D
378	53	(
379	02	2
380	08	8
381	65	×
382	43	RCL
383	15	15
384	65	×
385	43	RCL
386	06	06
387	45	Y^X
388	93	.
389	09	9
390	65	×
391	71	SBR
392	34	√X
393	65	×
394	71	SBR
395	44	SUM
396	65	×
397	43	RCL
398	08	08
399	33	X²
400	65	×
401	43	RCL
402	10	10
403	65	×
404	13	C
405	85	+
406	93	.
407	01	1
408	08	8
409	65	×
410	71	SBR
411	44	SUM
412	33	X²
413	65	×
414	43	RCL
415	07	07
416	33	X²
417	65	×
418	43	RCL
419	08	08
420	33	X²
421	65	×
422	53	(
423	43	RCL
424	19	19
425	55	÷
426	43	RCL
427	07	07
428	54	)
429	45	Y^X
430	01	1
431	06	6
432	65	×
433	13	C
434	54	)
435	55	÷
436	43	RCL
437	09	09
438	45	Y^X
439	03	3
440	95	=
441	28	LOG
442	65	×
443	01	1
444	00	0
445	75	-
446	03	3
447	95	=
448	99	PRT
449	32	X:T
450	16	A'
451	98	ADV
452	98	ADV
453	32	X:T
454	91	R/S

Program 3: HP 41CV Data Sheet

```
************

 *CV STEAM

************

ENTER  FLOW PPH
      62,000.000     ***
ENTER INLET PRSS PSIG
       2,485.000     ***
ENTER DISCH PRSS PSIG
         385.000     ***
ENTER  TEMP DEG F
         660.000     ***
ENTER VALVE FL
           1.000     ***
CALC SONIC
SIZE IN
           1.587     ***
CALC PRELIM
CV
          11.372     ***
ENTER VALV SIZE IN
           3.000     ***
ENTER DISCH PIPE SIZE IN
           4.000     ***
CALC   CV
          17.067     ***
************

ENTER DISCH PIPE WALL IN
           0.531     ***
ENTER ACOUSTIC EFFICENCY
       1.100-04      ***
CALC dBA
          94.989     ***

************
```

Program 3: HP 41CV Register Loading

SIZE 080

```
R00= 0.000000
R01= 0.000000
R02= 0.000000
R03= 0.000000
R04= 0.000000
R05= 0.000000
R06= 0.000000
R07= 0.000000
R08= 0.000000
R09= 0.000000
R10= 0.000000
R11= 0.000000
R12= 0.000000
```

```
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  0.000000
R17=  0.000000
R18=  0.000000
R19=  0.000000
R20=  0.000000
R21=  0.000000
R22=  0.000000
R23=  0.000000
R24=  0.945714
R25=  0.000000
R26= " *CV S"
R27= "TEAM "
R28= " FLOW "
R29= "PPH  "
R30=  26.270000
R31=  57.282900
R32=  57.515253
R33=  57.545253
R34=  57.606100
R35=  57.626300
R36=  0.000000
R37=  56.646566
R38=  56.676800
R39=  57.697700
R40=  57.547077
R41=  0.000000
R42=  56.680000
R43=  57.547172
R44=  57.737475
R45=  0.000000
R46=  56.760000
R47=  0.000000
R48=  0.000000
R49=  0.000000
R50=  0.000000
R51= "INLET "
R52= "PRSS P"
R53= "SIG  "
R54= "DISCH "
R55= "******"
R56= "CALC "
R57= "ENTER "
R58=  46.000000
R59=  0.000000
R60= " TEMP "
R61= "DEG F "
R62= "VALVE "
R63= "FL    "
R64= "SONIC "
R65= " SIZE "
R66= "IN    "
R67= "PRELIM"
R68= " CV   "
R69= "VALV S"
R70= "PIPE S"
R71= "PIPE W"
R72= "ALL IN"
R73= "ACOUST"
R74= "IC EFF"
R75= "ICENCY"
R76= "dBA"
R77= "IZE IN"
R78=  0.000000
R79=  0.000000
```

Program 3: HP 41CV Listing

SUBROUTINES

```
01♦LBL "CV STM"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 GTO d
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53♦LBL 01
54 XEQ J
55 GTO e
```

RE-ENTER VARIABLES

```
56♦LBL "REENTER"
57 ADV
58 1
59 +
60 STO 01
61 RCL IND 01
62 XEQ J
63 STOP
64 XEQ J
65 STO IND 01
66 ADV
67 SF 00
68 SF 02
69 STOP
70 GTO 02
```

BYPASS PRINTER

```
71♦LBL J
72 FC? 55
73 GTO 01
74 PRX
75 RTN
76♦LBL 01
77 VIEW X
78 RTN
```

CALC X_T

```
79♦LBL B
80 RCL 06
81 X↑2
82 .84
83 *
84 RTN
```

CALC P_1

```
85♦LBL F
86 RCL 03
87 15
88 +
89 RTN
```

CALC T_1

```
90♦LBL H
91 RCL 05
92 460
93 +
94 RTN
```

CALC $\frac{\Delta P}{P_1}$

```
95♦LBL D
96 RCL 03
97 RCL 04
98 -
99 XEQ F
100 /
101 RTN
```

CALC P_2

```
102♦LBL G
103 RCL 04
104 15
105 +
106 RTN
```

MAIN PROGRAM ENTER DATA

```
107♦LBL A
108 CF 02
109 1
110 STO 01
111 29
112 STO 58
113 XEQ a
114 XEQ d
115 XEQ a
116 XEQ e
```

CALC SONIC SIZE

```
117♦LBL 02
118 0
119 STO 00
120 XEQ H
121 18
122 /
123 SQRT
124 RCL 02
125 *
126 XEQ G
127 /
128 SQRT
129 .0454
130 *
131 STO 19
```

CALC PRELIM C_v

```
132 XEQ B
133 RCL 24
134 *
135 XEQ D
136 X<=Y?
137 GTO 01
138 RDN
139♦LBL 01
140 STO 20
141 XEQ H
142 RCL 20
143 /
144 18
145 /
146 SQRT
147 RCL 02
148 *
149 XEQ F
150 /
151 19.3
152 /
153 STO 16
```

CALC F_P

```
154 FS? 02
155 GTO 03
156 RCL 19
157 XEQ J
158 XEQ d
159 RCL 16
160 XEQ J
161 XEQ e
162♦LBL 03
163 RCL 07
164 RCL 08
165 /
166 X↑2
167 STO 00
168 CHS
169 1
170 +
171 X↑2
172 STO 18
173 593
174 /
175 RCL 16
176 RCL 07
177 X↑2
178 /
179 X↑2
180 STO 59
181 *
182 1
183 +
184 SQRT
185 1/X
186 STO 17
```

CALC X_{TP}

```
187 .5
188 RCL 18
189 *
190 1
191 +
192 RCL 00
193 X↑2
194 -
195 RCL 59
196 *
197 XEQ B
198 *
199 1000
200 /
201 1
202 +
203 1/X
204 XEQ B
205 *
206 RCL 17
207 X↑2
208 /
209 STO 18
210 0
211 STO 00
212 1
213 RCL 20
214 3
215 /
216 RCL 24
217 /
218 RCL 18
219 /
220 -
221 STO 18
```

CALC C_v

```
222 RCL 16
```

```
223 RCL 17
224 /
225 RCL 18
226 /
227 STO 15
228 XEQ J
```

CALC dBA

```
229 FS? 02
230 GTO 01
231 XEQ a
232 XEQ e
233 CF 00
234♦LBL 01
235 28
236 RCL 15
237 *
238 RCL 06
239 .9
240 Y↑X
241 *
242 XEQ F
243 *
244 XEQ G
245 *
246 RCL 08
247 X↑2
248 *
249 RCL 10
250 *
251 XEQ H
252 *
253 .18
254 XEQ G
255 X↑2
256 *
257 RCL 07
258 X↑2
259 *
260 RCL 08
261 X↑2
262 *
263 RCL 19
264 RCL 07
265 /
266 16
267 Y↑X
268 *
269 XEQ H
270 *
271 +
272 RCL 09
273 3
274 Y↑X
275 /
276 LOG
277 10
278 *
279 3
280 -
281 STO 21
282 XEQ J
283 FS? 00
284 STOP
285 XEQ a
286 RCL 21
287 RCL 15
288 VIEW X
289 BEEP
290 ADV
291 STOP
292 .END.
```

Program 3: Sequence of Calculations

1. Calculate minimum valve size for sonic velocity.

$$= .022\sqrt{\frac{W}{P_2}\sqrt{T_1}} \quad \text{inches}$$

2. Calculate pressure drop ratio factor.

$$X = \frac{\Delta P}{P_1} \quad \text{limited to a minimum of } .794\,F_L^2$$

3. Calculate preliminary valve size.

$$C_v = \frac{W}{81.93\,P_1}\sqrt{\frac{T_1}{X}}$$

4. Calculate piping geometry factor.

$$F_P = \left[1 + \left(\frac{1.5\left(1 - \left(\frac{d^2}{D^2}\right)\right)^2 \left(\frac{C_v}{d^2}\right)^2}{890}\right)\right]^{-1/2}$$

5. Calculate pressure drop ratio factor for piping geometry.

$$X_{TP} = \frac{X_T}{F_P^2}\left[1 + \left(\frac{X_T}{1000}\left(.5\left(1 - \left(\frac{d}{D}\right)^2\right)^2\right)\right.\right.$$
$$\left.\left. + \left(\left(1 - \left(\frac{d}{D}\right)^4\right)\left(\frac{C_v}{d^2}\right)^2\right)\right]^{-1}$$

6. Calculate expansion factor.

$$Y = 1 - \left(\frac{X}{2.84\,X_{TP}}\right)$$

7. Calculate final valve size.

$$\text{final } C_v = \frac{\text{preliminary } C_v}{F_P Y}$$

8. Calculate sound pressure level.

$$\text{dBA} = 10 \log$$
$$\left(\frac{28C_v\,F_L\,P_1\,P_2\,\eta\,T_1 + .18\,P_2^2 d^2 D^2\left(\frac{\text{sonic size}}{d}\right)^{16} T_1}{t^3}\right) - 3$$

Program 3: Nomenclature

- C_v Valve sizing coefficient, dimensionless
- d Nominal valve size, inches
- D Internal diameter of the piping, inches
- F_L Rated liquid pressure recovery factor, dimensionless
- F_P Piping geometry factor, dimensionless
- P_1 Upstream absolute static pressure, PSIA
- P_2 Downstream absolute static pressure, PSIA

ΔP	Pressure drop ($P_1 - P_2$) across the valve, PSI
t	Pipe wall thickness, inches
T_1	Absolute upstream temperature, °R
W	Weight rate of flow, pounds per hour
X	Ratio of pressure drop to absolute inlet static pressure ($\Delta P/P_1$), dimensionless
X_T	Rated pressure drop ratio factor, dimensionless
X_{TP}	Value of X_T for valve/fitting assembly, dimensionless
Y	Expansion factor, ratio of flow coefficient for a gas to that for a liquid at the same Reynolds number, dimensionless
η	Acoustical efficiency

References

"Control Valve Sizing Equations," ANSI/ISA S75.01, 1977.

Masoneilan Noise Control Manual, 1st Edition, Masoneilan International, Inc.

Program 4
Two-Phase Flow

Program 4: User Instructions

a) Initiate program, press A.
b) Enter:

1. Liquid flow, pounds per hour	Press R/S
2. Vapor flow, pounds per hour	Press R/S
3. Inlet pressure, PSIG	Press R/S
4. Pressure drop across valve, PSI	Press R/S
5. Flowing temperature, °F	Press R/S
6. Liquid specific gravity, dimensionless	Press R/S
7. Vapor molecular weight, dimensionless	Press R/S
8. Vapor compressibility factor, dimensionless	Press R/S
9. Vapor ratio of specific heats, dimensionless	Press R/S
10. Liquid vapor pressure, PSIA	Press R/S
11. Liquid critical pressure, PSIA	Press R/S

c) Program calculates pressure recovery factor F_L, dimensionless.

d) Enter:
   12. Selected valve recovery factor F_L, dimensionless — Press R/S
   13. Discharge pipe size, inches — Press R/S
e) Program calculates preliminary C_v.
f) Enter:
   14. Selected valve size, inches — Press R/S
g) Program calculates final C_v.

Note: All data can be changed using the E subroutine.

Program 4: TI 59 Data Sheet

```
*******************

    CALC      CV
  2 PHASE FLOW

*******************

ENTR LQUID FLOW   PPH
       20000.
ENTR VAPOR FLOW   PPH
         460.
ENTR INLET PRSS PSIG
          85.
ENTR     ΔP   PSI
          36.
ENTR  TEMP    °F
          80.
ENTR LQUID    SG
           1.
ENTR VAPOR    MW
        28.97
ENTR        Z
           1.
ENTR CP/CV
         1.4
ENTR VAPOR PRSS PSIA
         0.6
ENTR  CRIT PRSS PSIA
        3206.
CALC    MIN    FL
 .6017285462
ENTR  VALV    FL
        0.94
ENTR  DSCH PIPE SIZE
           3.
CALC PRELM    CV
 15.19846265
ENTR  VALV SIZE    IN
           2.
CALC      CV
 15.25545751

*******************
```

Program 4: TI 59 Register Loading

PARTITIONING
479.59

0.	00	0.	07
0.	01	0.	08
0.	02	0.	09
0.	03	0.	10
0.	04	0.	11
0.	05	0.	12
0.	06	0.	13
		0.	14
		0.	15
		0.	16

```
           0.    17
           0.    18
           0.    19
           0.    20
           0.    21
    33362413.    22
  3335172730.    23
    36244617.    24
    42132742.    25
    33243317.    26
    16361523.    27
    15352437.    28
      0.5648     29
     34.5439     30
 2431.533944     31
 2127.523944     32
   46.513842     33
    300.3637     34
 302431.4945     35
   7533.5341     36
  333624.524     37
 33353636.33     38
```

```
 21273243.46     39
 3043.523822     40
 3622.283822     41
   33362422.     42
     56.3532     43
 333323.2532     44
 7321.272624     45
 1533631542.     46
     56.2348     47
 1542.252431     48
   37173033.     49
       56.48     50
 2431271737.     51
 4213333235.     52
 2734412416.     53
 3323133617.     54
 5151515151.     55
 1513271500.     56
 1731373500.     57
          0.     58
          0.     59
```

Program 4: TI 59 Listing

SUBROUTINES

PRINT & STORE VARIABLES

```
000  76 LBL
001  10 E'
002  29 CP
003  01  1
004  44 SUM
005  58  58
006  73 RC*
007  58  58
008  22 INV
009  59 INT
010  52 EE
011  22 INV
012  52 EE
013  67  EQ
014  19 D'
015  85  +
016  05  5
017  07  7
018  95  =
019  17 B'
020  69 OP
021  21  21
022  73 RC*
023  01  01
024  87 IFF
025  00  00
026  00  00
027  31  31
028  91 R/S
029  72 ST*
030  01  01
031  73 RC*
032  01  01
033  99 PRT
034  61 GTO
035  10 E'
```

PRINT LINES

```
036  76 LBL
037  19 D'
038  01  1
039  44 SUM
040  58  58
041  73 RC*
042  58  58
043  76 LBL
044  17 B'
045  42 STO
046  59  59
047  73 RC*
048  59  59
049  69 OP
050  01  01
051  18 C'
052  69 OP
053  02  02
054  18 C'
055  69 OP
056  03  03
057  18 C'
058  69 OP
059  04  04
060  69 OP
061  05  05
062  92 RTN
```

DECODE LINES

```
063  76 LBL
064  18 C'
065  01  1
066  00  0
067  00  0
068  48 EXC
069  59  59
070  22 INV
071  59 INT
072  49 PRD
073  59  59
074  73 RC*
075  59  59
076  92 RTN
```

PRINT LINE OF STARS

```
077  76 LBL
```

```
078  16  A'
079  93  .
080  00  0
081  01  1
082  08  8
083  35  1/X
084  98  ADV
085  17  B'
086  98  ADV
087  92  RTN
```

RE-ENTER VARIABLES

```
088  76  LBL
089  15  E
090  99  PRT
091  85  +
092  01  1
093  95  =
094  42  STO
095  01  01
096  73  RC*
097  01  01
098  91  R/S
099  72  ST*
100  01  01
101  99  PRT
102  98  ADV
103  86  STF
104  00  00
105  86  STF
106  01  01
107  91  R/S
108  12  B
```

CALC P_1

```
109  76  LBL
110  22  INV
111  53  (
112  43  RCL
113  04  04
114  85  +
115  01  1
116  05  5
117  54  )
118  92  RTN
```

CALC T_1

```
119  76  LBL
120  23  LNX
121  53  (
122  43  RCL
123  06  06
124  85  +
125  04  4
126  06  6
127  00  0
128  54  )
129  92  RTN
```

CALC X_T

```
130  76  LBL
131  24  CE
132  53  (
133  43  RCL
134  13  13
135  33  X²
136  65  ×
137  93  .
138  08  8
139  04  4
140  54  )
141  92  RTN
```

CALC F_k

```
142  76  LBL
143  25  CLR
144  53  (
145  43  RCL
146  10  10
147  55  ÷
148  01  1
149  93  .
150  04  4
151  54  )
152  92  RTN
```

CALC F_F

```
153  76  LBL
154  32  X:T
155  53  (
156  93  .
157  09  9
158  06  6
159  75  -
160  93  .
161  02  2
162  08  8
163  65  ×
164  53  (
165  43  RCL
166  11  11
167  55  ÷
168  43  RCL
169  12  12
170  54  )
171  34  √X
172  54  )
173  92  RTN
```

CALC v_g

```
174  76  LBL
175  42  STO
176  53  (
177  01  1
178  00  0
179  93  .
180  07  7
181  02  2
182  65  ×
183  71  SBR
184  23  LNX
185  65  ×
186  43  RCL
187  09  09
188  55  ÷
189  43  RCL
190  08  08
191  55  ÷
192  71  SBR
193  22  INV
194  54  )
195  92  RTN
```

CALC v_f

```
196  76  LBL
197  43  RCL
198  53  (
199  93  .
200  00  0
201  01  1
202  06  6
203  00  0
204  03  3
205  03  3
206  55  ÷
207  43  RCL
208  07  07
209  54  )
210  92  RTN
```

CALC $\frac{w_g}{w_f + w_g}$

```
211  76  LBL
212  44  SUM
213  53  (
214  43  RCL
215  03  03
216  55  ÷
```

```
217  53  (
218  43  RCL
219  02  02
220  85  +
221  43  RCL
222  03  03
223  54  )
224  54  )
225  92  RTN
```

MAIN PROGRAM
ENTER DATA

```
226  76  LBL
227  11  A
228  22  INV
229  86  STF
230  01  01
231  01  1
232  42  STO
233  01  01
234  02  2
235  08  8
236  42  STO
237  58  58
238  16  A'
239  19  D'
240  19  D'
241  16  A'
242  10  E'
```

CALC MIN F_L

```
243  76  LBL
244  12  B
245  43  RCL
246  05  05
247  55  ÷
248  53  (
249  71  SBR
250  22  INV
251  75  -
252  71  SBR
253  32  X⇌T
254  65  ×
255  43  RCL
256  11  11
257  54  )
258  95  =
259  34  √X
260  87  IFF
261  01  01
262  34  √X
263  99  PRT
```

CALC v_g

```
264  10  E'
265  76  LBL
266  34  √X
267  43  RCL
268  03  03
269  65  ×
270  71  SBR
271  42  STO
272  55  ÷
273  53  (
274  71  SBR
275  42  STO
276  65  ×
277  43  RCL
278  03  03
279  85  +
280  71  SBR
281  43  RCL
282  65  ×
283  43  RCL
284  02  02
285  54  )
286  95  =
287  42  STO
288  16  16
```

CALC X

```
289  53  (
290  43  RCL
291  13  13
292  33  X²
293  65  ×
294  53  (
295  01  1
296  75  -
297  71  SBR
298  32  X⇌T
299  65  ×
300  43  RCL
301  11  11
302  55  ÷
303  71  SBR
304  22  INV
305  54  )
306  65  ×
307  53  (
308  01  1
309  75  -
310  43  RCL
311  16  16
312  54  )
313  85  +
314  53  (
315  71  SBR
316  25  CLR
317  65  ×
318  71  SBR
319  24  CE
320  65  ×
321  43  RCL
322  16  16
323  54  )
324  95  =
325  32  X⇌T
326  43  RCL
327  05  05
328  55  ÷
329  71  SBR
330  22  INV
331  95  =
332  22  INV
333  77  GE
334  33  X²
335  32  X⇌T
336  76  LBL
337  33  X²
338  42  STO
339  17  17
```

CALC v_e

```
340  01  1
341  75  -
342  43  RCL
343  17  17
344  55  ÷
345  03  3
346  55  ÷
347  71  SBR
348  25  CLR
349  55  ÷
350  71  SBR
351  24  CE
352  95  =
353  33  X²
354  35  1/X
355  65  ×
356  71  SBR
357  44  SUM
358  65  ×
359  71  SBR
360  42  STO
361  85  +
362  53  (
363  01  1
364  75  -
```

```
365  71 SBR
366  44 SUM
367  54  )
368  65  ×
369  71 SBR
370  43 RCL
371  95  =
372  42 STO
373  18  18
```

CALC PRELIM C_v

```
374  55  ÷
375  43 RCL
376  17  17
377  55  ÷
378  71 SBR
379  22 INV
380  95  =
381  34 ΓX
382  65  ×
383  53  (
384  43 RCL
385  02  02
386  85  +
387  43 RCL
388  03  03
389  54  )
390  55  ÷
391  06  6
392  03  3
393  93  .
394  03  3
395  95  =
396  42 STO
397  19  19
```

CALC F_P

```
398  87 IFF
399  01  01
400  35 1/X
401  99 PRT
402  10 E'
403  22 INV
404  86 STF
405  00  00
406  76 LBL
407  35 1/X
408  53  (
409  01  1
410  85  +
411  53  (
412  01  1
413  75  -
414  43 RCL
415  15  15
416  33 X²
417  55  ÷
418  43 RCL
419  14  14
420  33 X²
421  54  )
422  33 X²
423  55  ÷
424  05  5
425  09  9
426  03  3
427  65  ×
428  53  (
429  43 RCL
430  19  19
431  55  ÷
432  43 RCL
433  15  15
434  33 X²
435  54  )
436  33 X²
437  95  =
438  34 ΓX
439  35 1/X
440  42 STO
441  20  20
```

CALC C_v

```
442  43 RCL
443  19  19
444  55  ÷
445  43 RCL
446  20  20
447  95  =
448  99 PRT
449  42 STO
450  21  21
451  16 A'
452  98 ADV
453  98 ADV
454  43 RCL
455  21  21
456  91 R/S
```

Program 4: HP 41CV Data Sheet

```
************

* CV 2PHASE*

************

ENTER LIQUID FLOW PPH
       20,000.000    ***
ENTER VAPOR  FLOW PPH
          460.000    ***
ENTER INLET PRSS PSIG
           85.000    ***
ENTER dP PSI
           36.000    ***

ENTER TEMP DEG F
           80.000    ***
ENTER LQD SG·
            1.000    ***
ENTER VAP MW
           28.970    ***
ENTER VAP Z
            1.000    ***
ENTER CP/CV
            1.400    ***
ENTER VAP PRS PSIA
            0.600    ***
ENTER CRT PRS PSIA
        3,206.000    ***

CALC    MIN  FL
            0.602    ***
ENTER VALVE FL
            0.940    ***
ENTER DISCH PIPE SIZE IN
            3.000    ***
CALC    PRELIM
 CV
           15.198    ***
ENTER VALV SIZE IN
            2.000    ***
CALC     CV
           15.255    ***
************
```

Program 4: HP 41CV Register Loading

SIZE 080

```
R00=  0.000000
R01=  0.000000
R02=  0.000000
R03=  0.000000
R04=  0.000000
R05=  0.000000
R06=  0.000000
R07=  0.000000
R08=  0.000000
R09=  0.000000
R10=  0.000000
R11=  0.000000
R12=  0.000000
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  0.000000
R17=  0.000000
R18=  0.000000
R19=  0.000000
R20=  0.000000
R21=  0.000000
R22=  0.000000
R23=  0.000000
R24=  0.000000
R25=  0.000000
R26= "* CV 2"
R27= "PHASE*"
R28= "LIQUID"
R29= " FLOW "
R30=  26.270000
R31=  57.282951
R32=  57.522951
R33=  57.535460
R34=  57.610000
R35=  57.626300
R36=  57.640000
R37=  57.650000
R38=  57.660000
R39=  57.670000
R40=  57.686900
R41=  57.706900
R42=  0.000000
R43=  56.710000
R44=  57.727300
R45=  57.747576
R46=  0.000000
R47=  56.777800
R48=  57.797600
R49=  0.000000
R50=  56.780000
R51= "PPH   "
R52= "VAPOR "
R53= "INLET "
R54= "PRSS P"
R55= "******"
R56= "CALC  "
R57= "ENTER "
R58=  50.000000
R59=  0.000000
R60= "SIG   "
R61= "dP PSI"
R62= "TEMP D"
R63= "EG F  "
R64= "LQD SG"
R65= "VAP MW"
R66= "VAP Z "
R67= "CP/CV "
R68= "VAP PR"
R69= "S PSIA"
R70= "CRT PR"
R71= "MIN FL"
R72= "VALVE "
R73= "FL    "
R74= "DISCH "
R75= "PIPE S"
R76= "IZE IN"
R77= "PRELIM"
R78= " CV   "
R79= "VALV S"
```

Program 4: HP 41CV Listing

SUBROUTINES

```
01♦LBL "CV 2PH"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 GTO d
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53♦LBL 01
54 XEQ J
55 GTO e
```

RE-ENTER VARIABLES

```
56♦LBL "REENTER"
57 ADV
58 1
59 +
60 STO 01
61 RCL IND 01
```

```
62 XEQ J
63 STOP
64 XEQ J
65 STO IND 01
66 ADV
67 SF 00
68 SF 02
69 STOP
70 GTO 02
```

BYPASS PRINTER

```
71♦LBL J
72 FC? 55
73 GTO 01
74 PRX
75 RTN
76♦LBL 01
77 VIEW X
78 RTN
```

CALC P_1

```
79♦LBL B
80 RCL 04
81 15
82 +
83 RTN
```

CALC T_1

```
84♦LBL C
85 RCL 06
86 460
87 +
88 RTN
```

CALC X_T

```
89♦LBL D
90 RCL 13
91 X↑2
92 .84
93 *
94 RTN
```

CALC F_k

```
95♦LBL E
96 RCL 10
97 1.4
98 /
99 RTN
```

CALC F_F

```
100♦LBL F
101 RCL 11
102 RCL 12
103 /
104 SQRT
105 .28
106 *
107 CHS
108 .96
109 +
110 RTN
```

CALC v_g

```
111♦LBL G
112 10.72
113 XEQ C
114 *
115 RCL 09
116 *
117 RCL 08
118 /
119 XEQ B
120 /
121 RTN
```

CALC v_f

```
122♦LBL H
123 .016033
124 RCL 07
125 /
126 RTN
```

CALC $\frac{w_g}{w_f + w_g}$

```
127♦LBL I
128 RCL 02
129 RCL 03
130 +
131 1/X
132 RCL 03
133 *
134 RTN
```

MAIN PROGRAM

ENTER DATA

```
135♦LBL A
136 CF 02
137 1
138 STO 01
139 29
140 STO 58
141 XEQ a
142 XEQ d
143 XEQ a
144 XEQ e
```

CALC MIN F_L

```
145♦LBL 02
146 XEQ B
147 XEQ F
148 RCL 11
149 *
150 -
151 1/X
152 RCL 05
153 *
154 SQRT
155 FS? 02
156 GTO 01
157 XEQ J
```

CALC v_g

```
158 XEQ e
159♦LBL 01
160 RCL 03
161 XEQ G
162 *
163 XEQ G
164 RCL 03
165 *
166 XEQ H
167 RCL 02
168 *
169 +
170 /
171 STO 16
```

CALC X

```
172 XEQ F
173 RCL 11
174 *
175 XEQ B
176 /
177 CHS
178 1
179 +
180 RCL 13
181 X↑2
182 *
183 1
184 RCL 16
185 -
186 *
187 XEQ E
188 XEQ D
189 *
190 RCL 16
191 *
192 +
193 STO 17
194 RCL 05
195 XEQ B
196 /
197 RCL 17
198 X<>Y
```

```
199 X<=Y?
200 GTO 01
201 RDN
202•LBL 01
203 STO 17
```

CALC v_g

```
204 3
205 /
206 XEQ E
207 /
208 XEQ D
209 /
210 CHS
211 1
212 +
213 X↑2
214 1/X
215 XEQ I
216 *
217 XEQ G
218 *
219 1
220 XEQ I
221 -
222 XEQ H
223 *
224 +
225 STO 18
226 RCL 17
227 /
228 XEQ B
229 /
230 SQRT
231 RCL 02
232 RCL 03
233 +
234 *
235 63.3
236 /
237 STO 19
```

CALC F_P

```
238 FS? 02
239 GTO 01
240 XEQ J
241 XEQ e
242 CF 00
243•LBL 01
244 1
245 RCL 15
246 X↑2
247 RCL 14
248 X↑2
249 /
250 -
251 X↑2
252 593
253 /
254 RCL 19
255 RCL 15
256 X↑2
257 /
258 X↑2
259 *
260 1
261 +
262 SQRT
263 1/X
264 STO 20
```

CALC C_v

```
265 RCL 19
266 RCL 20
267 /
268 STO 21
269 XEQ J
270 FS? 00
271 STOP
272 XEQ a
273 RCL 21
274 VIEW X
275 BEEP
276 ADV
277 STOP
278 .END.
```

Program 4: Sequence of Calculations

1. Calculate minimum pressure recovery factor from process conditions.

$$F_L = \sqrt{\frac{\Delta P}{P_1 - P_v F_F}}$$

where

$$F_F = .96 - .28\sqrt{\frac{P_v}{P_c}}$$

2. Calculate the specific volume of the gas.

$$v_g = \frac{10.72\, T_1 Z}{M P_1}$$

3. Calculate the specific volume of the liquid.

$$v_f = \frac{.016033}{G_f}$$

4. Calculate the volume fraction of the gas.

$$V_g = \frac{w_g v_g}{w_g v_g + w_f v_f}$$

5. Calculate the pressure drop ratio factor.

$$X = \frac{\Delta P}{P_1}$$

limited to a minimum of $F_L^2\left(1 - \frac{F_F P_v}{P_1}\right)(1 - V_g) + (F_k X_T V_g)$

where

$$F_k = \frac{k}{1.4}$$

$$X_T = .84F_L^2$$

6. Calculate the expansion factor.

$$Y = 1 - \frac{X}{F_k X_T}$$

7. Calculate the effective specific volume for the fluid and gas.

$$v_e = \frac{f_g v_g}{Y^2} + \frac{(1 - f_g)}{63.3\ G_f}$$

8. Calculate the preliminary valve size.

$$C_v = \frac{(w_f + w_g)}{63.3}\sqrt{\frac{v_e}{XP_1}}$$

9. Calculate the piping geometry factor.

$$F_P = \left[1 + \left(\frac{1}{593}\left(1 - \left(\frac{d}{D}\right)^2\right)^2 \left(\frac{C_v}{d^2}\right)^2\right)\right]^{-1/2}$$

10. Calculate the final valve size.

$$C_v = \frac{\text{preliminary } C_v}{F_P}$$

Program 4: Nomenclature

C_v Valve sizing coefficient, dimensionless
d Nominal valve size, inches
D Internal diameter of the piping, inches
f_g Weight fraction of the gas, dimensionless
F_F Liquid critical pressure ratio factor, dimensionless
F_k Ratio of specific heats factor, dimensionless
F_L Rated liquid pressure recovery factor, dimensionless
F_P Piping geometry factor, dimensionless
G_f Specific gravity (ratio of densities) of the liquid at flowing temperature compared to water at base conditions, dimensionless
k Ratio of specific heats, dimensionless
M Molecular weight, dimensionless
P_1 Upstream absolute static pressure, PSIA
P_2 Downstream absolute static pressure, PSIA
P_c Critical pressure, PSIA
P_v Vapor pressure (absolute) of liquid at inlet temperature, PSIA
ΔP Pressure drop ($P_1 - P_2$) across the valve, PSI
ΔP_T Terminal pressure drop, PSI
T_1 Absolute upstream temperature, °R
v_e Effective specific volume for the fluid and gas, cubic feet per pound.
v_f Specific volume liquid, cubic feet per pound
v_g Specific volume gas, cubic feet per pound
V_g Volume fraction of gas
w_f Weight rate of flow—liquid, pounds per hour
w_g Weight rate of flow—gas, pounds per hour
x Ratio of pressure drop to absolute inlet static pressure ($\Delta P/P_1$), dimensionless
X_T Rated pressure drop ratio factor, dimensionless
Y Expansion factor, ratio of flow coefficient for a gas to that for a liquid at the same Reynolds number, dimensionless
Z Compressibility factor, dimensionless

References

J. W. Hutchison, *ISA Handbook of Control Valves,* 2nd Edition, ISA.

Typical Data

Representative F_L Factors at Full-Rated Travel for Full-Size Trim*

Valve Type	Flow Direction	Trim Type	F_L
Single-port or Double-port globe	either	ported plug	0.85–0.95
Double-port globe	either	contoured plug	0.85–0.90
Single-port globe	flow-to-open	contoured plug	0.85–0.90
Single-port globe	flow-to-close	contoured plug	0.75–0.85
Angle	flow-to-open	contoured plug	0.85–0.90
Angle	flow-to-close	venturi	0.45–0.55
Ball		characterized	0.60–0.65
Ball		regular port	0.55–0.60
Butterfly		60°	055–0.65

*These values are typical only for the types shown. Variations may occur due to other types of trim, full or reduced ports, and among manufacturers. (Extracted from ISA S75.01.)

F_d Valve-Style Modifier, Dimensionless

The factor F_d allows a single curve to correlate the data from a number of valve styles. F_d values of 1.0 can be used for V-notch ball valves and single-ported globe valves. An F_d of 0.7 may be used for valves with two parallel flow paths such as double-ported globe valves and butterfly valves. Caution must be used in applying the universal curve for other valve styles when the F_d has not been established. (Extracted from ISA S75.01.)

Physical Properties of Hydrocarbon Liquids

No.	Compound	Formula	Specific Gravity, 60°F/60°F	Critical Pressure, PSIA	Vapor Pressure, 100°F, PSIA
1	Methane	CH_4	0.3	667.8	5000
2	Ethane	C_2H_6	0.3564	707.8	800
3	Propane	C_3H_8	0.5077	616.3	190.
4	*n*-Butane	C_4H_{10}	0.5844	550.7	51.6
5	Isobutane	C_4H_{10}	0.5631	529.1	72.2
6	*n*-Pentane	C_5H_{12}	0.6310	488.6	15.570
7	Isopentane	C_5H_{12}	0.6247	490.4	20.44
8	Neopentane	C_5H_{12}	0.5967	464.0	35.9
9	*n*-Hexane	C_6H_{14}	0.6640	436.9	4.956
10	*2*Methylpentane	C_6H_{14}	0.6579	436.6	6.767
11	*3*-Methylpentane	C_6H_{14}	0.6689	453.1	6.098
12	Neohexane	C_6H_{14}	0.6540	446.8	9.856
13	*2,3*-Dimethylbutane	C_6H_{14}	0.6664	453.5	7.404

(table continued on next page)

Physical Properties of Hydrocarbon Liquids (continued)

No.	Compound	Formula	Specific Gravity, 60°F/60°F	Critical Pressure, PSIA	Vapor Pressure, 100°F, PSIA
14	*n*-Heptane	C_7H_{16}	0.6882	396.8	1.620
15	*2*-Methylhexane	C_7H_{16}	0.6830	396.5	2.271
16	*3*-Methylhexane	C_7H_{16}	0.6917	408.1	2.130
17	*3*-Ethylpentane	C_7H_{16}	0.7028	419.3	2.012
18	*2,2*-Dimethylpentane	C_7H_{16}	0.6782	402.2	3.492
19	*2,4*-Dimethylpentane	C_7H_{16}	0.6773	396.9	3.292
20	*3,3*-Dimethylpentane	C_7H_{16}	0.6976	427.2	2.773
21	Triptane	C_7H_{16}	0.6946	428.4	3.374
22	*n*-Octane	C_8H_{18}	0.7068	360.6	0.537
23	Diisobutyl	C_8H_{18}	0.6979	360.6	1.101
24	Isooctane	C_8H_{18}	0.6962	372.4	1.708
25	*n*-Nonane	C_9H_{20}	0.7217	332.	0.179
26	*n*-Decane	$C_{10}H_{22}$	0.7342	304.	0.0597
27	Cyclopentane	C_5H_{10}	0.7504	653.8	9.914
28	Methylcyclopentane	C_6H_{12}	0.7536	548.9	4.503
29	Cyclohexane	C_6H_{12}	0.7834	591.	3.264
30	Methylcyclohexane	C_7H_{14}	0.7740	503.5	1.609
31	Ethylene	C_2H_4	—	729.8	—
32	Propene	C_3H_6	0.5220	669.	226.4
33	*1*-Butene	C_4H_8	0.6013	583.	63.05
34	*cis-2*-Butene	C_4H_8	0.6271	610.	45.54
35	*trans-2*-Butene	C_4H_8	0.6100	595.	49.80
36	Isobutene	C_4H_8	0.6004	580.	63.40
37	*1*-Pentene	C_5H_{10}	0.6457	590.	19.115
38	*1,2*-Butadiene	C_4H_6	0.658	653.	20.
39	*1,3*-Butadiene	C_4H_6	0.6272	628.	60.
40	Isoprene	C_5H_8	0.6861	558.4	16.672
41	Acetylene	C_2H_2	0.615	890.4	—
42	Benzene	C_6H_6	0.8844	710.4	3.224
43	Toluene	C_7H_8	0.8718	595.9	1.032
44	Ethylbenzene	C_8H_{10}	0.8718	523.5	0.371
45	*o*-Xylene	C_8H_{10}	0.8848	541.4	0.264
46	*m*-Xylene	C_8H_{10}	0.8687	513.6	0.326
47	*p*-Xylene	C_8H_{10}	0.8657	509.2	0.342
48	Styrene	C_8H_8	0.9110	580.	(0.24)
49	Isopropylbenzene	C_9H_{12}	0.8663	465.4	0.188
50	Methyl alcohol	CH_4O	0.796	1174.2	4.63
51	Ethyl alcohol	C_2H_6O	0.794	925.3	2.3
52	Carbon monoxide	CO	0.801	507.	—
53	Carbon dioxide	CO_2	0.827	1071.	—
54	Hydrogen sulfide	H_2S	0.79	1306.	394.0
55	Sulfur dioxide	SO_2	1.397	1145.	88.

(table continued on next page)

Physical Properties of Hydrocarbon Liquids (continued)

No.	Compound	Formula	Specific Gravity, 60°F/60°F	Critical Pressure, PSIA	Vapor Pressure, 100°F, PSIA
56	Ammonia	NH_3	0.6173	1636.	212.
57	Air	N_2O_2	0.856	547.	—
58	Hydrogen	H_2	0.07	188.1	—
59	Oxygen	O_2	1.14	736.9	—
60	Nitrogen	N_2	0.808	493.0	—
61	Chlorine	Cl_2	1.414	1118.4	158.
62	Water	H_2O	1.000	3208.	0.9492
63	Helium	He	—	—	—
64	Hydrogen chloride	HCl	0.8558	1198.	925.

Physical Properties of Hydrocarbon Vapor

	k^* (C_p/C_v)	M
Acetaldehyde	1.14	44.05
Acetic acid	1.15	60.05
Acetylene	1.26	26.04
Air	1.40	28.97
Ammonia	1.33	17.03
Argon	1.67	39.94
Benzene	1.12	78.11
Butadiene 1.3	1.12	54.09
n-Butane	1.094	58.12
iso-Butane	1.094	58.12
Carbon dioxide	1.30	44.01
Carbon disulfide	1.21	76.13
Carbon monoxide	1.40	28.00
Chlorine	1.36	70.90
Cyclohexane	1.09	84.16
n-Decane	1.03	142.28
Dowtherm A	1.046	165.00
Ethane	1.22	30.07
Ethyl alcohol	1.13	46.07
Ethyl chloride	1.19	64.52
Ethylene (ethene)	1.26	28.05
Freon 11	1.14	137.37
Freon 12	1.14	120.92
Freon 22	1.18	86.48
Freon 114	1.09	170.93

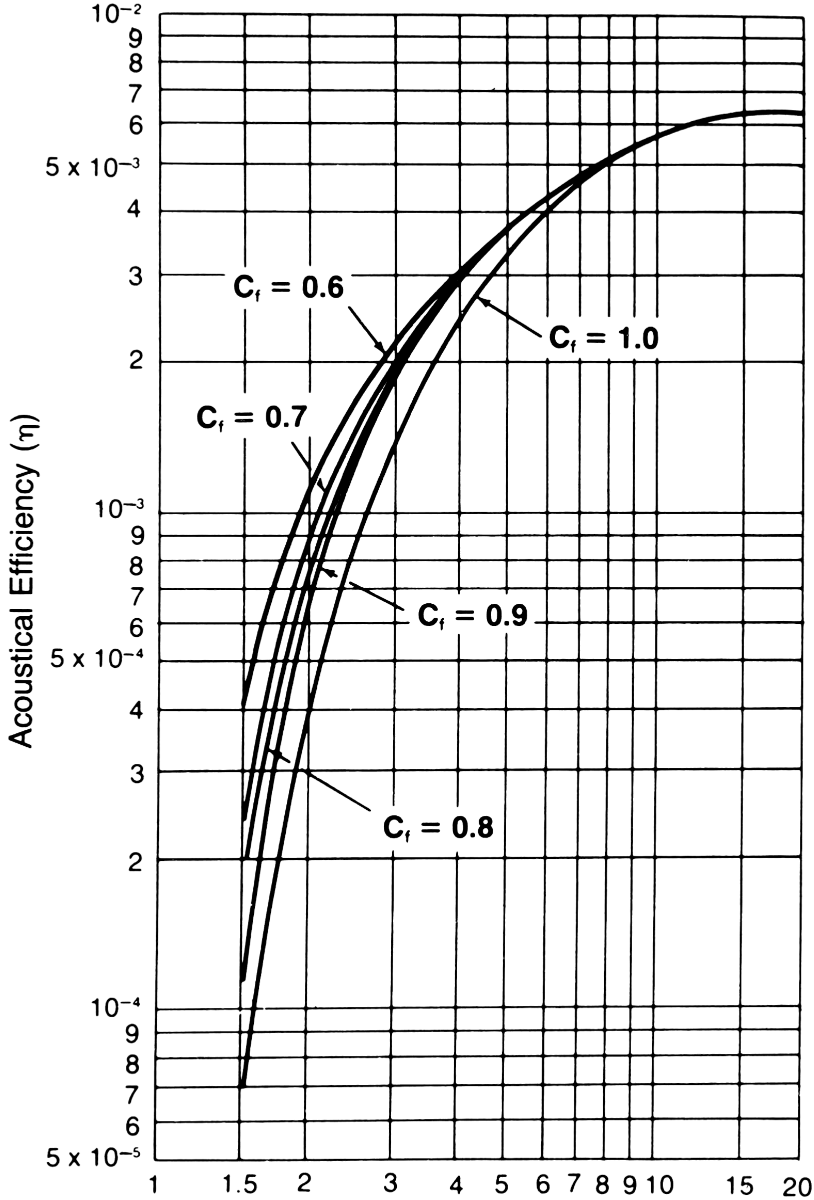
(table continued on next page)

Physical Properties of Hydrocarbon Liquids (continued)

	k^* (C_p/C_v)	M
Helium	1.66	4.00
n-Hexane	1.06	86.17
Hydrogen chloride	1.41	36.50
Hydrogen	1.41	2.016
Hydrogen sulfide	1.32	34.07
Methane	1.31	16.04
Methyl alcohol	1.20	32.04
Methyl butane	1.08	72.15
Methyl chloride	1.20	50.49
Natural gas	1.27	19.00
Nitric oxide	1.40	30.00
Nitrogen	1.40	28.00
Nitrous oxide	1.30	44.00
Nonane	1.04	128.25
n-Octane	1.05	114.22
Oxygen	1.40	32.00
n-Pentane	1.07	72.15
Propane	1.13	44.09
Propylene	1.15	42.08
Steam	1.324	18.02
Styrene	1.07	104.14
Sulfur dioxide	1.29	64.06
Toluene	1.09	92.13

**k*-values at 14.7 PSIG and 600°F.

Acoustical Efficiency: Conventional Valves
$P_1/P_2 > 1.5$

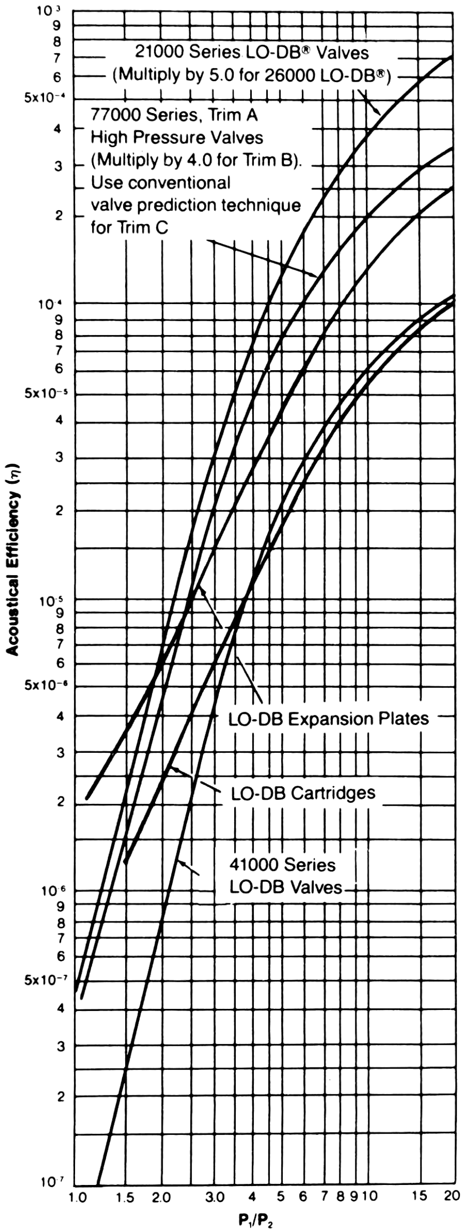


Courtesy Masoneilan International, Inc., *Noise Control Manual*

Acoustical Efficiency
$P_1/P_2 \leq 1.5$

P_1/P_2	η				
	$C_f = 1$	$C_f = 0.9$	$C_f = 0.8$	$C_f = 0.7$	$C_f = 0.6$
1.50	7×10^{-5}	1.4×10^{-4}	2.1×10^{-4}	2.4×10^{-4}	3.8×10^{-4}
1.40	5.2×10^{-5}	9.2×10^{-5}	1.5×10^{-4}	2.2×10^{-4}	3.0×10^{-4}
1.30	2.8×10^{-5}	5.4×10^{-5}	9.2×10^{-5}	1.4×10^{-4}	2.1×10^{-4}
1.25	1.9×10^{-5}	3.8×10^{-5}	6.8×10^{-5}	1.1×10^{-4}	1.6×10^{-4}
1.20	1.2×10^{-5}	2.5×10^{-5}	4.7×10^{-5}	7.8×10^{-5}	1.2×10^{-4}
1.15	6.4×10^{-6}	1.4×10^{-5}	2.9×10^{-5}	5.0×10^{-5}	8.0×10^{-5}
1.10	2.6×10^{-6}	6.6×10^{-6}	1.4×10^{-5}	2.7×10^{-5}	4.6×10^{-5}
1.05	5.4×10^{-7}	1.7×10^{-6}	4.2×10^{-6}	9.1×10^{-6}	1.7×10^{-5}
1.01	1.4×10^{-8}	6.6×10^{-8}	2.4×10^{-7}	7.1×10^{-7}	1.7×10^{-6}

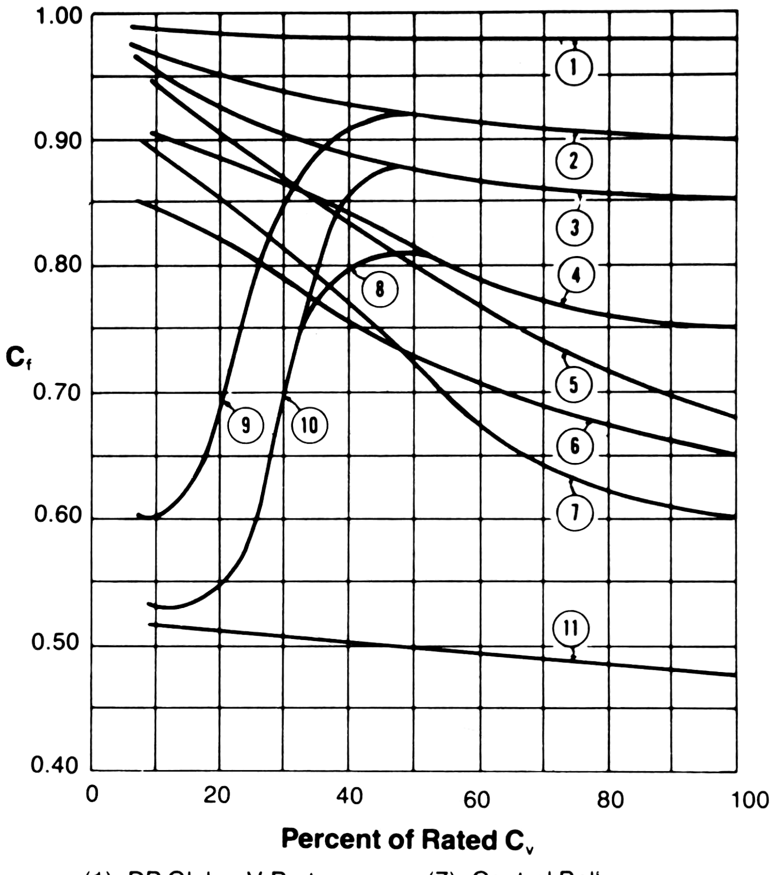
Courtesy Masoneilan International, Inc., *Noise Control Manual*



Acoustical Efficiency: LO-DB Equipment

Courtesy Masoneilan International, Inc., *Noise Control Manual*

Variation of C_f with Valve Opening
$C_f = F_L$



(1) DP Globe: V-Port
(2) SP Globe: Flow-to-open
(3) Camflex: Flow-to-open
(4) Split Body: Flow-to-open
(5) Camflex: Flow-to-close
(6) Butterfly (MiniTork)
(7) Control Ball
(8) Split Body: Flow-to-close
(9) DP Globe: Contoured
(10) SP Globe: Flow-to-close
(11) 71000 Series Angle Valve: Flow-to-close

Courtesy Masoneilan International, Inc., *Noise Control Manual*

Pipe Data*

Nominal Pipe Size, Inches	Outside Diameter, Inches	Identification: Steel: Iron Pipe Size	Identification: Steel: Sched. No.	Identification: Stainless Steel Sched. No.	Wall Thickness (t) Inches	Inside Diameter (D) Inches
		—	—	10S	.049	.307
⅛	0.405	STD	40	40S	.068	.269
		XS	80	80S	.095	.215
		—	—	10S	.065	.410
¼	0.540	STD	40	40S	.088	.364
		XS	80S	80S	.119	.302
		—	—	10S	.065	.545
⅜	0.675	STD	40	40S	.091	.493
		XS	80	80S	.126	.423
		—	—	5S	.065	.710
		—	—	10S	.083	.674
½	0.840	STD	40	40S	.109	.622
		XS	80	80S	.147	.546
		—	160	—	.187	.466
		XXS	—	—	.294	.252
		—	—	5S	.065	.920
		—	—	10S	.083	.884
¾	1.505	STD	40	40S	.113	.824
		XS	80	80S	.154	.742
		—	160	—	.219	.612
		XXS	—	—	.308	.434
		—	—	5S	.065	1.185
		—	—	10S	.109	1.097
1	1.315	STD	40	40S	.133	1.049
		XS	80	80S	.179	.957
		—	160	—	.250	.815
		XXS	—	—	.358	.599
		—	—	5S	.065	1.530
		—	—	10S	.109	1.442
1¼	1.660	STD	40	40S	.140	1.380
		XS	80	80S	.191	1.278
		—	160	—	.250	1.160
		XXS	—	—	.382	.896
		—	—	5S	.065	1.770
		—	—	10S	.109	1.682
1½	1.900	STD	40	40S	.154	1.610
		XS	80	80S	.200	1.500

*Identification, wall thickness, and weights are extracted from ANSI B36 19. The notations STD, XS, and XXS indicate standard, extra strong, and double extra strong pipe, respectively.
(Table continued on next page)

Pipe Data* (continued)

Nominal Pipe Size, Inches	Outside Diameter, Inches	Identification: Steel: Iron Pipe Size	Identification: Steel: Sched. No.	Identification: Stainless Steel Sched. No.	Wall Thickness (t) Inches	Inside Diameter (D) Inches
		—	160	—	.218	1.338
		XXS	—	—	.400	1.100
2	2.375	—	—	5S	.065	2.245
		—	—	10S	.109	2.157
		STD	40	40S	.154	2.067
		XS	80	80S	.218	1.939
		—	160	—	.344	1.687
		XXS	—	—	.436	1.503
2½	2.875	—	—	5S	.083	2.709
		—	—	10S	.120	2.635
		STD	40	40S	.203	1.469
		XS	80	80S	.276	2.323
		—	160	—	.375	2.125
		XXS	—	—	.552	1.771
3	3.500	—	—	5S	.083	3.334
		—	—	10S	.120	3.260
		STD	40	40S	.216	3.068
		XS	80	80S	.300	2.900
		—	160	—	.438	2.624
		XXS	—	—	.600	2.300
3½	4.000	—	—	5S	.083	3.834
		—	—	10S	.120	3.760
		STD	40	40S	.226	3.548
		XS	80	80S	.318	3.364
4	4.500	—	—	5S	.083	4.334
		—	—	10S	.120	4.260
		STD	40	40S	.237	4.026
		XS	80	80S	.337	3.826
		—	120	—	.438	3.624
		—	160	—	.531	3.438
		XXS	—	—	.674	3.152
5	5.563	—	—	5S	.109	5.345
		—	—	10S	.134	5.295
		STD	40	40S	.258	5.047
		XS	80	80S	.375	4.813
		—	120	—	.500	4.563
		—	160	—	.625	4.313
		XXS	—	—	.750	4.063

*Identification, wall thickness, and weights are extracted from ANSI B36 19. The notations STD, XS, and XXS indicate standard, extra strong, and double extra strong pipe, respectively. (Table continued on next page)

Pipe Data* (continued)

Nominal Pipe Size, Inches	Outside Diameter, Inches	Identification: Steel: Iron Pipe Size	Identification: Steel: Sched. No.	Identification: Stainless Steel Sched. No.	Wall Thickness (t) Inches	Inside Diameter (D) Inches
		—	—	5S	.109	6.407
		—	—	10S	.134	6.357
		STD	40	40S	.280	6.065
6	6.625	XS	80	80S	.432	5.761
		—	120	—	.562	5.501
		—	160	—	.719	5.187
		XXS	—	—	.864	4.897
		—	—	5S	.109	8.407
		—	—	10S	.148	8.329
		—	20	—	.250	8.125
		—	30	—	.277	8.071
		STD	40	40S	.322	7.981
8	8.625	—	60	—	.406	7.813
		XS	80	80S	.500	7.625
		—	100	—	.594	7.437
		—	120	—	.719	7.187
		—	140	—	.812	7.001
		XXS	—	—	.875	6.875
		—	160	—	.906	6.813
		—	—	5S	.134	10.482
		—	—	10S	.165	10.420
		—	20	—	.250	10.250
		—	30	—	.307	10.136
		STD	40	40S	.365	10.020
10	10.750	XS	60	80S	.500	9.750
		—	80	—	.594	9.562
		—	100	—	.719	9.312
		—	120	—	.844	9.062
		XXS	140	—	1.000	8.750
		—	160	—	1.125	8.500
		—	—	5S	.156	12.438
		—	—	10S	.180	12.390
		—	20	—	.250	12.250
		—	30	—	.330	12.090
		STD	—	40S	.375	12.000
		—	40	—	.406	11.938
12	12.75	XS	—	80S	.500	11.750
		—	60	—	.562	11.626
		—	80	—	.688	11.374
		—	100	—	.844	11.062

*Identification, wall thickness, and weights are extracted from ANSI B36 19. The notations STD, XS, and XXS indicate standard, extra strong, and double extra strong pipe, respectively.
(Table continued on next page)

Pipe Data* (continued)

Nominal Pipe Size, Inches	Outside Diameter, Inches	Identification: Steel, Iron Pipe Size	Identification: Steel, Sched. No.	Identification: Stainless Steel Sched. No.	Wall Thickness (t) Inches	Inside Diameter (D) Inches
		XXS	120	—	1.000	10.750
		—	140	—	1.125	10.500
		—	160	—	1.312	10.126
14	14.00	—	—	5S	.156	13.688
		—	—	10S	.188	13.624
		—	10	—	.250	13.500
		—	20	—	.312	13.376
		STD	30	—	.375	13.250
		—	40	—	.438	13.124
		XS	—	—	.500	13.000
		—	60	—	.594	12.812
		—	80	—	.750	12.500
		—	100	—	.938	12.124
		—	120	—	1.094	11.812
		—	140	—	1.250	11.500
		—	160	—	1.406	11.188
16	16.00	—	—	5S	.165	15.670
		—	—	10S	.188	15.624
		—	10	—	.250	15.500
		—	20	—	.312	15.376
		STD	30	—	.375	15.250
		XS	40	—	.500	15.000
		—	60	—	.656	14.688
		—	80	—	.844	14.312
		—	100	—	1.031	13.938
		—	120	—	1.219	13.562
		—	140	—	1.438	13.124
		—	160	—	1.594	12.812
18	18.00	—	—	5S	.165	17.670
		—	—	10S	.188	17.624
		—	10	—	.250	17.500
		—	20	—	.312	17.376
		STD	—	—	.375	17.250
		—	30	—	.438	17.124
		XS	—	—	.500	17.000
		—	40	—	.562	16.876
		—	60	—	.750	16.500
		—	80	—	.938	16.124
		—	100	—	1.156	15.688
		—	120	—	1.375	15.250

*Identification, wall thickness, and weights are extracted from ANSI B36 19. The notations STD, XS, and XXS indicate standard, extra strong, and double extra strong pipe, respectively.
(Table continued on next page)

Pipe Data* (continued)

Nominal Pipe Size, Inches	Outside Diameter, Inches	Identification: Steel: Iron Pipe Size	Identification: Steel: Sched. No.	Identification: Stainless Steel Sched. No.	Wall Thickness (t) Inches	Inside Diameter (D) Inches
		—	140	—	1.562	14.876
		—	160	—	1.781	14.438
		—	—	5S	.188	19.624
		—	—	10S	.218	19.564
		—	10	—	.250	19.500
		STD	20	—	.375	19.250
		XS	30	—	.500	19.000
20	20.00	—	40	—	.594	18.812
		—	60	—	.812	18.376
		—	80	—	1.031	17.938
		—	100	—	1.281	17.438
		—	120	—	1.500	17.000
		—	140	—	1.750	16.500
		—	160	—	1.969	16.062
			—			
		—	—	5S	.188	21.624
		—	10	10S	.218	21.564
		—	20	—	.250	21.500
		STD	30	—	.375	21.250
22	22.00	XS	40	—	.500	21.000
		—	60	—	.875	20.250
		—	80	—	1.125	19.75
		—	100	—	1.375	19.25
		—	120	—	1.625	18.75
		—	140	—	1.875	18.25
		—	160	—	2.125	17.75
		—	—	5S	.218	23.564
		—	10	10S	.250	23.500
		STD	20	—	.375	23.250
		XS	—	—	.500	23.000
		—	30	—	.562	22.876
24	24.00	—	40	—	.688	22.624
		—	60	—	.969	22.062
		—	80	—	1.219	21.562
		—	100	—	1.531	20.938
		—	120	—	1.812	20.376
		—	140	—	2.062	19.876
		—	160	—	2.344	19.312

*Identification, wall thickness, and weights are extracted from ANSI B36 19. The notations STD, XS, and XXS indicate standard, extra strong, and double extra strong pipe, respectively.
(Table continued on next page)

Pipe Data* (continued)

Nominal Pipe Size, Inches	Outside Diameter, Inches	Identification: Steel: Iron Pipe Size	Identification: Steel: Sched. No.	Identification: Stainless Steel Sched. No.	Wall Thickness (t) Inches	Inside Diameter (D) Inches
		—	10	—	.312	25.376
26	26.00	STD	—	—	.375	25.250
		XS	20	—	.500	25.000
		—	10	—	.312	27.376
28	28.00	STD	—	—	.375	27.250
		XS	20	—	.500	27.000
		—	30	—	.625	26.750
		—	—	5S	.250	29.500
		—	10	10S	.312	29.376
30	30.00	STD	—	—	.375	29.250
		XS	20	—	.500	29.000
		—	30	—	.625	28.750
		—	10	—	.312	31.376
		STD	—	—	.375	31.250
32	32.00	XS	20	—	.500	31.000
		—	30	—	.625	30.750
		—	40	—	.688	30.624
		—	10	—	.344	33.312
		STD	—	—	.375	33.250
34	34.00	XS	20	—	.500	33.000
		—	30	—	.625	32.750
		—	40	—	.688	32.624
		—	10	—	.312	35.376
		STD	—	—	.375	35.250
36	36.00	XS	20	—	.500	35.000
		—	30	—	.625	34.750
		—	40	—	.750	34.500

*Identification, wall thickness, and weights are extracted from ANSI B36 19. The notations STD, XS, and XXS indicate standard, extra strong, and double extra strong pipe, respectively.

CHAPTER THREE

Pressure Drop Across Control Valves

Program 5 Line Pressure Drop
Typical Data

This program is not an instrument engineering program but is included so that the pressure drop available across a control valve may be determined if the piping configuration is known.

In order for a control valve to regulate flow, there must be a pressure drop across it. For good control, this pressure drop should be proportional to the pressure drop incurred in the associated piping system. The program will calculate the pressure drop through the associated piping system; the pressure drop for the control valve should be 50% of this calculated value. For valves controlling flow on the discharge of centrifugal pumps, many process engineers take an arbitrary 10 PSI drop across the valve.

The formulas used here are suitable for both liquid and vapor flows. However, for gas calculations, if the dynamic loss exceeds 10% of the inlet pressure, the calculation should be made for increments of less than 100 feet, with the gas density corrected for each section.

For a more in-depth description, refer to Crane Technical Paper No. 410C, *Flow of Fluids Through Valves, Fittings and Pipe*.

Program 5
Line Pressure Drop

Program 5: User Instructions

a) Initiate program, press A.
b) Enter:
   1. Flowrate, pounds per hour — Press R/S

2. Density (specific weight), pounds per cubic foot — Press R/S
3. Absolute viscosity, centipoises — Press R/S
4. Pipeline inside diameter, inches — Press R/S

c) Program calculates pressure drop (PSI per 100 feet) and velocity (feet per second).
d) If it is desired to investigate different line sizes, press B and re-enter:
   5. Pipeline inside diameter, inches — Press R/S
e) Program will recalculate pressure drop (PSI per 100 feet) and velocity.

A reasonable velocity for liquids is 10–15 feet per second; for gases and vapors, 100–150 feet per second. When a satisfactory velocity is found, calculate the system dynamic loss as

$$\left(\text{calculated pressure drop per 100 ft} \times \frac{\text{total equivalent length}}{100}\right) \text{PSI}$$

where the total equivalent length is the straight lengths of pipe plus the equivalent lengths of the fittings as determined by the nomograph on page 76. The pressure drop across the control valve should be 50% of this figure.

Any change in elevation of the pipe will produce a static head, which may have to be allowed for in the valve.

Note: If conditions are selected which result in R_D in the critical zone (2000–3000), the program will ask for a different line size.

Program 5: TI 59 Data Sheet

```
********************

 LINE PRESSURE DROP

********************
ENTR  FLOW   PPH
         5000.
ENTR DNSTY  PPCF
           55.
ENTR VISC     CP
            5.

ENTR  LINE  DIA  INS
       3.068
     CRIT   RD

      2056.714472

ENTR  LINE  DIA  INS
         2.067
CALC ΔP/100 FT   PSI
          0.18
CALC VELOCITY   FPS
          1.08

ENTR  LINE  DIA  INS
         4.026
CALC ΔP/100 FT   PSI
          0.01
CALC VELOCITY   FPS
          0.29

********************
```

Program 5: TI 59 Register Loading

PARTITIONING
479.59

0.	00
0.	01
0.	02
0.	03
0.	04
0.	05
0.	06
0.	07
0.	08
0.	09
0.	10
0.	11
0.	12
0.	13
0.	14
0.	15
0.	16
0.	17
0.	18
0.	19
0.	20
0.	21
0.	22
0.	23
0.	24
0.	25
0.	26
0.	27
0.	28
0.	29
0.	30
0.	31
100213700.	32
56.363534	33
213336.	34
2437450000.	35
4217273215.	36
56.423241	37
54.535251	38
351600.4039	39
1535243700.	40
333624.	41
7533630201.	42
243136.4645	43
162413.4847	44
1533.544443	45
4224361500.	46
33331521.	47
1631363745.	48
333323.5049	49
21273243.	50
1635323300.	51
3641351700.	52
33351736.	53
27243117.	54
5151515151.	55
1513271500.	56
1731373500.	57
0.	58
0.	59

Program 5: TI 59 Listing

PRINT & STORE VARIABLES

```
000  76 LBL
001  10 E'
002  22 INV
003  59 INT
004  85  +
005  05  5
006  07  7
007  95  =
008  19 D'
009  69 OP
010  21  21
011  73 RC*
012  01  01
013  91 R/S
014  99 PRT
015  72 ST*
016  01  01
017  92 RTN
```

PRINT LINES

```
018  76 LBL
019  19 D'
020  42 STO
021  59  59
022  73 RC*
023  59  59
024  69 OP
025  01  01
026  18 C'
027  69 OP
028  02  02
029  18 C'
030  69 OP
031  03  03
032  18 C'
033  69 OP
034  04  04
035  69 OP
036  05  05
037  92 RTN
```

DECODE LINES

```
038  76 LBL
039  18 C'
040  01  1
041  00  0
042  00  0
043  48 EXC
044  59  59
045  22 INV
046  59 INT
```

```
047   49  PRD
048   59   59
049   73  RC÷
050   59   59
051   92  RTN
```

PRINT LINE OF STARS

```
052   76  LBL
053   16  A'
054   93   .
055   00   0
056   01   1
057   08   8
058   35  1/X
059   98  ADV
060   19  D'
061   98  ADV
062   92  RTN
```

MAIN PROGRAM ENTER DATA

```
063   76  LBL
064   11   A
065   22  INV
066   58  FIX
067   01   1
068   42  STO
069   01   01
070   16  A'
071   43  RCL
072   38   38
073   19  D'
074   16  A'
075   43  RCL
076   49   49
077   10  E'
078   43  RCL
079   44   44
080   10  E'
081   43  RCL
082   43   43
083   10  E'
```

ENTER D & CALC RD

```
084   76  LBL
085   12   B
086   03   3
087   00   0
088   00   0
089   00   0
090   32  X:T
091   22  INV
092   58  FIX
093   93   .
094   00   0
095   01   1
096   09   9
097   42  STO
098   07   07
099   98  ADV
100   04   4
101   42  STO
102   01   01
103   43  RCL
104   45   45
105   10  E'
106   06   6
107   93   .
108   03   3
109   01   1
110   65   ×
111   43  RCL
112   02   02
113   55   ÷
114   43  RCL
115   05   05
116   55   ÷
117   43  RCL
118   04   04
119   95   =
120   42  STO
121   06   06
122   77   GE
123   22  INV
```

CHECK FOR LAMINAR AND CRITICAL RD

```
124   32  X:T
125   02   2
126   00   0
127   00   0
128   00   0
129   77   GE
130   43  RCL
```

PRINT CRITICAL R_D

```
131   43  RCL
132   39   39
133   22  INV
134   59  INT
135   19  D'
136   43  RCL
137   06   06
138   99  PRT
139   12   B
140   76  LBL
```

CALC f TURBULENT R_D

```
141   22  INV
142   43  RCL
143   37   37
144   19  D'
145   76  LBL
146   13   C
147   43  RCL
148   07   07
149   66  PAU
150   34  √X
151   35  1/X
152   65   ×
153   02   2
154   93   .
155   05   5
156   01   1
157   55   ÷
158   43  RCL
159   06   06
160   85   +
161   93   .
162   00   0
163   00   0
164   01   1
165   08   8
166   55   ÷
167   03   3
168   93   .
169   07   7
170   55   ÷
171   43  RCL
172   05   05
173   95   =
174   42  STO
175   09   09
176   65   ×
177   93   .
178   08   8
179   06   6
180   08   8
181   06   6
182   94  +/-
183   85   +
184   93   .
185   05   5
186   65   ×
187   43  RCL
188   07   07
189   45  Y^X
190   01   1
191   93   .
192   05   5
193   94  +/-
194   95   =
195   42  STO
196   08   08
197   93   .
```

```
198  00  0
199  00  0
200  00  0
201  00  0
202  00  0
203  01  1
204  32  X:T
205  43  RCL
206  09  09
207  28  LOG
208  65  ×
209  02  2
210  94  +/-
211  75  -
212  43  RCL
213  07  07
214  34  √X
215  35  1/X
216  95  =
217  55  ÷
218  43  RCL
219  08  08
220  95  =
221  22  INV
222  44  SUM
223  07  07
224  50  I×I
225  77  GE
226  13  C
```

CALC ΔP

```
227  76  LBL
228  23  LNX
229  58  FIX
230  02  02
231  43  RCL
232  07  07
233  65  ×
234  93  .
235  00  0
236  00  0
237  00  0
238  03  3
239  03  3
240  06  6
241  65  ×
242  43  RCL
243  02  02
244  33  X²
245  55  ÷
246  43  RCL
247  03  03
248  55  ÷
249  43  RCL
250  05  05
251  45  Y^X
252  05  5
253  95  =
254  99  PRT
```

CALC VELOCITY

```
255  43  RCL
256  33  33
257  19  D'
258  43  RCL
259  02  02
260  55  ÷
261  43  RCL
262  03  03
263  55  ÷
264  09  9
265  00  0
266  00  0
267  55  ÷
268  89  π
269  55  ÷
270  53  (
271  43  RCL
272  05  05
273  55  ÷
274  01  1
275  02  2
276  54  )
277  33  X²
278  95  =
279  99  PRT
280  91  R/S
281  32  X:T
282  16  A'
283  98  ADV
284  98  ADV
285  98  ADV
286  32  X:T
287  91  R/S
```

CALC f LAMINAR R_D

```
288  76  LBL
289  43  RCL
290  43  RCL
291  37  37
292  19  D'
293  06  6
294  04  4
295  55  ÷
296  43  RCL
297  06  06
298  95  =
299  42  STO
300  07  07
301  61  GTO
302  23  LNX
```

Program 5: HP 41CV Data Sheet

```
*************

  *LINE  dP*

*************

ENTER FLOW PPH
      5,000.000     ***
ENTER DENSITY PPCF
         55.000     ***
ENTER VISCOSITY cP
          5.000     ***
ENTER LINE DIA INS
          3.068     ***
CRITICAL RD
      2,056.714     ***

ENTER LINE DIA INS
          2.067     ***
CALC    dP/100
FT
          0.178     ***
CALC   VELOCI
 TY FPS
          1.084     ***

ENTER LINE DIA INS
          4.026     ***
CALC    dP/100
FT
          0.006     ***
CALC    VELOCI
TY FPS
          0.286     ***

*************
```

Program 5: HP 41CV Register Loading

SIZE 080

```
R00=  0.000000
R01=  0.000000
R02=  0.000000
R03=  0.000000
R04=  0.000000
R05=  0.000000
R06=  0.000000
R07=  0.000000
R08=  0.000000
R09=  0.000000
R10=  0.000000
R11=  0.000000
R12=  0.000000
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  2.000000
R17=  0.000000
R18=  0.000000
R19=  0.000000
R20=  0.000000
R21=  0.000000
R22=  0.000000
R23=  0.000000
R24=  0.000000
R25=  0.000000
R26= " *LINE"
R27= "  dP* "
R28=  0.000000
R29=  26.270000
R30=  57.394000
R31=  57.414200
R32=  57.434400
R33=  0.000000
R34=  57.454600
R35=  0.000000
R36=  51.520000
R37=  56.474800
R38=  56.495000
R39= "FLOW P"
R40= "PH    "
R41= "DENSIT"
R42= "Y PPCF"
R43= "VISCOS"
R44= "ITY cP"
R45= "LINE D"
R46= "IA INS"
R47= "dP/100"
R48= "FT    "
R49= "VELOCI"
R50= "TY FPS"
R51= "CRITIC"
R52= "AL RD"
R53=  0.000000
R54=  0.000000
R55= "******"
R56= "CALC  "
R57= "ENTER "
R58=  0.000000
R59=  0.000000
R60=  0.000000
R61=  0.000000
R62=  0.000000
R63=  0.600000
R64=  0.000000
R65=  0.000000
R66=  0.000000
R67=  0.000000
R68=  0.000000
R69=  0.000000
R70=  0.000000
R71=  0.000000
R72=  0.000000
R73=  0.000000
R74=  0.000000
R75=  0.000000
R76=  0.000000
R77=  0.000000
R78=  0.000000
R79=  0.000000
```

Program 5: HP 41CV Listing

SUBROUTINES

```
01♦LBL "LINE dP"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 RTN
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53♦LBL 01
54 XEQ J
55 GTO e
```

RE-ENTER VARIABLES

```
56♦LBL "REENTER"
57 ADV
58 1
59 +
60 STO 01
61 RCL IND 01
62 XEQ J
```

```
63 STOP
64 XEQ J
65 STO IND 01
66 ADV
67 SF 00
68 SF 02
69 STOP
70 GTO B
```

BYPASS PRINTER

```
71♦LBL J
72 FC? 55
73 GTO 01
74 PRX
75 RTN
76♦LBL 01
77 VIEW X
78 RTN
```

MAIN PROGRAM ENTER DATA

```
79♦LBL A
80 1
81 STO 01
82 28
83 STO 58
84 XEQ a
85 XEQ d
86 XEQ a
87 XEQ e
88 CF 02
```

ENTER PIPE SIZE

```
89♦LBL B
90 4
91 STO 01
92 33
93 STO 58
94 XEQ e
```

CALC R_D

```
95 .019
96 STO 07
97 6.31
98 RCL 02
99 *
100 RCL 05
101 /
102 RCL 04
103 /
104 STO 06
```

DETERMINE FLOW ZONE

```
105 3000
106 X<=Y?
107 GTO G
108 RCL 06
109 2000
110 X>Y?
111 GTO 02
112 XEQ d
113 RCL 06
114 XEQ J
115 GTO "NEW SZE"
```

CALC f LAMINAR FLOW

```
116♦LBL 02
117 64
118 RCL 06
119 /
120 STO 07
121 GTO 03
```

CALC f TURBULENT FLOW

```
122♦LBL G
123 RCL 07
124 PSE
125 SQRT
126 1/X
127 2.51
128 *
129 RCL 06
130 /
131 .0018
132 RCL 05
133 /
134 3.7
135 /
136 +
137 STO 09
138 -.8686
139 *
140 RCL 07
141 -1.5
142 Y↑X
143 .5
144 *
145 +
146 STO 08
147 RCL 09
148 LOG
149 -2
150 *
151 RCL 07
152 SQRT
153 1/X
154 -
155 RCL 08
156 /
157 ST- 07
158 ABS
159 .000001
160 X<>Y
161 X>Y?
162 GTO G
```

CALC dP/100 ft

```
163♦LBL 03
164 36
165 STO 58
166 XEQ d
167 RCL 07
168 .000336
169 *
170 RCL 02
171 X↑2
172 *
173 RCL 03
174 /
175 RCL 05
176 5
177 Y↑X
178 /
179 STO 10
180 XEQ J
```

CALC VELOCITY

```
181 XEQ d
182 RCL 02
183 RCL 03
184 /
185 900
186 /
187 PI
188 /
189 RCL 05
190 12
191 /
192 X↑2
193 /
194 XEQ J
195 FC? 00
196 STOP
197 FS? 02
198 STOP
199 CF 00
200 XEQ a
201 RCL 10
202 VIEW X
203 BEEP
204 ADV
205 STOP
```

TRY DIFFERENT SIZE PIPE

```
206♦LBL "NEW SZE"
207 CF 00
208 CF 02
209 ADV
210 GTO B
211 .END.
```

Program 5: Sequence of Calculations

1. Calculate Reynolds number.

$$R_D = \frac{6.31W}{D\mu}$$

Reynolds numbers up to 2000 indicate laminar flow; those greater than 3000 indicate turbulent flow. The critical zone 2000–3000 is not calculated. The program will request a different pipe diameter to avoid the zone.

2. Laminar-flow friction factor.[1]

$$f = \frac{64}{R_D}$$

3. Turbulent-flow friction factor (the Colebrook equation).

$$\frac{1}{\sqrt{f}} = -2 \log \left(\frac{.0018}{3.7D} + \frac{2.51}{R_D \sqrt{f}} \right)$$

Solve by iteration:

$$\text{let} \quad Fx = -2 \log \left(\frac{.0018}{3.7D} + \frac{2.51}{R_D \sqrt{f}} \right) - \frac{1}{\sqrt{f}}$$

and

$$F^1x = .8686 \left(\frac{.0018}{3.7D} + \frac{2.51}{R_D \sqrt{f}} \right) - \frac{f^{-3/2}}{2}$$

Start with $f = .019$ and calculate Fx/F^1x. If greater than .000001, subtract Fx/F^1x from the current value of f and repeat until the error is smaller than .000001.

4. Calculate line pressure drop per 100 feet.[2]

$$\Delta P = \frac{.000336 f W^2}{D^5 \gamma_f} \quad \text{PSI per 100 feet}$$

5. Calculate line velocity.

$$v = \frac{W}{900\gamma_f \pi D^2} \quad \text{feet per second}$$

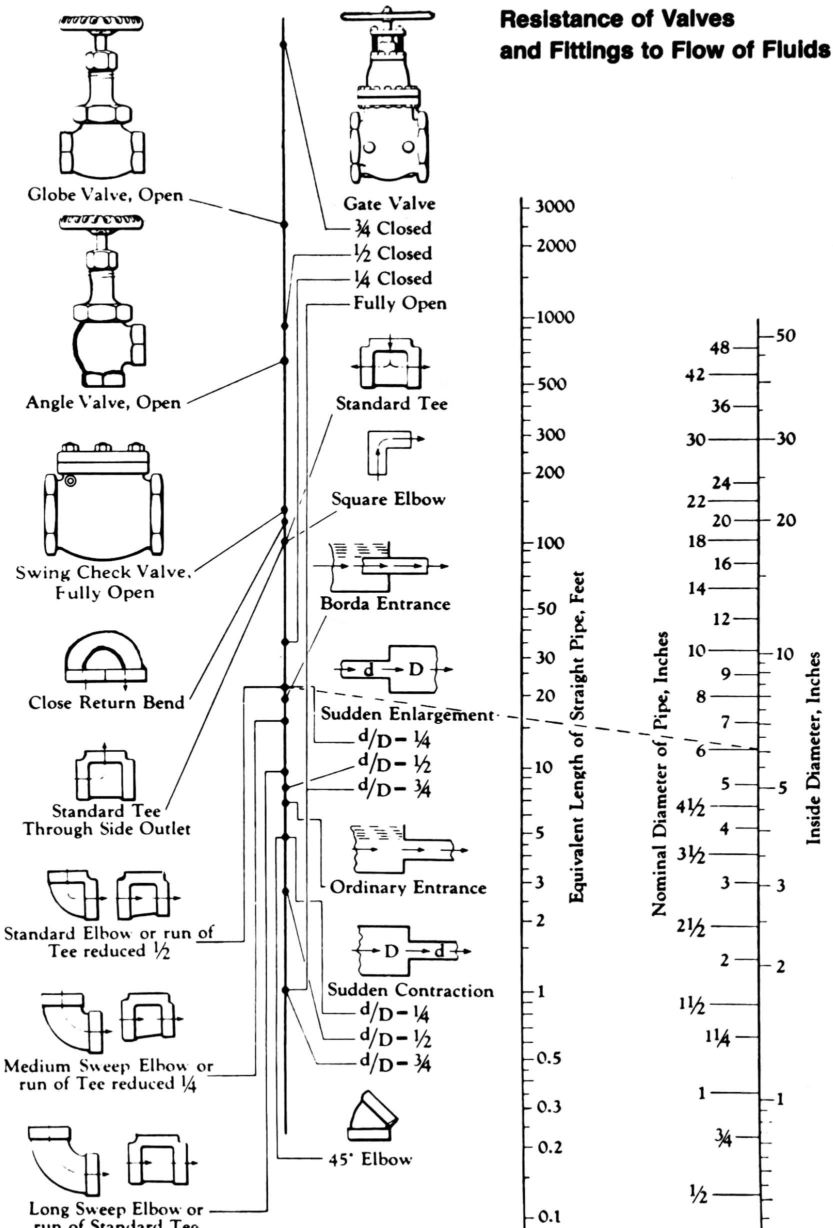
Program 5: Nomenclature

D Internal diameter of pipe, inches
f Friction factor, dimensionless
ΔP Pressure drop factor, PSI per 100 feet of pipe
R_D Reynolds number, dimensionless
W Rate of flow, pounds per hour
v Velocity through pipe, feet per second
γ_f Density or specific weight, pounds per cubic foot
μ Absolute viscosity, centipoises

Literature Cited

1. Crane Company Technical Paper No. 410C.
2. Crane Company Technical Paper No. 410C.

Typical Data



(Courtesy the Crane Company)

CHAPTER FOUR

Flow Elements

The most popular method of measuring flow is by inserting a restriction in the line and measuring the pressure differential across it. This method is simple, reliable, acceptably accurate for most process flow applications, inexpensive, and well understood.

The permanent pressure loss caused by the restriction varies with the device selected. The square-edge orifice plate causes a permanent pressure loss between 50% and 90% of the differential—typically 60% of 50 inches of water at operating flow, approximately equal to 1.1 PSI. The venturi tube causes a typical loss of only 0.2 PSI; the flow tube is somewhere between these two.

The power savings realized when using the low-loss devices on large flows will very often pay for their greater initial cost in a short period of time. For this reason venturies will often be found on large water lines, and flow nozzles will be found on boiler feedwater and steam lines and on centrifugal compressor discharge lines. A modification of the pitot tube is available which also has a very low permanent pressure loss and a significantly lower price than the venturi. This is sized in Programs 17 and 18.

There are several pressure-tap locations available for use with orifice plates. By far the most popular are the orifice flange taps.

Orifice flanges are special wide flanges (300 pound minimum rating) having two equally spaced taps around the circumference at a distance of 15/16 inch from the flange face. On horizontal lines they can be installed with the taps at the 45° points, thereby providing the choice of liquid or gas taps for each location. An option is to install them in either the vertical or horizontal plane. However, the bottom tap tends to be a sediment trap and should not be used.

Pipe taps 2.5 pipe diameters upstream from the orifice and 8 pipe diameters downstream are sometimes used on large-diameter alloy pipe where the cost of orifice flanges may be high. Pipe taps do not have the flexibility of flange taps, and being field constructed they are more prone to manufacturing error.

Corner taps are sometimes used on pipe sizes smaller than two inches in order to get a measurement of the differential pressure closer to the orifice plate.

All devices measuring flow by differential pressure require a reasonable length of straight pipe upstream and downstream from the device (typical flow elements are shown in Figure 4-1). The amount of straight pipe is dependent on upstream piping geometry and the beta ratio. Curves showing various configurations are available from ASME and AGA. A typical requirement is 20 pipe diameters upstream and 5 downstream. However, a valve in the upstream line increases the upstream requirement considerably.

The calculations for sizing these devices assume that the pipe is reasonably round, straight, and smooth, and that the taps are cylindrical and burr free.

The best way to ensure that these requirements are met is to purchase prefabricated meter runs. These are made from selected pipe under more favorable conditions than field construction. Prefabricated calibrated meter runs are also available. Their cost is rarely, if ever, justified.

There are several things to consider when sizing these devices. The first is that the flow is directly proportional to the square root of the differential pressure. This gives limited turn-down capability. Flows less than 30% of the maximum chart range are difficult to read. If the rangeability must be larger than 3:1, two transmitters can be used if the cost can be justified.

Size the orifice plate so that normal flow is 70%–80% of the maximum range. This is slightly over the mid-range of the differential pressure and allows for reasonable deviations of flow both above and below normal.

It has been the practice to round out the maximum range so that an even chart multiplier is obtained. With a computer performing plant material balances, it is becoming more prevalent not to do this because the computer uses more accurate, or different, process data than those for which the orifice plate was calculated. Thus, the chart multiplier inevitably becomes an awkward number. A better choice under these circumstances is to round out the orifice bore size to the nearest eighth of an inch, thus making it possible to keep an inventory of standard sizes.

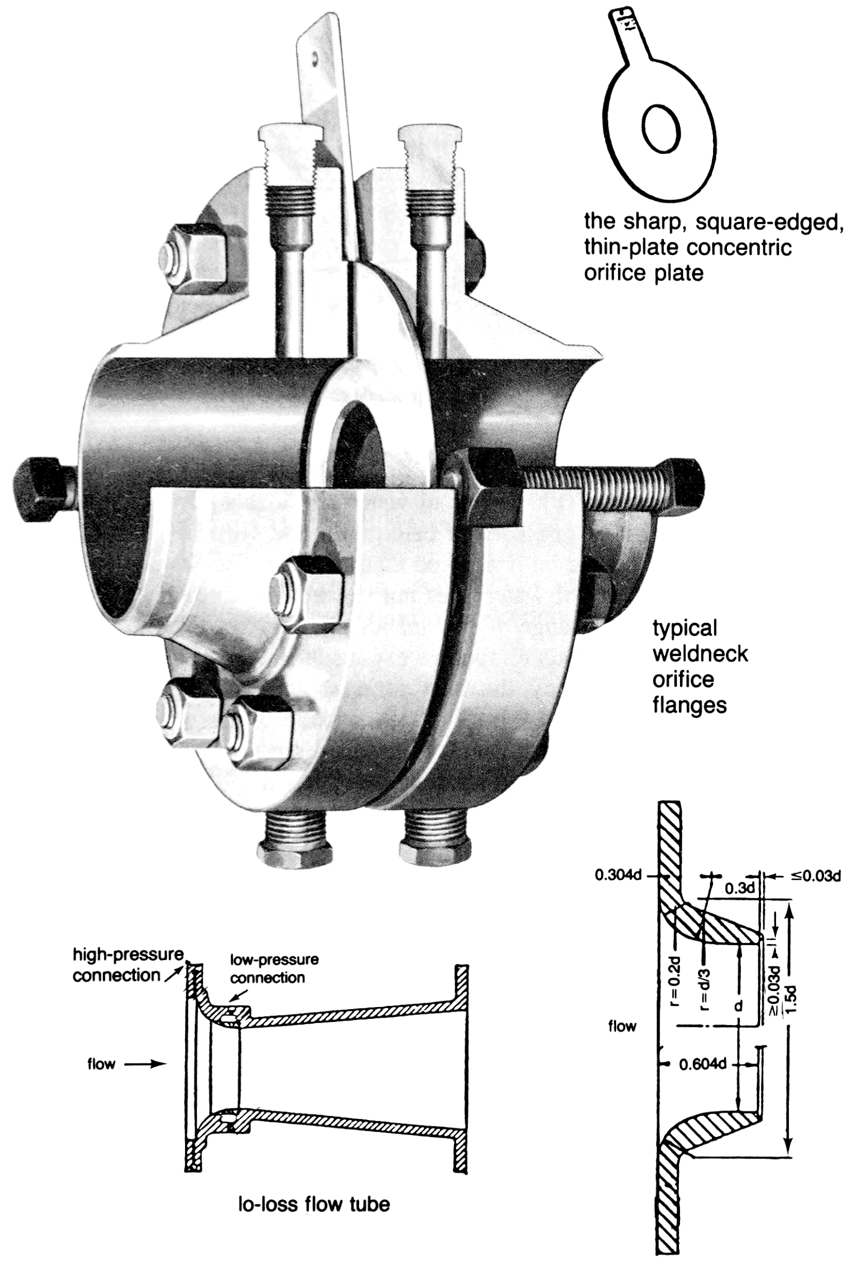
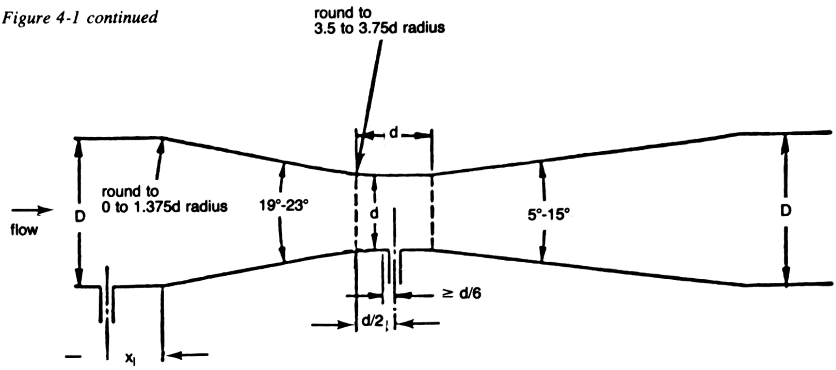


Figure 4-1. Typical flow elements.

(figure continued on next page)

Figure 4-1 continued



critical dimensions of the classical venturi tube

A differential range of 100 inches of water provides a good compromise of instrument sensitivity and ease of calibration and will fit most flow situations. Gas flows should be limited so that the numerical value of the differential range in inches of water does not exceed the upstream pressure in PSIA (i.e. a differential range of 100 inches of water requires an upstream pressure of 100 PSIA). This eliminates expansion factor problems.

For best overall accuracy the beta ratio should be within the limits 0.25–0.7, preferably around 0.6. If it falls outside of these limits, change the differential range and recalculate. Where it is not possible to change the differential range, the meter run size can be changed.

Accuracy of the Calculation

The accuracy is limited by the process data. The formulas used have been proven over the years, and all applicable correction factors are included in the program.

Most of these data are based on *The Principles and Practice of Flowmeter Engineering* by L. K. Spink. It is recommended that a copy be obtained for reference purposes.

Program 6
Liquid Flow—Orifice Plate, Flange Taps

Program 6: User Instructions

a) Initiate program, press A.

b) Enter:

1. Flowrate, pounds per hour	Press R/S
2. Flow temperature, °F	Press R/S
3. Specific gravity at flow temperature, dimensionless	Press R/S
4. Differential range, inches of water	Press R/S
5. Pipe inside diameter, inches	Press R/S
6. Absolute viscosity, centipoises	Press R/S

c) Program calculates beta ratio (dimensionless) and orifice bore (inches).

d) If an even-sized orifice bore is required, press C and enter:

7. Required orifice bore, inches	Press R/S

e) Program will calculate beta ratio (dimensionless) and new flowrate (pounds per hour).

Notes:

1. The E subroutine is available to re-enter data and recalculate.
2. Viscosity correction is automatic.
3. If the orifice plate material is not 316SS or 304SS, see Table of Equal Thermal Expansion Temperatures for Various Orifice Plate Materials, page 162.

Program 6: TI 59 Data Sheet

```
********************

 LIQD ORIFICE  CALC
    FLANGE TAPS

********************

ENTR  FLOW  PPH
     100000.
ENTR  TEMP   °F
        150.
ENTR     SG
        0.98
ENTR DIFF RANGE IN W
        100.
ENTR PIPE     ID  INS
       4.026

ENTR VISC     CP
             0.8
CALC BETA RATIO
 .5810050277
CALC  ORIFICE     INS
 2.339126241

********************

ENTR  ORIFICE     INS
           2.375
CALC BETA RATIO
 .5899155489
CALC  FLOW  PPH
 103700.4948

********************
```

Program 6: TI 59 Register Loading

PARTITIONING
479.59

0.	00	3513372432.	29
0.	01	28.545356	30
0.	02	41.5251	31
0.	03	2416.4237	32
0.	04	243136.3436	33
0.	05	37173033.35	34
0.	06	3622.504948	35
0.	07	7321.473233	36
0.	08	333323.4645	37
0.	09	1417371300.	38
0.	10	56.3829	39
0.	11	56.545333	40
0.	12	21.545333	41
0.	13	21273243.	42
0.	14	56.3829	43
0.	15	56.4237	44
0.	16	1533.	45
0.	17	4224361500.	46
0.	18	3324331700.	47
1200.	19	24310043.	48
3.3282	20	3513312217.	49
5.425	21	1624212100.	50
1.196	22	37133336.	51
0.00001	23	2713312217.	52
0.51804	24	2415170000.	53
6.425	25	32352421.	54
0.0567	26	5151515151.	55
2831.	27	1513271500.	56
27243416.	28	1731373500.	57
		0.	58
		0.	59

Program 6: TI 59 Listing

SUBROUTINES
PRINT & STORE VARIABLES

000	76	LBL
001	10	E'
002	29	CP
003	01	1
004	44	SUM
005	58	58
006	73	RC*
007	58	58
008	22	INV
009	59	INT
010	52	EE
011	22	INV
012	52	EE
013	67	EQ
014	19	D'
015	85	+
016	05	5
017	07	7
018	95	=
019	17	B'
020	69	OP
021	21	21
022	73	RC*
023	01	01
024	87	IFF
025	00	00
026	00	00
027	35	35
028	91	R/S
029	72	ST*
030	01	01
031	93	.
032	05	5
033	42	STO
034	12	12
035	73	RC*
036	01	01
037	99	PRT
038	61	GTO
039	10	E'

PRINT LINES

040	76	LBL
041	19	D'
042	01	1
043	44	SUM
044	58	58
045	73	RC*
046	58	58

```
047   76  LBL
048   17  B'
049   42  STO
050   59   59
051   73  RC*
052   59   59
053   69  OP
054   01   01
055   18  C'
056   69  OP
057   02   02
058   18  C'
059   69  OP
060   03   03
061   18  C'
062   69  OP
063   04   04
064   69  OP
065   05   05
066   92  RTN
```

DECODE LINES

```
067   76  LBL
068   18  C'
069   01   1
070   00   0
071   00   0
072   48  EXC
073   59   59
074   22  INV
075   59  INT
076   49  PRD
077   59   59
078   73  RC*
079   59   59
080   92  RTN
```

PRINT LINE OF STARS

```
081   76  LBL
082   16  A'
083   93   .
084   00   0
085   01   1
086   08   8
087   35  1/X
088   98  ADV
089   17  B'
090   98  ADV
091   92  RTN
```

RE-ENTER VARIABLES

```
092   76  LBL
093   15   E
094   99  PRT
095   85   +
096   01   1
097   95   =
098   42  STO
099   01   01
100   73  RC*
101   01   01
102   91  R/S
103   72  ST*
104   01   01
105   99  PRT
106   98  ADV
107   86  STF
108   00   00
109   91  R/S
110   12   B
```

CALC S

```
111   76  LBL
112   44  SUM
113   53   (
114   43  RCL
115   12   12
116   66  PAU
117   33  X²
118   65   ×
119   93   .
120   05   5
121   09   9
122   08   8
123   85   +
124   43  RCL
125   12   12
126   45  YX
127   03   3
128   65   ×
129   93   .
130   00   0
131   01   1
132   85   +
133   43  RCL
134   12   12
135   45  YX
136   43  RCL
137   25   25
138   65   ×
139   43  RCL
140   24   24
141   54   )
142   92  RTN
143   76  LBL
144   23  LNX
145   92  RTN
```

ITERATE β (ENDS AT 351)

```
146   76  LBL
147   14   D
148   43  RCL
149   23   23
150   32  X:T
151   53   (
152   71  SBR
153   44  SUM
154   75   -
155   43  RCL
156   11   11
157   55   ÷
158   43  RCL
159   10   10
160   54   )
161   55   ÷
162   53   (
163   43  RCL
164   12   12
165   65   ×
166   43  RCL
167   22   22
168   85   +
169   43  RCL
170   12   12
171   33  X²
172   65   ×
173   93   .
174   00   0
175   03   3
176   85   +
177   43  RCL
178   12   12
179   45  YX
180   43  RCL
181   21   21
182   65   ×
183   43  RCL
184   20   20
185   54   )
186   95   =
187   22  INV
188   44  SUM
189   12   12
190   50  I×I
191   77   GE
192   14   D
```

CALC F_c WHEN $R_D > 700\beta^{1.3}$

```
193   43  RCL
194   09   09
195   32  X:T
```

```
196  07   7
197  00   0
198  00   0
199  65   ×
200  43  RCL
201  12   12
202  45  Y×
203  01   1
204  93   .
205  03   3
206  95   =
207  42  STO
208  18   18
209  42  STO
210  15   15
211  55   ÷
212  02   2
213  95   =
214  42  STO
215  14   14
216  55   ÷
217  43  RCL
218  09   09
219  95   =
220  35  1/X
221  34  ΓX
222  65   ×
223  09   9
224  00   0
225  95   =
226  38  SIN
227  55   ÷
228  43  RCL
229  12   12
230  45  Y×
231  93   .
232  01   1
233  05   5
234  95   =
235  42  STO
236  17   17
237  43  RCL
238  14   14
239  77   GE
240  80  GRD
241  43  RCL
242  17   17
243  50  I×I
244  34  ΓX
245  42  STO
246  17   17
```

CALC F_c WHEN $R_D \leqslant 700\beta^{1.3}$

```
247  43  RCL
248  18   18
249  77   GE
250  80  GRD
251  01   1
252  42  STO
253  17   17
254  43  RCL
255  09   09
256  42  STO
257  18   18
258  42  STO
259  15   15
260  43  RCL
261  19   19
262  77   GE
263  80  GRD
264  42  STO
265  18   18
```

CALC F_c WHEN $R_D > 1200$

```
266  76  LBL
267  80  GRD
268  29  CP
269  43  RCL
270  12   12
271  75   -
272  93   .
273  02   2
274  95   =
275  77   GE
276  42  STO
277  33  X²
278  85   +
279  76  LBL
280  42  STO
281  53   (
282  43  RCL
283  12   12
284  65   ×
285  03   3
286  93   .
287  09   9
288  54   )
289  22  INV
290  23  LNX
291  65   ×
292  08   8
293  93   .
294  07   7
295  65   ×
296  43  RCL
297  15   15
298  45  Y×
299  93   .
300  08   8
301  09   9
302  94  +/-
303  54   )
304  95   =
305  75   -
306  53   (
307  24  CE
308  65   ×
309  53   (
310  43  RCL
311  14   14
312  55   ÷
313  43  RCL
314  18   18
315  54   )
316  45  Y×
317  53   (
318  43  RCL
319  12   12
320  34  ΓX
321  34  ΓX
322  75   -
323  93   .
324  01   1
325  02   2
326  54   )
327  65   ×
328  53   (
329  01   1
330  75   -
331  43  RCL
332  18   18
333  55   ÷
334  43  RCL
335  19   19
336  54   )
337  34  ΓX
338  54   )
339  95   =
340  65   ×
341  43  RCL
342  17   17
343  85   +
344  93   .
345  09   9
346  09   9
347  07   7
348  95   =
349  42  STO
350  10   10
351  92  RTN
```

MAIN PROGRAM ENTER DATA

```
352  76  LBL
353  11   A
```

```
354  22  INV
355  86  STF
356  01   01
357  01   1
358  42  STO
359  01   01
360  42  STO
361  10   10
362  02   2
363  09   9
364  42  STO
365  58   58
366  16  A'
367  19  D'
368  19  D'
369  16  A'
370  10  E'
371  22  INV
372  86  STF
373  00   00
```

CALC S

```
374  76  LBL
375  12   B
376  03   3
377  09   9
378  42  STO
379  58   58
380  43  RCL
381  02   02
382  55   ÷
380  43  RCL
381  02   02
382  55   ÷
383  43  RCL
384  06   06
385  33  X²
386  55   ÷
390  85   +
391  43  RCL
392  26   26
393  65   ×
394  43  RCL
395  03   03
396  54   )
397  55   ÷
398  53   (
399  43  RCL
400  04   04
401  65   ×
402  43  RCL
403  05   05
404  54   )
405  34  ΓX
406  95   =
407  42  STO
408  11   11
```

CALC R_D

```
409  04   4
410  93   .
411  04   4
412  02   2
413  65   ×
414  43  RCL
415  02   02
416  55   ÷
417  43  RCL
418  06   06
419  55   ÷
420  43  RCL
421  07   07
422  95   =
423  42  STO
424  09   09
```

CALC β

```
425  14   D
426  14   D
427  14   D
428  43  RCL
429  12   12
430  99  PRT
```

CALC d

```
431  19  D'
432  43  RCL
433  06   06
434  65   ×
435  43  RCL
436  12   12
437  76  LBL
438  38  SIN
439  95   =
440  99  PRT
441  32  X:T
442  16  A'
443  98  ADV
444  32  X:T
445  91  R/S
```

ENTER REQD BORE

```
446  76  LBL
447  13   C
448  07   7
449  42  STO
450  01   01
451  04   4
452  00   0
453  42  STO
454  58   58
```

CALC β

```
455  10  E'
456  43  RCL
457  08   08
458  55   ÷
459  43  RCL
460  06   06
461  95   =
462  42  STO
463  12   12
464  99  PRT
465  71  SBR
466  44  SUM
467  42  STO
468  16   16
```

CALC FLOW

```
469  19  D'
470  43  RCL
471  02   02
472  55   ÷
473  43  RCL
474  11   11
475  65   ×
476  43  RCL
477  16   16
478  61  GTO
479  38  SIN
```

(Program 6: HP 41CV Data Sheet on next page)

Program 6: HP 41CV Data Sheet

```
*************
ORIFICE LIQD
FLANGE  TAPS

*************

ENTER FLOW  PPH
   100,000.0000   ***
ENTER TEMP DEG F
       150.0000   ***
ENTER SG
         0.9800   ***

ENTER DIFF RANGE INS H2O
         100.0000   ***
ENTER PIPE ID INS
           4.0260   ***
ENTER VISCOSITY cP
           0.8000   ***
CALC   BETA
RATIO
           0.5810   ***
CALC ORIFICE
 BORE  INS
           2.3391   ***
*************

                 2.3391

ENTER REQD  ORIFICE INS
           2.3750   ***
CALC   BETA
RATIO
           0.5899   ***
CALC   FLOW
PPH
     103,700.4948   ***

*************
```

Program 6: HP 41CV Register Loading

SIZE 080

```
R00=  0.000000
R01=  0.000000
R02=  0.000000
R03=  0.000000
R04=  0.000000
R05=  0.000000
R06=  0.000000
R07=  0.000000
R08=  0.000000
R09=  0.000000
R10=  0.000000
R11=  0.000000
R12=  0.000000
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  0.000000
R17=  0.000000
R18=  0.000000
R19=  1,200.000000
R20=  3.328200
R21=  5.425000
R22=  1.196000
R23=  0.000010
R24=  0.518040
R25=  6.425000
R26=  0.056700
R27=  2,831.000000
R28=  0.000000
R29=  0.000000
R30=  72.450000
R31=  46.470000
R32=  57.484900
R33=  57.505100
R34=  57.520000
R35=  57.535460
R36=  57.616200
R37=  57.636400
R38=  0.000000
R39=  56.656600
R40=  71.676869
R41=  57.707273
R42=  0.000000
R43=  56.656600
R44=  56.484900
R45=  "E LIQD"
R46=  "FLANGE"
R47=  "  TAPS"
R48=  "FLOW  "
R49=  "PPH   "
R50=  "TEMP D"
R51=  "EG F  "
R52=  "SG    "
R53=  "DIFF R"
R54=  "ANGE I"
R55=  "******"
R56=  "CALC  "
R57=  "ENTER "
R58=  44.000000
R59=  0.000000
R60=  "NS H2O"
R61=  "PIPE I"
R62=  "D INS "
R63=  "VISCOS"
R64=  "ITY cP"
R65=  "BETA  "
R66=  "RATIO "
R67=  "RIFICE"
R68=  " BORE "
R69=  "INS   "
R70=  "REQD  "
R71=  "CALC O"
R72=  "ORIFIC"
R73=  "E INS "
R74=  0.000000
R75=  0.000000
R76=  0.000000
R77=  0.000000
R78=  0.000000
R79=  0.000000
```

Program 6: HP 41CV Listing

SUBROUTINES

```
01♦LBL "FT LIQ"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
```

```
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 GTO d
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53 .5
54 STO 12
55 RCL IND 01
56♦LBL 01
57 XEQ J
58 GTO e
```

RE-ENTER VARIABLES

```
59♦LBL "REENTER"
60 ADV
61 1
62 +
63 STO 01
64 RCL IND 01
65 XEQ J
66 STOP
67 XEQ J
68 STO IND 01
69 ADV
70 SF 00
71 SF 02
72 STOP
73 GTO 02
```

BYPASS PRINTER

```
74♦LBL J
75 FC? 55
76 GTO 01
77 PRX
78 RTN
79♦LBL 01
80 VIEW X
81 RTN
```

CALC S

```
82♦LBL G
83 RCL 12
84 PSE
85 X↑2
86 .598
87 *
88 RCL 12
89 3
90 Y↑X
91 .01
92 *
93 +
94 RCL 12
95 RCL 25
96 Y↑X
97 RCL 24
98 *
99 +
100 RTN
```

ITERATE β (ENDS AT 218)

```
101♦LBL D
102 RCL 12
103 RCL 22
104 *
105 RCL 12
106 X↑2
107 .03
108 *
109 +
110 RCL 12
111 RCL 21
112 Y↑X
113 RCL 20
114 *
115 +
116 1/X
117 XEQ G
118 RCL 11
119 RCL 10
120 /
121 -
122 *
123 ST- 12
124 ABS
125 RCL 23
126 X<>Y
127 X>Y?
128 GTO D
```

CALC F_c WHEN $R_D \leq 700\beta^{1.3}$

```
129 RCL 12
130 1.3
131 Y↑X
132 700
133 *
134 STO 18
135 STO 15
136 2
137 /
138 STO 14
139 RCL 09
140 /
141 1/X
142 SQRT
143 90
144 *
145 SIN
146 RCL 12
147 .15
148 Y↑X
149 /
150 STO 17
151 RCL 09
152 RCL 14
153 X>Y?
154 GTO I
155 RCL 17
156 ABS
157 SQRT
158 STO 17
```

CALC F_c WHEN $R_D > 700\beta^{1.3}$

```
159 RCL 09
160 RCL 18
161 X>Y?
162 GTO I
163 1
164 STO 17
165 RCL 09
166 STO 18
167 STO 15
```

```
168 RCL 09
169 RCL 19
170 X>Y?
171 GTO I
172 STO 18
```

CALC F_C WHEN $R_D = 1200$

```
173♦LBL I
174 0
175 RCL 12
176 .2
177 -
178 X>Y?
179 0
180 X↑2
181 RCL 12
182 3.9
183 *
184 E↑X
185 8.7
186 *
187 RCL 15
188 -.89
189 Y↑X
190 *
191 +
192 STO 28
193 RCL 14
194 RCL 18
195 /
196 RCL 12
197 SQRT
198 SQRT
199 .12
200 -
201 Y↑X
202 *
203 1
204 RCL 18
205 RCL 19
206 /
207 -
208 SQRT
209 *
210 CHS
211 RCL 28
212 +
213 RCL 17
214 *
215 .997
216 +
217 STO 10
218 RTN
```

MAIN PROGRAM ENTER DATA

```
219♦LBL A
220 CF 02
221 1
222 STO 01
223 STO 10
224 29
225 STO 58
226 XEQ a
227 XEQ d
228 XEQ d
229 XEQ a
230 XEQ e
231 CF 00
```

CALC S

```
232♦LBL 02
233 39
234 STO 58
235 RCL 02
236 RCL 06
237 X↑2
238 /
239 RCL 27
240 RCL 26
241 RCL 03
242 *
243 +
244 /
245 RCL 04
246 RCL 05
247 *
248 SQRT
249 /
250 STO 11
```

CALC R_D

```
251 4.42
252 RCL 02
253 *
254 RCL 06
255 /
256 RCL 07
257 /
258 STO 09
```

CALC β

```
259 XEQ D
260 XEQ D
261 XEQ D
262 RCL 12
263 XEQ J
```

CALC d

```
264 XEQ d
265 RCL 06
266 RCL 12
267 *
268 STO 29
269 GTO 01
```

ENTER REQD BORE

```
270♦LBL "EVEN SZ"
271 7
272 STO 01
273 40
274 STO 58
275 XEQ e
```

CALC β

```
276 RCL 08
277 RCL 06
278 /
279 STO 12
280 XEQ J
281 XEQ G
282 STO 16
```

CALC FLOW

```
283 XEQ d
284 RCL 02
285 RCL 11
286 /
287 RCL 16
288 *
289 STO 29
290♦LBL 01
291 XEQ J
292 FS? 00
293 STOP
294 XEQ a
295 RCL 29
296 VIEW X
297 BEEP
298 ADV
299 STOP
300 .END.
```

Program 6: Sequence of Calculations

1. Calculate the S value.

$$S = \frac{W_m}{D^2(2831 + .0567T_f)\sqrt{G_f h_m}}$$

2. Calculate Reynolds number.

$$R_D = \frac{4.42\, W_m}{D\mu}$$

3. Iterate to find uncorrected beta ratio.

$$S = 0.598\beta^2 + .01\beta^3 + .518\beta^{6.425}$$

$$fx = 0.598\beta^2 + .01\beta^3 + .518\beta^{6.425} - S$$

$$f^1x = 1.196\beta + .03\beta^2 + 3.3282\beta^{5.425}$$

Start with $\beta = 0.5$ and calculate fx/f^1x. If greater than 0.00001, subtract fx/f^1x from current value of β and repeat until the error is less than 0.00001.

4. Calculate Reynolds number correction factor.
If $R_D < 350\ \beta^{1.3}$:

$$F_c = \left[A - \left(A\,(.5^{(\beta^{.25} - .12)}\sqrt{1 - \frac{700\beta^{1.3}}{1200}}\right)\right]$$

$$\left[\frac{\text{SIN}\left(90\sqrt{\dfrac{R_D}{350\beta^{1.3}}}\right)}{\beta^{.15}}\right] + .997$$

where

$$A = (\beta - .2)^2 + (8.7e^{3.9\beta})(700\beta^{1.3})^{-.89}$$

when

$$\beta - .2 > 0$$

$(\beta - .2)^2 = 0$

If $350^{1.3} < R_D < 700\beta^{1.3}$:

$$F_c = \left[A - \left(A(.5^{(\beta^{.25}-.12)}) \sqrt{\frac{1 - 700\beta^{1.3}}{1200}}\right)\right]$$

$$\left[\sqrt{\frac{\text{SIN}\left(90\sqrt{\frac{R_D}{350\beta^{1.3}}}\right)}{\beta^{.15}}}\right] + .997$$

If $700\beta^{1.3} < R_D < 1200$:

$$F_c = \left[A - \left(A\,\frac{(350\beta^{1.3})}{R_D}^{(\beta^{.25}-.12)} \sqrt{1 - \frac{R_D}{1200}}\right)\right] + .997$$

When $R_D > 1200$:

$$F_c = (A + .997)$$

5. Divide original S by F_c for viscosity correction.
6. Repeat step 3 for new β for corrected S.
7. Repeat step 4 for final F_c for corrected β.
8. Repeat step 5 for final S.
9. Repeat step 3 for final β.
10. Calculate orifice bore.

$$d = \beta D \text{ inches}$$

11. Calculate flowrate for an even-sized orifice plate.

$$\beta = \frac{d}{D}$$

$$S = .598\beta^2 + .01\beta^3 + .518\beta^{6.425}$$

$$\text{new flow} = \frac{\text{new } S}{\text{original } S} \times \text{original flow, pounds per hour}$$

Program 6: Nomenclature

A	Partial calculation of F_c, dimensionless
D	Inside diameter of pipe, inches
d	Diameter of orifice bore, inches
F_c	Reynolds number correction factor, dimensionless
G_f	Specific gravity of liquid at flowing temperature, dimensionless
h_m	Maximum differential range, inches of water
R_D	Reynolds number, dimensionless
S	Beta ratio index, dimensionless
T_f	Flowing temperature, °F
W_m	Maximum rate of flow, pounds per hour
μ	Absolute viscosity, centipoises
β	Beta ratio d/D, dimensionless

References

L. K. Spink, *The Principles and Practice of Flowmeter Engineering*, The Foxboro Company.

Program 7
Liquid Flow—Orifice Plate, Pipe Taps

Program 7: User Instructions

Non-viscous liquid program, press A.

a) Enter:
   1. Flowrate, pounds per hour — Press R/S
   2. Flow temperature, °F — Press R/S
   3. Specific gravity at flow temperature, dimensionless — Press R/S
   4. Differential range, inches of water — Press R/S
   5. Pipe inside diameter, inches — Press R/S

b) Program calculates beta ratio (dimensionless) and orifice bore (inches).

c) If an even-sized orifice bore is required, Press C and enter:
   6. Required orifice bore, inches — Press R/S

d) Program calculates beta ratio (dimensionless) and new flowrate (pounds per hour).

Viscous liquid program, press B.

a) Enter:
   1. Flowrate, pounds per hour — Press R/S
   2. Temperature, °F — Press R/S
   3. Specific gravity at flow temperature, dimensionless — Press R/S
   4. Differential range, inches of water — Press R/S
   5. Pipe inside diameter, inches — Press R/S
   6. Absolute viscosity, centipoises — Press R/S

b) Program calculates Reynolds number, dimensionless.

c) Refer to appropriate R_D/F_c chart and enter:
   7. Reynolds number correction factor F_c, dimensionless — Press R/S

d) Program calculates beta ratio (dimensionless) and orifice bore (inches).

e) If an even-size orifice bore is required, press C and enter:
   8. Required orifice bore, inches — Press R/S

f) Program calculates beta ratio (dimensionless) and new flowrate (pounds per hour).

Notes:

1. The E subroutine is available to re-enter data and recalculate.
2. If plate material is not 316SS or 304SS, refer to Table of Equal Thermal Expansion Temperatures for Various Orifice Plate Materials, page 162.

Program 7: TI 59 Data Sheet

```
********************

FLOW  ORIFICE  CALC
    PIPE  TAPS
  NON VISC LIQUID

********************

ENTR FLOW    PPH
      100000.
ENTR TEMP      °F
        150.
ENTR     SG
        0.98
ENTR DIFF RANGE IN W
        100.
```

```
ENTR PIPE ID       INS
        4.026
CALC BETA RATIO
 .5349820569
CALC  ORIFICE      INS
 2.153837761

********************

ENTR  ORIFICE      INS
        2.125
CALC BETA RATIO
 .5278191754
CALC FLOW      PPH
 96541.62602

********************
```

```
********************

FLOW  ORIFICE  CALC
     PIPE   TAPS
 VISCOUS   LIQUID

********************

ENTR FLOW    PPH
     100000.
ENTR TEMP      °F
        150.
ENTR     SG
        0.98
ENTR DIFF RANGE IN W
        100.
ENTR PIPE ID      INS
       4.026
ENTR  VISC    CP
         10.
```

```
CALC REYNOLDS N°
 10988.57427
ENTR      FC
          1.038
CALC BETA RATIO
 .5273929056
CALC  ORIFICE     INS
 2.123283638

********************

ENTR  ORIFICE     INS
          2.125
CALC BETA RATIO
 .5278191754
CALC FLOW    PPH
 100210.2078

********************
```

Program 7: TI 59 Register Loading

PARTITIONING
479.59

0.	00
0.	01
0.	02
0.	03
0.	04
0.	05
0.	06
0.	07
0.	08
0.	09
0.	10
0.	11
0.	12
0.	13
0.	14
0.	15
0.	16
0.	17
0.	18
0.	19
0.	20
4.424	21
57.37	22
56.545	23
56.535242	24
56.3635	25
56.39382	26
41.323143	27
51.413143	28
54.535256	29
37177[illegible]300.	30
2724[illegible]441.	31
3241360000.	32
37133336.	33
3324331700.	34
3513372432.	35
1417371300.	36
2115.3433	37
2716360031.	38
3517453132.	39
1533.535247	40
42243615.37	41
243136.414	42
2416000000.	43
3324331700.	44
24310043.48	45
3513312217.	46
1624212100.	47
3622.444342	48
7321.474645	49
333323.3049	50
313231.545	51
2415170000.	52
32352421.	53
2127324300.	54
5151515151.	55
1513271500.	56
1731373500.	57
0.	58
0.	59

Program 7: TI 59 Listing

SUBROUTINES

ENTER & STORE VARIABLES

```
000  76 LBL
001  10 E'
002  22 INV
003  59 INT
004  85  +
005  05  5
006  07  7
007  95  =
008  19 D'
009  69 OP
010  21  21
011  73 RC*
012  01  01
013  87 IFF
014  01  01
015  00  00
016  20  20
017  91 R/S
018  72 ST*
019  01  01
020  99 PRT
021  92 RTN
```

PRINT LINES

```
022  76 LBL
023  19 D'
024  42 STO
025  59  59
026  73 RC*
027  59  59
028  69 OP
029  01  01
030  18 C'
031  69 OP
032  02  02
033  18 C'
034  69 OP
035  03  03
036  18 C'
037  69 OP
038  04  04
039  69 OP
040  05  05
041  92 RTN
```

DECODE LINES

```
042  76 LBL
043  18 C'
044  01  1
045  00  0
046  00  0
047  48 EXC
048  59  59
049  22 INV
050  59 INT
051  49 PRD
052  59  59
053  73 RC*
054  59  59
055  92 RTN
```

PRINT LINE OF STARS

```
056  76 LBL
057  16 A'
058  93  .
059  00  0
060  01  1
061  08  8
062  35 1/X
063  98 ADV
064  19 D'
065  98 ADV
066  92 RTN
```

RE-ENTER VARIABLES

```
067  76 LBL
068  15  E
069  99 PRT
070  85  +
071  01  1
072  95  =
073  42 STO
074  01  01
075  73 RC*
076  01  01
077  91 R/S
078  72 ST*
079  01  01
080  99 PRT
081  98 ADV
082  22 INV
083  86 STF
084  03  03
085  86 STF
086  01  01
087  61 GTO
088  24 CE
089  76 LBL
090  34 ΓX
091  87 IFF
092  01  01
093  33 X²
094  61 GTO
095  45 YX
096  76 LBL
097  97 DSZ
098  87 IFF
099  01  01
100  11  A
101  61 GTO
102  98 ADV
103  76 LBL
104  99 PRT
105  87 IFF
106  01  01
107  12  B
108  61 GTO
109  90 LST
```

MAIN PROGRAM

NONVISCOUS LIQUID ENTER DATA

```
110  76 LBL
111  11  A
112  87 IFF
113  02  02
114  99 PRT
115  76 LBL
116  90 LST
117  01  1
118  42 STO
119  08  08
120  22 INV
121  86 STF
122  03  03
123  22 INV
124  86 STF
125  02  02
126  86 STF
127  00  00
128  43 RCL
129  28  28
130  61 GTO
131  42 STO
```

VISCOUS LIQUID ENTER DATA

```
132  76 LBL
133  12  B
134  87 IFF
135  00  00
136  97 DSZ
137  76 LBL
138  98 ADV
139  22 INV
140  86 STF
141  00  00
```

```
142   86  STF
143   02   02
144   86  STF
145   03   03
146   43  RCL
147   27   27
148   76  LBL
149   42  STO
150   42  STO
151   58   58
152   93   .
153   05   5
154   42  STO
155   12   12
156   01   1
157   42  STO
158   01   01
159   16  A'
160   43  RCL
161   29   29
162   19  D'
163   43  RCL
164   37   37
165   22  INV
166   59  INT
167   19  D'
168   43  RCL
169   58   58
170   19  D'
171   16  A'
172   43  RCL
173   51   51
174   10  E'
175   43  RCL
176   50   50
177   10  E'
178   43  RCL
179   45   45
180   10  E'
181   43  RCL
182   49   49
183   10  E'
184   43  RCL
185   48   48
186   10  E'
187   87  IFF
188   03   03
189   52  EE
190   22  INV
191   86  STF
192   01   01
193   76  LBL
194   52  EE
195   87  IFF
196   00   00
197   43  RCL
198   43  RCL
199   42   42
200   10  E'
```

CALC R_D

```
201   76  LBL
202   24  CE
203   87  IFF
204   00   00
205   43  RCL
206   43  RCL
207   26   26
208   19  D'
209   43  RCL
210   02   02
211   65   ×
212   43  RCL
213   21   21
214   55   ÷
215   43  RCL
216   06   06
217   55   ÷
218   43  RCL
219   07   07
220   95   =
221   99  PRT
```

ENTER F_c

```
222   43  RCL
223   22   22
224   19  D'
225   43  RCL
226   08   08
227   87  IFF
228   03   03
229   34  √X
230   76  LBL
231   45  Yˣ
232   91  R/S
233   42  STO
234   08   08
235   76  LBL
236   33  X²
237   99  PRT
238   22  INV
239   87  IFF
240   03   03
241   43  RCL
242   22  INV
243   86  STF
244   01   01
245   76  LBL
246   43  RCL
247   22  INV
248   87  IFF
249   01   01
250   80  GRD
251   91  R/S
```

CALC S FROM PROCESS DATA

```
252   76  LBL
253   80  GRD
254   43  RCL
255   02   02
256   55   ÷
257   43  RCL
258   06   06
259   33  X²
260   55   ÷
261   53   (
262   02   2
263   08   8
264   03   3
265   01   1
266   85   +
267   93   .
268   00   0
269   05   5
270   06   6
271   07   7
272   65   ×
273   43  RCL
274   03   03
275   54   )
276   55   ÷
277   53   (
278   43  RCL
279   04   04
280   65   ×
281   43  RCL
282   05   05
283   54   )
284   34  √X
285   55   ÷
286   43  RCL
287   08   08
288   95   =
289   42  STO
290   11   11
```

CALC β

```
291   43  RCL
292   25   25
293   19  D'
294   14   D
```

CALC d

```
295  43  RCL
296  24   24
297  19  D'
298  43  RCL
299  06   06
300  65   x
301  43  RCL
302  12   12
303  95   =
304  42  STO
305  13   13
306  99  PRT
307  16  A'
308  98  ADV
309  98  ADV
310  98  ADV
311  43  RCL
312  13   13
313  91  R/S
```

CALC S FROM β

```
314  76  LBL
315  44  SUM
316  53   (
317  43  RCL
318  12   12
319  66  PAU
320  33  X2
321  65   x
322  93   .
323  05   5
324  08   8
325  09   9
326  02   2
327  05   5
328  85   +
329  43  RCL
330  12   12
331  45  YX
332  03   3
333  65   x
334  93   .
335  02   2
336  07   7
337  02   2
338  05   5
339  75   -
340  43  RCL
341  12   12
342  45  YX
343  04   4
344  65   x
345  93   .
346  08   8
347  02   2
348  05   5
349  85   +
350  43  RCL
351  12   12
352  45  YX
353  05   5
354  65   x
355  01   1
356  93   .
357  07   7
358  05   5
359  54   )
360  92  RTN
```

ITERATE FOR β

```
361  76  LBL
362  14   D
363  93   .
364  00   0
365  00   0
366  00   0
367  00   0
368  01   1
369  32  X:T
370  76  LBL
371  25  CLR
372  71  SBR
373  44  SUM
374  75   -
375  43  RCL
376  11   11
377  95   =
378  55   ÷
379  53   (
380  43  RCL
381  12   12
382  65   x
383  01   1
384  93   .
385  01   1
386  07   7
387  08   8
388  05   5
389  85   +
390  43  RCL
391  12   12
392  33  X2
393  65   x
394  93   .
395  08   8
396  01   1
397  07   7
398  05   5
399  75   -
400  43  RCL
401  12   12
402  45  YX
403  03   3
404  65   x
405  03   3
406  93   .
407  03   3
408  85   +
409  43  RCL
410  12   12
411  45  YX
412  04   4
413  65   x
414  08   8
415  93   .
416  07   7
417  05   5
418  54   )
419  95   =
420  22  INV
421  44  SUM
422  12   12
423  50  IXI
424  77   GE
425  25  CLR
426  43  RCL
427  12   12
428  99  PRT
429  92  RTN
```

ENTER REQD BORE

```
430  76  LBL
431  13   C
432  08   8
433  42  STO
434  01   01
435  43  RCL
436  40   40
437  10  E'
```

CALC β

```
438  43  RCL
439  25   25
440  19  D'
441  43  RCL
442  09   09
443  55   ÷
444  43  RCL
445  06   06
446  95   =
447  42  STO
448  12   12
```

```
449   99 PRT
450   71 SBR
451   44 SUM
452   42 STO
453   16  16
```

CALC FLOW

```
454   43 RCL
455   23  23
456   19 D'
457   43 RCL
458   02  02
459   55  ÷
460   43 RCL
461   11  11
462   65  ×
463   43 RCL
464   16  16
465   95  =
466   99 PRT
467   42 STO
468   13  13
469   16 A'
470   98 ADV
471   98 ADV
472   43 RCL
473   13  13
474   91 R/S
```

Program 7: HP 41CV Data Sheet

```
************

ORIFICE LIQD
*PIPE  TAPS*
NON  VISCOUS

************

ENTER FLOW  PPH
    100,000.0000    ***
ENTER TEMP DEG F
        150.0000    ***
ENTER SG
          0.9800    ***
ENTER DIFF RANGE INS H2O
        100.0000    ***
ENTER PIPE ID INS
          4.0260    ***
CALC  BETA
RATIO
          0.5350    ***
CALC ORIFICE
   BORE  INS
          2.1538    ***

************

              2.1538

ENTER REQD  ORIFICE INS
          2.1250    ***
CALC  BETA
RATIO
          0.5278    ***
CALC  FLOW
PPH
     96,541.6260    ***

************


************

ORIFICE LIQD
*PIPE  TAPS*
   VISCOUS

************

ENTER FLOW  PPH
    100,000.0000    ***
ENTER TEMP DEG F
        150.0000    ***
ENTER SG
          0.9800    ***
ENTER DIFF RANGE INS H2O
        100.0000    ***

ENTER PIPE ID INS
          4.0260    ***
ENTER VICOSITY cP
         10.0000    ***
CALC  REYNOL
DS NO
     10,988.5743    ***
ENTER FC
          1.0380    ***
CALC  BETA
RATIO
          0.5274    ***
CALC ORIFICE
   BORE  INS
          2.1233    ***

************

              2.1233

ENTER REQD  ORIFICE INS
          2.1250    ***
CALC  BETA
RATIO
          0.5278    ***
CALC  FLOW
PPH
    100,210.2078    ***


************
```

Program 7: HP 41CV Register Loading

SIZE 080

```
R00=  0.000000
R01=  0.000000
R02=  0.000000
R03=  0.000000
R04=  0.000000
R05=  0.000000
R06=  0.000000
R07=  0.000000
R08=  0.000000
R09=  0.000000
R10=  0.000000
R11=  0.000000
R12=  0.000000
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  0.000000
R17=  0.000000
R18=  0.000000
```

```
R19=  0.000000
R20=  0.000000
R21=  0.000000
R22= "ISCOUS"
R23= "COUS  "
R24=  0.000000
R25= "E LIQD"
R26= "*PIPE "
R27= " TAPS*"
R28= "   VIS"
R29= "COUS  "
R30=  0.000000
R31=  67.252627
R32=  28.290000
R33=  57.717200
R34=  57.505100
R35=  57.520000
R36=  57.535460
R37=  57.616200
R38=  0.000000
R39=  57.636400
R40=  0.000000
R41=  56.737400
R42=  57.750000
R43=  0.000000
R44=  56.656600
R45=  76.776869
R46=  57.706769
R47=  0.000000
R48=  56.656600
R49=  56.717200
R50= "TEMP D"
R51= "EG F  "
R52= "SG    "
R53= "DIFF R"
R54= "ANGE I"
R55= "******"
R56= "CALC  "
R57= "ENTER "
R58=  0.000000
R59=  0.000000
R60= "NS H20"
R61= "PIPE I"
R62= "D INS "
R63= "VICOS"
R64= "ITY cP"
R65= "BETA  "
R66= "RATIO "
R67= "ORIFIC"
R68= "   BOR"
R69= "E INS "
R70= "REQD  "
R71= "FLOW  "
R72= "PPH   "
R73= "REYNOL"
R74= "DS NO "
R75= "FC    "
R76= "CALC O"
R77= "RIFICE"
R78= "   VIS"
R79= "NON  V"
```

Program 7: HP 41CV Listing

SUBROUTINES

```
01♦LBL "PT LIQ"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 RTN
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53 .5
54 STO 12
55 RCL IND 01
56♦LBL 01
57 XEQ J
58 GTO e
```

RE-ENTER VARIABLES

```
59♦LBL "REENTER"
60 ADV
61 1
62 +
63 STO 01
64 RCL IND 01
65 XEQ J
66 STOP
67 XEQ J
68 STO IND 01
69 ADV
70 SF 00
71 SF 02
72 STOP
73 GTO 02
```

BYPASS PRINTER

```
74♦LBL J
75 FC? 55
76 GTO 01
77 PRX
78 RTN
79♦LBL 01
80 VIEW X
81 RTN
```

CALC S

```
82♦LBL G
```

```
83 RCL 12
84 PSE
85 X↑2
86 .58925
87 *
88 RCL 12
89 3
90 Y↑X
91 .2725
92 *
93 +
94 RCL 12
95 4
96 Y↑X
97 .825
98 *
99 -
100 RCL 12
101 5
102 Y↑X
103 1.75
104 *
105 +
106 RTN
```

MAIN PROGRAM

NONVISCOUS

```
107♦LBL A
108 FC? 00
109 CF 04
110 FS? 04
111 GTO "PT VISC"
112 SF 03
113 RCL 22
114 STO 29
115 RCL 79
116 GTO 01
```

VISCOUS

```
117♦LBL "PT VISC"
118 FC? 00
119 CF 03
120 FS? 03
121 GTO A
122 SF 04
123 RCL 23
124 STO 29
125 RCL 78
```

ENTER DATA

```
126♦LBL 01
127 STO 28
128 1
129 STO 01
130 30
131 STO 58
132 XEQ a
133 XEQ d
134 XEQ d
135 XEQ a
136 XEQ e
137 FS? 03
138 GTO 01
139 XEQ e
140 XEQ d
```

CALC R_D

```
141 4.424
142 RCL 02
143 *
144 RCL 06
145 /
146 RCL 07
147 /
148 STO 19
149 XEQ J
```

ENTER F_c

```
150 XEQ e
```

CALC S

```
151♦LBL 01
152 CF 00
153♦LBL 02
154 43
155 STO 58
156 XEQ d
157 RCL 02
158 FS? 03
159 GTO 01
160 RCL 08
161 /
162♦LBL 01
163 RCL 06
164 X↑2
165 /
166 .0567
167 RCL 03
168 *
169 2831
170 +
171 /
172 RCL 04
173 RCL 05
174 *
175 SQRT
176 /
177 STO 11
```

CALC β

```
178♦LBL D
179 XEQ G
180 RCL 11
181 -
182 RCL 12
183 1.1785
184 *
185 RCL 12
186 X↑2
187 .8175
188 *
189 +
190 RCL 12
191 3
192 Y↑X
193 3.3
194 *
195 -
196 RCL 12
197 4
198 Y↑X
199 8.75
200 *
201 +
202 /
203 ST- 12
204 ABS
205 .00001
206 X<>Y
207 X>Y?
208 GTO D
209 RCL 12
210 XEQ J
```

CALC d

```
211 XEQ d
212 RCL 06
213 RCL 12
214 *
215 STO 13
216 STO 21
217 GTO 01
```

ENTER REQD BORE

```
218♦LBL "EVEN SZ"
219 8
220 STO 01
221 45
222 STO 58
223 XEQ e
224 XEQ d
225 RCL 09
226 RCL 06
227 /
228 STO 12
229 XEQ J
230 XEQ G
231 STO 16
```

```
CALC FLOW
 232 XEQ d
 233 RCL 02
 234 RCL 11
 235 /
 236 RCL 16
 237 *
 238 STO 21
 239+LBL 01
 240 XEQ J
 241 FS? 00
 242 STOP
 243 XEQ a
 244 CF 02
 245 RCL 21
 246 VIEW X
 247 BEEP
 248 ADV
 249 STOP
 250 RTN
 251 .END.
```

Program 7: Sequence of Calculations

1. Calculate S value.

$$S = \frac{W_m}{D^2\,(2831 + .0567T_f)\,\sqrt{G_f h_m}}$$

2. Calculate Reynolds number.

$$R_D = \frac{4.42\,W_m}{D\mu}$$

3. Iterate to find beta ratio.

$$S = .58925\beta^2 + .2725\beta^3 - .825\beta^4 + 1.75\beta^5$$

$$fx = .58925\beta^2 + .2725\beta^4 - .825\beta^4 + 1.75\beta^5 - S$$

$$f^1x = 1.1785\beta + .8175\beta^2 - 3.3\beta + 8.75\beta^4$$

   Start with $\beta = 0.5$ and calculate fx/f^1x. If greater than 0.00001, subtract fx/f^1x from current value of β and repeat until the error is less than 0.00001.

4. Calculate orifice bore.

$$d = \beta D \text{ inches}$$

5. Calculate flowrate for an even-sized orifice plate.

$$\beta = \frac{d}{D}$$

$$S = .58925\beta^2 + .2725\beta^3 - .825\beta^4 + 1.75\beta^5$$

$$\text{new flow} = \frac{\text{new } S}{\text{original } S} \times \text{original flow, pounds per hour}$$

Program 7: Nomenclature

D	Inside diameter of pipe, inches
d	Diameter of orifice bore, inches
F_c	Reynolds number correction factor, dimensionless
G_f	Specific gravity of liquid at flowing temperature
h_m	Maximum differential range, inches of water
S	Beta ratio index, dimensionless
T_f	Flowing temperature, °F
W_m	Maximum rate of flow, pounds per hour
μ	Absolute viscosity, centipoises
β	Beta ratio d/D, dimensionless

References

L. K. Spink, *The Principles and Practice of Flowmeter Engineering,* The Foxboro Company.

Program 8
Liquid Flow—Flow Nozzle and Venturi

Program 8: User Instructions

Non-viscous liquid program, press A.

a) Enter:
   1. Flowrate, pounds per hour — Press R/S
   2. Flow temperature, °F — Press R/S
   3. Specific gravity at flow temperature, dimensionless — Press R/S
   4. Differential range, inches of water — Press R/S
   5. Pipe inside diameter, inches — Press R/S

b) Program calculates beta ratio (dimensionless) and nozzle diameter (inches).

c) If an even-sized nozzle is required, Press C and enter:
   6. Required nozzle bore, inches — Press R/S

d) Program calculates beta ratio (dimensionless) and new flowrate (pounds per hour).

Viscous liquid program, press B.

a) Enter:

1. Flowrate, pounds per hour	Press R/S
2. Flow temperature, °F	Press R/S
3. Specific gravity at flow temperature, dimensionless	Press R/S
4. Differential range, inches of water	Press R/S
5. Pipe inside diameter, inches	Press R/S
6. Absolute viscosity, centipoises	Press R/S

b) Program calculates Reynolds number, dimensionless.

c) Refer to appropriate R_D/F_c chart and enter:

7. Reynolds number correction factor F_c, dimensionless	Press R/S

d) Program calculates beta ratio (dimensionless) and nozzle bore (inches).

e) If an even-sized nozzle bore is required, press C as before.

Notes:

1. The E subroutine is available to re-enter data and recalculate.
2. If the orifice plate material is not 316SS or 304SS, see Table of Equal Thermal Expansion Temperatures for Various Orifice Plate Materials, page 162.

Program 8: TI 59 Data Sheet

```
********************


FLOW NOZZLE     CALC
  NON VISC LIQUID


********************


ENTR FLOW    PPH
     100000.
ENTR TEMP     °F
       150.
ENTR    SG
       0.98
ENTR DIFF RANGE IN W
       100.
ENTR PIPE ID      INS
      4.026
```

```
CALC BETA RATIO
 .4674978969
CALC NOZZLE        INS
 1.882146533


********************



ENTR NOZZLE        INS
          1.875
CALC BETA RATIO
 .4657228018
CALC FLOW    PPH
 99208.30127


********************
```

```
********************

FLOW NOZZLE    CALC
 VISCOUS   LIQUID

********************

ENTR FLOW    PPH
     100000.
ENTR TEMP     °F
       150.
ENTR    SG
       0.98
ENTR DIFF RANGE IN W
       100.
ENTR PIPE ID     INS
      4.026
ENTR  VISC   CP
         10.
```

```
CALC REYNLDS N°
 10988.57427
ENTR    FC
       0.972
CALC BETA RATIO
 .4738726927
CALC NOZZLE       INS
 1.907811461

********************

ENTR NOZZLE       INS
        1.875
CALC BETA RATIO
 .4657228018
CALC FLOW    PPH
 96430.46883

********************
```

Program 8: TI 59 Register Loading

PARTITIONING
479.59

0.	00	54.535256	29
0.	01	3717303300.	30
0.	02	27243441.	31
0.	03	3241360000.	32
0.	04	37133336.	33
0.	05	3324331700.	34
0.	06	3513372432.	35
0.	07	1417371300.	36
0.	08	2115.3433	37
0.	09	1636003173.	38
0.	10	3517453127.	39
0.	11	1533.535242	40
0.	12	42243615.37	41
0.	13	243136.414	42
0.	14	2416000000.	43
0.	15	3324331700.	44
0.	16	24310043.48	45
0.	17	3513312217.	46
0.	18	1624212100.	47
0.	19	3622.444342	48
0.	20	7321.474645	49
0.	21	333323.3049	50
57.37	22	313231.545	51
56.545	23	1700000000.	52
56.535242	24	3132464627.	53
56.0635	25	2127324300.	54
56.3478	26	5151515151.	55
41.323143	27	1513271500.	56
51.413143	28	1731373500.	57
		0.	58
		0.	59

Program 8: TI 59 Listing

SUBROUTINES ENTER & STORE VARIABLES

```
000   76 LBL
001   10 E'
002   22 INV
003   59 INT
004   85  +
005   05  5
006   07  7
007   95  =
008   19 D'
009   69 OP
010   21  21
011   73 RC*
012   01  01
013   87 IFF
014   01  01
015   00  00
016   20  20
017   91 R/S
018   72 ST*
019   01  01
020   99 PRT
021   92 RTN
```

PRINT LINES

```
022   76 LBL
023   19 D'
024   42 STO
025   59  59
026   73 RC*
027   59  59
028   69 OP
029   01  01
030   18 C'
031   69 OP
032   02  02
033   18 C'
034   69 OP
035   03  03
036   18 C'
037   69 OP
038   04  04
039   69 OP
040   05  05
041   92 RTN
```

DECODE LINES

```
042   76 LBL
043   18 C'
044   01  1
045   00  0
046   00  0
047   48 EXC
048   59  59
049   22 INV
050   59 INT
051   49 PRD
052   59  59
053   73 RC*
054   59  59
055   92 RTN
```

PRINT LINE OF STARS

```
056   76 LBL
057   16 A'
058   93  .
059   00  0
060   01  1
061   08  8
062   35 1/X
063   98 ADV
064   19 D'
065   98 ADV
066   92 RTN
```

RE-ENTER VARIABLES

```
067   76 LBL
068   15  E
069   99 PRT
070   85  +
071   01  1
072   95  =
073   42 STO
074   01  01
075   73 RC*
076   01  01
077   91 R/S
078   72 ST*
079   01  01
080   99 PRT
081   98 ADV
082   22 INV
083   86 STF
084   03  03
085   86 STF
086   01  01
087   61 GTO
088   24 CE
089   76 LBL
090   34 √X
091   87 IFF
092   01  01
093   33 X²
094   61 GTO
095   45 YX
096   76 LBL
097   97 DSZ
098   87 IFF
099   01  01
100   11  A
101   61 GTO
102   98 ADV
103   76 LBL
104   99 PRT
105   87 IFF
106   01  01
107   12  B
108   61 GTO
109   90 LST
```

MAIN PROGRAM NONVISCOUS LIQUID ENTER DATA

```
110   76 LBL
111   11  A
112   87 IFF
113   02  02
114   99 PRT
115   76 LBL
116   90 LST
117   01  1
118   42 STO
119   08  08
120   22 INV
121   86 STF
122   03  03
123   22 INV
124   86 STF
125   02  02
126   86 STF
127   00  00
128   43 RCL
129   28  28
130   61 GTO
131   42 STO
```

VISCOUS LIQUID ENTER DATA

```
132   76 LBL
133   12  B
134   87 IFF
135   00  00
136   97 DSZ
137   76 LBL
138   98 ADV
```

```
139   22  INV
140   86  STF
141   00   00
142   86  STF
143   02   02
144   86  STF
145   03   03
146   43  RCL
147   27   27
148   76  LBL
149   42  STD
150   42  STD
151   58   58
152   93   .
153   05   5
154   42  STD
155   12   12
156   01   1
157   42  STD
158   01   01
159   16  A'
160   43  RCL
161   29   29
162   19  D'
163   43  RCL
164   58   58
165   19  D'
166   16  A'
167   43  RCL
168   51   51
169   10  E'
170   43  RCL
171   50   50
172   10  E'
173   43  RCL
174   45   45
175   10  E'
176   43  RCL
177   49   49
178   10  E'
179   43  RCL
180   48   48
181   10  E'
182   87  IFF
183   03   03
184   52  EE
185   22  INV
186   86  STF
187   01   01
188   76  LBL
189   52  EE
190   87  IFF
191   00   00
192   43  RCL
193   43  RCL
194   42   42
195   10  E'
```

CALC R_D

```
196   76  LBL
197   24  CE
198   87  IFF
199   00   00
200   43  RCL
201   43  RCL
202   26   26
203   19  D'
204   04   4
205   93   .
206   04   4
207   02   2
208   04   4
209   65   ×
210   43  RCL
211   02   02
212   55   ÷
213   43  RCL
214   06   06
215   55   ÷
216   43  RCL
217   07   07
218   95   =
219   99  PRT
```

ENTER F_c

```
220   43  RCL
221   22   22
222   19  D'
223   43  RCL
224   08   08
225   87  IFF
226   03   03
227   34  √X
228   76  LBL
229   45  Y^X
230   91  R/S
231   42  STD
232   08   08
233   76  LBL
234   33  X²
235   99  PRT
236   22  INV
237   87  IFF
238   03   03
239   43  RCL
240   22  INV
241   86  STF
242   01   01
243   76  LBL
244   43  RCL
245   22  INV
246   87  IFF
247   01   01
248   80  GRD
249   91  R/S
```

CALC S

```
250   76  LBL
251   80  GRD
252   43  RCL
253   02   02
254   55   ÷
255   43  RCL
256   06   06
257   33  X²
258   55   ÷
259   53   (
260   02   2
261   08   8
262   03   3
263   01   1
264   85   +
265   93   .
266   00   0
267   05   5
268   06   6
269   07   7
270   65   ×
271   43  RCL
272   03   03
273   54   )
274   55   ÷
275   53   (
276   43  RCL
277   04   04
278   65   ×
279   43  RCL
280   05   05
281   54   )
282   34  √X
283   55   ÷
284   43  RCL
285   08   08
286   95   =
287   42  STD
288   11   11
```

CALC β and d

```
289   43  RCL
290   25   25
291   19  D'
```

```
292   14   D
293   43  RCL
294   24   24
295   19  D'
296   43  RCL
297   06   06
298   65   X
299   43  RCL
300   12   12
301   95   =
302   42  STO
303   13   13
304   99  PRT
305   16  A'
306   98  ADV
307   98  ADV
308   98  ADV
309   43  RCL
310   13   13
311   91  R/S
```

SUBROUTINE TO CALC S

```
312   76  LBL
313   44  SUM
314   53   (
315   53   (
316   43  RCL
317   12   12
318   66  PAU
319   45  YX
320   04   4
321   55   ÷
322   53   (
323   01   1
324   75   -
325   43  RCL
326   12   12
327   45  YX
328   04   4
329   54   )
330   54   )
331   34  ΓX
332   65   X
333   93   .
334   09   9
335   08   8
336   54   )
337   92  RTN
```

ITERATE FOR β

```
338   76  LBL
339   14   D
340   93   .
341   00   0
342   00   0
343   00   0
344   01   1
345   32  X:T
346   76  LBL
347   25  CLR
348   71  SBR
349   44  SUM
350   75   -
351   43  RCL
352   11   11
353   95   =
354   55   ÷
355   53   (
356   43  RCL
357   12   12
358   45  YX
359   03   3
360   65   X
361   04   4
362   54   )
363   45  YX
364   93   .
365   05   5
366   65   X
367   93   .
368   04   4
369   09   9
370   95   =
371   22  INV
372   44  SUM
373   12   12
374   50  IXI
375   77   GE
376   25  CLR
377   43  RCL
378   12   12
379   99  PRT
380   92  RTN
```

ENTER REQD BORE

```
381   76  LBL
382   13   C
383   08   8
384   42  STO
385   01   01
386   43  RCL
387   40   40
388   10  E'
```

CALC β

```
389   43  RCL
390   25   25
391   19  D'
392   43  RCL
393   09   09
394   55   ÷
395   43  RCL
396   06   06
397   95   =
398   42  STO
399   12   12
400   99  PRT
401   71  SBR
402   44  SUM
403   42  STO
404   16   16
```

CALC FLOW

```
405   43  RCL
406   23   23
407   19  D'
408   43  RCL
409   02   02
410   55   ÷
411   43  RCL
412   11   11
413   65   X
414   43  RCL
415   16   16
416   95   =
417   99  PRT
418   42  STO
419   13   13
420   16  A'
421   98  ADV
422   98  ADV
423   43  RCL
424   13   13
425   91  R/S
```

Program 8: HP 41CV Data Sheet

```
************

FLOW   NOZZLE
NON   VISCOUS
   LIQUID

************

ENTER FLOW  PPH
    100,000.0000     ***
ENTER TEMP DEG F
         150.0000    ***
ENTER SG
           0.9800    ***
ENTER DIFF RANGE INS H20
         100.0000    ***
ENTER PIPE ID INS
           4.0260    ***
CALC   BETA
RATIO
           0.4675    ***
CALC  ORIFICE
 BORE   INS
           1.8821    ***

************

                1.8821
```

```
ENTER REQD  NOZZLE INS
           1.8750    ***
CALC   BETA
RATIO
           0.4657    ***
CALC   FLOW
PPH
       99,208.3013   ***

************
************

FLOW   NOZZLE
   VISCOUS
   LIQUID

************

ENTER FLOW  PPH
    100,000.0000     ***
ENTER TEMP DEG F
         150.0000    ***
ENTER SG
           0.9800    ***
ENTER DIFF RANGE INS H20
         100.0000    ***
ENTER PIPE ID INS
           4.0260    ***
```

```
ENTER VICOSITY cP
          10.0000    ***
CALC   REYNOL
DS NO
      10,988.5743    ***
ENTER FC
           0.9720    ***
CALC   BETA
RATIO
           0.4739    ***
CALC  ORIFICE
 BORE   INS
           1.9078    ***

************

                1.9078

ENTER REQD  NOZZLE INS
           1.8750    ***
CALC   BETA
RATIO
           0.4657    ***
CALC   FLOW
PPH
       96,430.4689   ***

************
```

Program 8: HP 41CV Register Loading

SIZE 080

```
R00=  0.000000
R01=  0.000000
R02=  0.000000
R03=  0.000000
R04=  0.000000
R05=  0.000000
R06=  0.000000
R07=  0.000000
R08=  0.000000
R09=  0.000000
R10=  0.000000
R11=  0.000000
R12=  0.000000
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  0.000000
R17=  0.000000
R18=  0.000000
R19=  0.000000
```

```
R20=  0.000000
R21=  0.000000
R22= "ISCOUS"
R23= "COUS  "
R24= "   LIQ"
R25= "UID   "
R26= "NOZZLE"
R27= " TAPS*"
R28= "   VIS"
R29= "COUS  "
R30=  71.260000
R31=  71.260000
R32=  28.292425
R33=  57.717200
R34=  57.505100
R35=  57.520000
R36=  57.535460
R37=  57.616200
R38=  0.000000
R39=  57.636400
R40=  0.000000
```

```
R41=  56.737400
R42=  57.750000
R43=  0.900000
R44=  56.656600
R45=  76.776869
R46=  57.702669
R47=  0.000000
R48=  56.656600
R49=  56.717200
R50= "TEMP D"
R51= "EG F  "
R52= "SG    "
R53= "DIFF R"
R54= "ANGE I"
R55= "******"
R56= "CALC  "
R57= "ENTER "
R58=  0.000000
R59=  0.000000
R60= "NS H20"
R61= "PIPE I"
```

```
R62= "D INS "
R63= "VICOS"
R64= "ITY cP"
R65= "BETA  "
R66= "RATIO "
R67=  0.000000
R68= " BORE "
R69= " INS  "
R70= "REQD  "
R71= "FLOW  "
R72= "PPH   "
R73= "REYNOL"
R74= "DS NO "
R75= "FC    "
R76= "CALC O"
R77= "RIFICE"
R78= "   VIS"
R79= "NON  V"
```

Program 8: HP 41CV Listing

SUBROUTINES

```
01♦LBL "FN LIQ"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 RTN
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53 .5
54 STO 12
55 RCL IND 01
56♦LBL 01
57 XEQ J
58 GTO e
```

RE-ENTER VARIABLES

```
59♦LBL "REENTER"
60 ADV
61 1
62 +
63 STO 01
64 RCL IND 01
65 XEQ J
66 STOP
67 XEQ J
68 STO IND 01
69 ADV
70 SF 00
71 SF 02
72 STOP
73 GTO 02
```

BYPASS PRINTER

```
74♦LBL J
75 FC? 55
76 GTO 01
77 PRX
78 RTN
79♦LBL 01
80 VIEW X
81 RTN
```

CALC S

```
82♦LBL G
83 RCL 12
84 PSE
85 X↑2
86 X↑2
87 ENTER↑
88 CHS
89 1
90 +
91 /
92 SQRT
93 .98
94 *
95 RTN
```

MAIN PROGRAM NONVISCOUS

```
96♦LBL A
97 FC? 00
98 CF 04
99 FS? 04
100 GTO "FN VISC"
101 SF 03
102 RCL 22
103 STO 29
104 RCL 79
105 GTO 01
```

VISCOUS

```
106♦LBL "FN VISC"
107 FC? 00
108 CF 03
109 FS? 03
110 GTO A
111 SF 04
112 RCL 23
113 STO 29
114 RCL 78
```

ENTER DATA

```
115♦LBL 01
116 STO 28
117 1
118 STO 01
119 30
120 STO 58
```

```
121 XEQ a
122 XEQ d
123 XEQ d
124 XEQ a
125 XEQ e
126 FS? 03
127 GTO 01
128 XEQ e
129 XEQ d
```

CALC R_D

```
130 4.424
131 RCL 02
132 *
133 RCL 06
134 /
135 RCL 07
136 /
137 STO 19
138 XEQ J
```

ENTER F_c

```
139 XEQ e
```

CALC S

```
140♦LBL 01
141 CF 00
142♦LBL 02
143 43
144 STO 58
145 XEQ d
146 RCL 02
147 FS? 03
148 GTO 01
149 RCL 08
150 /
151♦LBL 01
152 RCL 06
153 X↑2
154 /
155 .0567
156 RCL 03
157 *
158 2831
159 +
160 /
161 RCL 04
162 RCL 05
163 *
164 SQRT
165 /
166 STO 11
```

CALC β

```
167♦LBL D
168 XEQ G
169 RCL 11
170 -
171 RCL 12
172 3
173 Y↑X
174 4
175 *
176 SQRT
177 .49
178 /
179 /
180 ST- 12
181 ABS
182 .0001
183 X<>Y
184 X>Y?
185 GTO D
186 RCL 12
187 XEQ J
```

CALC d

```
188 XEQ d
189 RCL 06
190 RCL 12
191 *
192 STO 13
193 STO 21
194 GTO 01
```

ENTER REQD BORE CALC β

```
195♦LBL "EVEN SZ"
196 8
197 STO 01
198 45
199 STO 58
200 XEQ e
201 XEQ d
202 RCL 09
203 RCL 06
204 /
205 STO 12
206 XEQ J
207 XEQ G
208 STO 16
```

CALC FLOW

```
209 XEQ d
210 RCL 02
211 RCL 11
212 /
213 RCL 16
214 *
215 STO 21
216♦LBL 01
217 XEQ J
218 FS? 00
219 STOP
220 XEQ a
221 CF 02
222 RCL 21
223 VIEW X
224 BEEP
225 ADV
226 STOP
227 RTN
228 .END.
```

Program 8: Sequence of Calculations

1. Calculate S value.

$$S = \frac{W_m}{D^2\,(2831 + .0567T_f)\,\sqrt{G_f h_m}}$$

2. Calculate Reynolds number.

$$R_D = \frac{4.424\,W_m}{D\mu_{cp}}$$

3. Iterate to find beta ratio.

$$S = .98\sqrt{\frac{\beta^4}{1-\beta^4}}$$

$$fx = .98\sqrt{\frac{\beta^4}{1-\beta^4}} - S$$

$$f^1x = .49\sqrt{4\beta^3}$$

Start with $\beta = 0.5$ and calculate fx/f^1x. If greater than 0.0001, subtract fx/f^1x from current value of β and repeat until the error is less than 0.0001.

4. Calculate orifice bore.

$$d = \beta D \text{ inches}$$

5. Calculate flowrate for even-sized nozzle or venturi.

$$\beta = \frac{d}{D}$$

$$S = .98\sqrt{\frac{\beta^4}{1-\beta^4}}$$

$$\text{new flow} = \frac{\text{new } S}{\text{original } S} \times \text{original flow, pounds per hour.}$$

Program 8: Nomenclature

D	Inside diameter of pipe, inches
d	Diameter of orifice bore, inches
F_c	Reynolds number correction factor, dimensionless
G_f	Specific gravity of liquid at flowing temperature, dimensionless
h_m	Maximum differential range, inches of water
S	Beta ratio index, dimensionless
T_f	Flowing temperature, °F
W_m	Maximum rate of flow, pounds per hour
μ_{cp}	Absolute viscosity, centipoises
β	Beta ratio d/D, dimensionless

References

L. K. Spink, *The Principles and Practice of Flowmeter Engineering*, The Foxboro Company.

Program 9
Liquid Flow—Universal Calculation

This program calculates S and uses tables to find β. It can be used for all liquid calculations, but it is particularly useful for quadrant-edged orifices and low-loss tubes, for which the tables on page 120 are provided.

Program 9: User Instructions

Non-viscous liquid program, press A.

a) Enter:
   1. Flowrate, pounds per hour — Press R/S
   2. Flow temperature, °F — Press R/S
   3. Specific gravity at flow temperature, dimensionless — Press R/S
   4. Differential range, inches of water — Press R/S
   5. Pipe inside diameter, inches — Press R/S
   6. Weep hole diameter, inches — Press R/S

b) Program calculates S value, dimensionless.

c) From appropriate S table, enter:
   7. Beta ratio, dimensionless — Press R/S

d) Program calculates orifice diameter, inches.

e) If an even-sized orifice bore is required, press C and enter:
   8. Required orifice bore, inches — Press R/S

f) Program calculates beta ratio, dimensionless.

g) From appropriate S table, enter:
   9. S value, dimensionless — Press R/S

h) Program calculates new flowrate, pounds per hour.

Viscous liquid program, press B.

a) Enter:
   1. Flowrate, pounds per hour — Press R/S
   2. Flow temperature, °F — Press R/S
   3. Specific gravity at flow temperature, dimensionless — Press R/S

4. Differential range, inches of water	Press R/S
5. Pipe diameter, inches of water	Press R/S
6. Weep hole diameter, inches	Press R/S
7. Absolute viscosity, centipoises	Press R/S

b) Program calculates Reynolds number.

c) From appropriate R_D/F_c chart, enter:

8. Reynolds number correction factor F_c	Press R/S

d) Program calculates S value, dimensionless.

e) From appropriate S table, enter:

9. Beta ratio, dimensionless	Press R/S

f) Program calculates orifice bore, inches. If an even-sized orifice bore is required, press C as before.

Notes:
1. The E subroutine is not available in the TI program.
2. If the orifice plate material is not 316SS or 304SS, see Table of Equal Thermal Expansion Temperatures for Various Orifice Plate Materials, page 162.

Program 9: TI 59 Data Sheet

```
********************

FLOW  ORIFICE  CALC
  NON VISC LIQUID

********************

ENTR FLOW          PPH
      100000.
ENTR FLOW  TEMP   °F
        150.
ENTR FLOW      SG
         0.98
ENTR DIFF RANGE IN W
        100.
ENTR PIPE ID      INS
       4.026
ENTR WEEP HOLE    INS
          0.
CALC   S  VALUE
 .2194809257
ENTR BETA RATIO
        0.535
CALC  ORIFICE     INS
      2.15391

********************
```

```
ENTR  ORIFICE     INS
        2.125
CALC BETA RATIO
 .5278191754
ENTR    S   VALUE
        0.2119
CALC FLOW         PPH
 96545.97515

********************

********************

FLOW  ORIFICE  CALC
 VISCOUS    LIQUID

********************

ENTR FLOW         PPH
      100000.
ENTR FLOW  TEMP   °F
        150.
ENTR FLOW     SG
         0.98
```

```
ENTR DIFF RANGE IN W
        100.
ENTR PIPE ID       INS
       4.026
ENTR WEEP HOLE     INS
          0.
ENTR FLOW  VISC     CP
         10.
CALC REYNLDS N%
 10988.57427

ENTR   FC
          1.028
CALC   S  VALUE
 0.213502846
ENTR BETA RATIO
         0.5295
CALC  ORIFICE      INS
      2.131767

   ****************
```

Program 9: TI 59 Register Loading

PARTITIONING
479.59

0.	00
0.	01
0.	02
0.	03
0.	04
0.	05
0.	06
0.	07
0.	08
0.	09
0.	10
0.	11
0.	12
0.	13
3241360000.	14
0.	15
0.	16
0.534944	17
49.144847	18
56.525138	19
0.3332	20
56.3534	21
0.373638	22
0.394738	23
0.42414	24
0.5343	25
0.534658	26
50.494847	27
53.525156	28
211500.	29
1636003173.	30
3517453127.	31
3513372402.	32
1417371300.	33
4213274117.	34
360000.	35
2332271700.	36
4317173300.	37
243136.	38
3324331700.	39
24310043.	40
[illegible]513312217.	41
1624212100.	42
3622.	43
1533.	44
333323.7321	45
37173003.	46
2416000000.	47
27243441.	48
42243615.	49
313231.	50
2415170000.	51
32352421.	52
2127324300.	53
55.555555	54
5151515151.	55
1513271500.	56
1731373500.	57
0.	58
0.	59

Program 9: TI 59 Listing

SUBROUTINES
PRINT & STORE
VARIABLES

```
000  76  LBL
001  42  STO
002  85   +
003  05   5
004  07   7
005  95   =
006  71  SBR
007  61  GTO
008  69  OP
009  21   21
010  73  RC*
011  01   01
012  91  R/S
013  99  PRT
014  72  ST*
015  01   01
016  92  RTN
```

PRINT LINES

```
017  76  LBL
018  61  GTO
019  42  STO
020  59   59
021  73  RC*
022  59   59
023  69  OP
024  01   01
025  71  SBR
026  43  RCL
027  69  OP
028  02   02
029  71  SBR
030  43  RCL
031  69  OP
032  03   03
033  71  SBR
034  43  RCL
035  69  OP
036  04   04
037  69  OP
038  05   05
039  92  RTN
```

DECODE LINES

```
040  76  LBL
041  43  RCL
042  01   1
043  00   0
044  00   0
045  48  EXC
046  59   59
047  22  INV
048  59  INT
049  49  PRD
050  59   59
051  73  RC*
052  59   59
053  92  RTN
054  76  LBL
055  59  INT
056  22  INV
057  59  INT
058  52  EE
059  06   6
060  22  INV
061  52  EE
062  42  STO
063  58   58
064  92  RTN
```

ENTER COMMON DATA

```
065  76  LBL
066  22  INV
067  93   .
068  05   5
069  03   3
070  00   0
071  00   0
072  04   4
073  05   5
074  71  SBR
075  42  STO
076  43  RCL
077  45   45
078  71  SBR
079  59  INT
080  43  RCL
081  26   26
082  71  SBR
083  42  STO
084  43  RCL
085  25   25
086  71  SBR
087  42  STO
088  43  RCL
089  24   24
090  71  SBR
091  42  STO
092  43  RCL
093  23   23
094  71  SBR
095  42  STO
096  43  RCL
097  22   22
098  71  SBR
099  42  STO
100  92  RTN
```

CALC S

```
101  76  LBL
102  23  LNX
103  43  RCL
104  21   21
105  71  SBR
106  61  GTO
107  43  RCL
108  02   02
109  55   ÷
110  43  RCL
111  06   06
112  33  X²
113  55   ÷
114  53   (
115  02   2
116  08   8
117  03   3
118  01   1
119  85   +
120  93   .
121  00   0
122  05   5
123  06   6
124  07   7
125  65   ×
126  43  RCL
127  03   03
128  54   )
129  55   ÷
130  43  RCL
131  04   04
132  34  √X
133  55   ÷
134  43  RCL
135  05   05
136  34  √X
137  55   ÷
138  43  RCL
139  10   10
140  95   =
141  42  STO
142  11   11
143  99  PRT
```

ENTER β

```
144  01   1
145  01   1
146  42  STO
147  01   01
148  43  RCL
149  20   20
150  71  SBR
151  42  STO
```

CALC d

```
152  43  RCL
153  19   19
154  71  SBR
155  61  GTO
156  53   (
157  43  RCL
158  06   06
159  65   ×
160  43  RCL
161  12   12
162  54   )
163  33  X²
164  75   -
165  43  RCL
166  07   07
167  33  X²
168  95   =
169  34  √X
170  95   =
171  42  STO
```

```
172   13   13
173   99  PRT
174   98  ADV
175   43  RCL
176   54   54
177   71  SBR
178   61  GTO
179   98  ADV
180   98  ADV
181   98  ADV
182   43  RCL
183   13   13
184   91  R/S
```

MAIN PROGRAM NONVISCOUS LIQUID ENTER DATA

```
185   76  LBL
186   11   A
187   01   1
188   42  STO
189   01   01
190   42  STO
191   10   10
192   98  ADV
193   43  RCL
194   54   54
195   71  SBR
196   61  GTO
197   98  ADV
198   43  RCL
199   28   28
200   71  SBR
201   61  GTO
202   43  RCL
203   27   27
204   71  SBR
205   61  GTO
206   98  ADV
207   71  SBR
208   22  INV
209   61  GTO
210   23  LNX
```

VISCOUS LIQUID ENTER DATA

```
211   76  LBL
212   12   B
213   01   1
214   42  STO
215   01   01
216   98  ADV
217   43  RCL
218   54   54
219   71  SBR
220   61  GTO
221   98  ADV
222   43  RCL
223   28   28
224   71  SBR
225   61  GTO
226   43  RCL
227   18   18
228   71  SBR
229   61  GTO
230   98  ADV
231   71  SBR
232   22  INV
233   43  RCL
234   17   17
235   71  SBR
236   42  STO
```

CALC R_D

```
237   05   5
238   06   6
239   93   .
240   03   3
241   01   1
242   03   3
243   71  SBR
244   61  GTO
245   43  RCL
246   02   02
247   65   ×
248   04   4
249   93   .
250   04   4
251   02   2
252   04   4
253   55   ÷
254   43  RCL
255   08   08
256   55   ÷
257   43  RCL
258   06   06
259   95   =
260   42  STO
261   09   09
262   99  PRT
```

ENTER F_c

```
263   69  OP
264   21   21
265   93   .
266   02   2
267   09   9
268   71  SBR
269   42  STO
270   61  GTO
271   23  LNX
```

ENTER REQD BORE CALC β

```
272   76  LBL
273   13   C
274   01   1
275   04   4
276   42  STO
277   01   01
278   93   .
279   05   5
280   02   2
281   05   5
282   01   1
283   03   3
284   08   8
285   71  SBR
286   42  STO
287   05   5
288   06   6
289   93   .
290   03   3
291   03   3
292   03   3
293   02   2
294   71  SBR
295   61  GTO
296   53   (
297   53   (
298   43  RCL
299   15   15
300   33  X²
301   75   -
302   43  RCL
303   07   07
304   33  X²
305   54   )
306   55   ÷
307   43  RCL
308   06   06
309   33  X²
310   54   )
311   34  √X
312   95   =
313   99  PRT
```

ENTER S

```
314   93   .
315   03   3
316   05   5
317   03   3
318   04   4
319   71  SBR
320   42  STO
```

CALC FLOW

```
321  05   5
322  06   6
323  93   .
324  05   5
325  03   3
326  00   0
327  00   0
328  04   4
329  05   5
330  71 SBR
331  61 GTO
332  43 RCL
333  02  02
334  55   ÷
335  43 RCL
336  11  11
337  65   ×
338  43 RCL
339  16  16
340  95   =
341  99 PRT
342  42 STO
343  13  13
344  98 ADV
345  43 RCL
346  54  54
347  71 SBR
348  61 GTO
349  98 ADV
350  98 ADV
351  98 ADV
352  43 RCL
353  13  13
354  91 R/S
```

Program 9: HP 41CV Data Sheet

```
************

ORIFICE LIQD
NON  VISCOUS

************

ENTER FLOW  PPH
    100,000.0000     ***
ENTER TEMP DEG F
         150.0000    ***
ENTER SG
           0.9800    ***
ENTER DIFF RANGE INS H20
         100.0000    ***
ENTER PIPE ID INS
           4.0260    ***
ENTER WEEP HOLE  DIA INS
           0.0000    ***
CALC    S
           0.2195    ***
ENTER BETA  RATIO
           0.5350    ***
CALC ORIFICE
   BORE  INS
           2.1539    ***

************

                 2.1539
ENTER REQD  ORIFICE INS
           2.1250    ***
CALC   BETA
RATIO
           0.5278    ***
ENTER S
           0.2119    ***
CALC   FLOW
PPH
      96,545.9752    ***

************

************

ORIFICE LIQD
    VISCOUS

************

ENTER FLOW  PPH
    100,000.0000     ***
ENTER TEMP DEG F
         150.0000    ***
ENTER SG
           0.9800    ***
ENTER DIFF RANGE INS H20
         100.0000    ***
ENTER PIPE ID INS
           4.0260    ***
ENTER WEEP HOLE  DIA INS
           0.0000    ***
ENTER VISCOSITY cP
          10.0000    ***
CALC   REYNOL
DS  NO
      10,988.5743    ***
ENTER FC
           1.0280    ***
CALC    S
           0.2135    ***
ENTER BETA  RATIO
           0.5295    ***
CALC ORIFICE
   BORE  INS
           2.1318    ***

************

                 2.1318

ENTER REQD  ORIFICE INS
           2.1250    ***
CALC   BETA
RATIO
           0.5278    ***
ENTER S
           0.2119    ***
CALC   FLOW
PPH
      99,249.2625    ***

************
```

Program 9: HP 41CV Register Loading

SIZE 080

```
R00= 0.000000
R01= 0.000000
R02= 0.000000
R03= 0.000000
R04= 0.000000
R05= 0.000000
R06= 0.000000
R07= 0.000000
R08= 0.000000
R09= 0.000000
R10= 0.000000
R11= 0.000000
R12= 0.000000
```

```
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  0.000000
R17=  0.000000
R18= "CALC O"
R19= "   VIS"
R20= "COUS  "
R21= "NON  V"
R22= "ISCOUS"
R23= "REQD  "
R24= "E INS "
R25= "ORIFIC"
R26= "E LIQD"
R27= "NON  V"
R28= "ISCOUS"
R29= "RIFICE"
R30=  25.262723
R31=  57.535400
R32=  57.606100
R33=  57.620000
R34=  57.636465
R35=  57.666700
R36=  57.686970
R37=  0.000000
R38=  57.717200
R39=  0.000000
R40=  56.737400
R41=  57.750000
R42=  0.000000
R43=  56.760000
R44=  57.777800
R45=  0.000000
R46=  18.297924
R47=  57.232524
R48=  0.000000
R49=  56.777800
R50=  57.760000
R51=  0.000000
R52=  56.535400
R53= "FLOW  "
R54= "PPH   "
R55= "******"
R56= "CALC  "
R57= "ENTER "
R58=  0.000000
R59=  0.000000
R60= "TEMP D"
R61= "EG F  "
R62= "SG    "
R63= "DIFF R"
R64= "ANGE I"
R65= "NS H2O"
R66= "PIPE I"
R67= "D INS "
R68= "WEEP H"
R69= "OLE  D"
R70= "IA INS"
R71= "VISCOS"
R72= "ITY cP"
R73= "REYNOL"
R74= "DS NO "
R75= "FC    "
R76= "S     "
R77= "BETA  "
R78= "RATIO "
R79= "   BOR"
```

Program 9: HP 41CV Listing

SUBROUTINES

```
01♦LBL "UN LIQ"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 RTN
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53♦LBL 01
54 XEQ J
55 GTO e
```

RE-ENTER VARIABLES

```
56♦LBL "REENTER"
57 ADV
58 1
59 +
60 STO 01
61 FC? 03
62 GTO 01
63 7
64 RCL 01
65 X<=Y?
66 GTO 01
67 2
68 ST+ 01
69♦LBL 01
70 RCL IND 01
71 XEQ J
72 STOP
73 XEQ J
74 STO IND 01
75 ADV
76 SF 00
77 SF 02
78 STOP
79 GTO 02
```

BYPASS PRINTER

```
80♦LBL J
81 FC? 55
82 GTO 01
83 PRX
84 RTN
85♦LBL 01
86 VIEW X
87 RTN
```

MAIN PROGRAM NONVISCOUS

```
88♦LBL A
89 FC? 00
90 CF 04
91 FS? 04
92 GTO "UN VISC"
93 SF 03
94 RCL 21
95 STO 27
96 RCL 22
97 GTO 01
```

VISCOUS

```
98♦LBL "UN VISC"
99 FC? 00
100 CF 03
101 FS? 03
102 GTO A
103 SF 04
104 RCL 19
105 STO 27
106 RCL 20
```

ENTER DATA

```
107♦LBL 01
108 STO 28
109 1
110 STO 01
111 29
112 STO 58
113 XEQ a
114 XEQ d
115 XEQ a
116 XEQ e
117 FS? 03
118 GTO 01
119 XEQ e
120 XEQ d
```

CALC R_D

```
121 4.424
122 RCL 02
123 *
124 RCL 06
125 /
126 RCL 08
127 /
128 STO 17
129 XEQ J
```

ENTER F_c

```
130 XEQ e
```

CALC S

```
131♦LBL 01
132 CF 02
133♦LBL 02
134 9
135 STO 01
136 42
137 STO 58
138 XEQ d
139 RCL 02
140 FS? 03
141 GTO 01
142 RCL 09
143 /
144♦LBL 01
145 RCL 06
146 X↑2
147 /
148 .0567
149 RCL 03
150 *
151 2831
152 +
153 /
154 RCL 04
155 RCL 05
156 *
157 SQRT
158 /
159 STO 13
160 XEQ J
```

CALC d

```
161 XEQ e
162 FC? 02
163 CF 00
164 XEQ d
165 RCL 10
166 RCL 06
167 *
168 X↑2
169 RCL 07
170 X↑2
171 -
172 SQRT
173 STO 14
174 GTO 01
```

ENTER REQD BORE

```
175♦LBL "EVEN SZ"
176 10
177 STO 01
178 46
179 STO 58
180 XEQ e
```

CALC β

```
181 XEQ d
182 RCL 11
183 X↑2
184 RCL 07
185 X↑2
186 +
187 RCL 06
188 X↑2
189 /
190 SQRT
191 STO 15
192 XEQ J
```

ENTER S

```
193 XEQ e
```

CALC FLOW

```
194 XEQ d
195 RCL 12
196 RCL 13
197 /
198 RCL 02
199 *
200 STO 14
201♦LBL 01
202 XEQ J
203 FS? 00
204 STOP
205 XEQ a
206 RCL 14
207 VIEW X
208 BEEP
209 ADV
210 STOP
211 .END.
```

Program 9: Sequence of Calculations

1. Calculate S value.

$$S = \frac{W_m}{D^2\,(2831 + .0567T_f)\sqrt{G_f h_m}}$$

2. Calculate Reynolds number.

$$R_D = \frac{4.42\,W_m}{D\,\mu}$$

3. Calculate orifice bore.

$$d = \sqrt{(\beta D)^2 - (d_h)^2}\ \text{inches}$$

4. Calculate flowrate for an even-sized orifice.

$$\beta = \sqrt{\frac{d^2 - d_h^2}{D^2}}$$

$$\text{new flow} = \frac{\text{new } S}{\text{original } S} \times \text{original flowrate, pounds per hour}$$

Program 9: Nomenclature

D	Inside diameter of pipe, inches
d	Diameter of orifice bore, inches
d_h	Weep hole diameter, inches
F_c	Reynolds number correction factor, dimensionless
G_f	Specific gravity of liquid at flowing temperature, dimensionless
h_m	Maximum differential range, inches of water
S	Beta ratio index, dimensionless
T_f	Flowing temperature, °F
W_m	Maximum rate of flow, pounds per hour
μ	Absolute viscosity, centipoises
β	Beta ratio d/D, dimensionless

References

L. K. Spink, *The Principles and Practice of Flowmeter Engineering*, The Foxboro Company.

Typical Data

S Values for Lo-Loss Tube*

d/D	*S*	*d/D*	*S*	*d/D*	*S*
.35	.1048	.51	.2183	.67	.3873
.36	.1106	.52	.2268	.68	.4005
.37	.1167	.53	.2356	.69	.4147
.38	.1228	.54	.2446	.70	.4289
.39	.1292	.55	.2539	.71	.4442
.40	.1356	.56	.2634	.72	.4595
.41	.1423	.57	.2733	.73	.4761
.42	.1492	.58	.2832	.74	.4930
.43	.1561	.59	.2933	.75	.5111
.44	.1632	.60	.3041	.76	.5298
.45	.1705	.61	.3149	.77	.5493
.46	.1781	.62	.3260	.78	.5702
.47	.1857	.63	.3375	.79	.5919
.48	.1936	.64	.3493	.80	.6153
.49	.2016	.65	.3617	.81	.6401
.50	.2098	.66	.3741	.82	.6666

*Extracted from *The Principles and Practice of Flowmeter Engineering*, L. K. Spink, The Foxboro Company.

S Values and Radius of Quadrant-Edge Orifices*
Thickness at Throat = Radius, *r*

$\beta = \frac{d}{D}$	*S*	$\frac{r}{D}$	$\beta = \frac{d}{D}$	*S*	$\frac{r}{D}$	$\beta = \frac{d}{D}$	*S*	$\frac{r}{D}$	$\beta = \frac{d}{D}$	*S*	$\frac{r}{D}$
.20	.0305	.0198	.31	.0748	.0325	.42	.1407	.0492	.53	.237	.0781
	.0321	.0203		.0773	.0331		.1443	.0501		.243	.0801
.21	.0338	.0209	.32	.0798	.0338	.43	.1480	.0511	.54	.248	.0822
	.0355	.0214		.0824	.0344		.1518	.0520		.254	.0845
.22	.0372	.0220	.33	.0850	.0351	.44	.1556	.0530	.55	.260	.0869
	.0390	.0225		.0877	.0358		.1595	.0540		.266	.0895
.23	.0408	.0231	.34	.0904	.0364	.45	.1635	.0550	.56	.272	.0922
	.0426	.0236		.0931	.0371		.1675	.0561		.279	.0950
.24	.0445	.0242	.35	.0959	.0378	.46	.1716	.0572	.57	.285	.0980
	.0464	.0247		.0987	.0385		.1758	.0583		.292	.101
.25	.0484	.0253	.36	.1016	.0392	.47	.1801	.0595	.58	.298	.104
	.0504	.0259		.1045	.0400		.1844	.0607		.305	.108
.26	.0524	.0264	.37	.1075	.0407	.48	.1888	.0619	.59	.312	.113
	.0545	.0270		.1106	.0415		.1933	.0632		.319	.119
.27	.0566	.0276	.38	.1137	.0423	.49	.1978	.0646	.60	.326	.125
	.0587	.0282		.1169	.0431		.2024	.0660		.333	.132
.28	.0609	.0288	.39	.1201	.0439	.50	.2070	.0675	.61	.341	.141
	.0631	.0294		.1234	.0448		.212	.0691		.348	.152
.29	.0654	.0300	.40	.1267	.0456	.51	.217	.0708	.62	.356	.164
	.0677	.0306		.1301	.0465		.222	.0725		.364	.178
.30	.0700	.0312	.41	.1336	.0474	.52	.227	.0743	.63	.372	.192
	.0724	.0318		.1371	.0483		.232	.0762		.380	.205

*From Delft Report 1312M of Royal Dutch Shell Laboratory, Delft, Holland.

Program 10
Gas or Vapor Flow—Orifice Plate, Flange Taps

Program 10: User Instructions

a) For the TI program, enter 5 OP 17 for nonstandard partitioning (559.49 is the display of the required partitioning).
b) Initiate program, press A.
c) Enter:

1. Flowrate, pounds per hour	Press R/S
2. Flow temperature, °F	Press R/S
3. Flow pressure, PSIG	Press R/S
4. Specific weight, pounds per cubic foot	Press R/S
5. Differential range, inches of water	Press R/S
6. Pipe inside diameter, inches	Press R/S
7. Specific heat ratio C_p/C_v, dimensionless	Press R/S
8. Absolute viscosity, centipoises	Press R/S

d) Program calculates beta ratio (dimensionless) and orifice bore (inches).
e) If an even-sized orifice bore is required, press C and enter:

9. Required orifice bore	Press R/S

f) Program calculates beta ratio (dimensionless) and new flowrate (pounds per hour).

Notes:
1. The E subroutine is available to change data and recalculate.
2. If the orifice plate material is not 316SS or 304SS, see Table of Equal Thermal Expansion Temperatures for Various Orifice Plate Materials, page 162.
3. See Program 16 for specific weight calculation.

(Program 10 continued on next page)

Program 10: TI 59 Data Sheet

```
********************

  GAS ORIFICE  CALC
     FLNGE TAPS

********************

ENTR FLOW    PPH
       2500.
ENTR  TEMP    °F
        366.
ENTR PRSS PSIG
        150.
ENTR SPCFC    WT PPCF
       0.364
ENTR DIFF RANGE IN W
        100.
ENTR PIPE     ID   INS
       2.067

ENTR CP/CV
       1.332
ENTR  VISC    CP
       0.015
CALC BETA
 .6366489413
CALC  ORIFICE     INS
 1.315953362

********************

ENTR  ORIFICE     INS
       1.375
CALC BETA
 .6652152879
CALC FLOW    PPH
 2781.206417

********************
```

Program 10: TI 59 Register Loading

PARTITIONING
559.49

0.	00	3336242200.	24
0.	01	3335363600.	25
0.	02	37133336.	26
0.	03	2127312217.	27
0.	04	2415170000.	28
0.	05	32352421.	29
0.	06	32.292846	30
0.	07	0.2726	31
0.	08	221336.4039	32
0.	09	243136.3837	33
0.	10	2416.2524	34
0.	11	1533.233622	35
0.	12	4337.212019	36
0.	13	7321.183433	37
0.	14	37173033.17	38
1417371300.	15	333323.1635	39
42243615.	16	2127324300.	40
1533631542.	17	46.15	41
3324331700.	18	46.292833	42
24310043.	19	47.292833	43
3513312217.	20	46.4039	44
1624212100.	21	5151515151.	45
33331521.	22	1513271500.	46
3633152115.	23	1731373500.	47
		0.	48
		0.	49

Program 10: TI 59 Listing

PRINT & STORE VARIABLES

```
000  76 LBL
001  10 E'
002  01  1
003  44 SUM
004  48  48
005  73 RC*
006  48  48
007  22 INV
008  59 INT
009  52 EE
010  22 INV
011  52 EE
012  67  EQ
013  19 D'
014  85  +
015  04  4
016  07  7
017  95  =
018  17 B'
019  69 OP
020  21  21
021  73 RC*
022  01  01
023  87 IFF
024  00  00
025  00  00
026  30  30
027  91 R/S
028  72 ST*
029  01  01
030  99 PRT
031  61 GTO
032  10 E'
```

PRINT LINES

```
033  76 LBL
034  19 D'
035  01  1
036  44 SUM
037  48  48
038  73 RC*
039  48  48
040  76 LBL
041  17 B'
042  42 STO
043  49  49
044  73 RC*
045  49  49
046  69 OP
047  01  01
048  18 C'
049  69 OP
050  02  02
051  18 C'
052  69 OP
053  03  03
054  18 C'
055  69 OP
056  04  04
057  69 OP
058  05  05
059  92 RTN
```

DECODE LINES

```
060  76 LBL
061  18 C'
062  01  1
063  00  0
064  00  0
065  48 EXC
066  49  49
067  22 INV
068  59 INT
069  49 PRD
070  49  49
071  73 RC*
072  49  49
073  92 RTN
```

PRINT LINE OF STARS

```
074  76 LBL
075  16 A'
076  93  .
077  00  0
078  02  2
079  02  2
080  35 1/X
081  98 ADV
082  17 B'
083  98 ADV
084  92 RTN
```

ITERATE FOR β

```
085  76 LBL
086  12  B
087  93  .
088  03  3
089  06  6
090  04  4
091  85  +
092  93  .
093  00  0
094  07  7
095  06  6
096  55  ÷
097  43 RCL
098  07  07
099  34 √X
100  95  =
101  42 STO
102  13  13
103  76 LBL
104  22 INV
105  29 CP
106  93  .
107  05  5
108  09  9
109  09  9
110  03  3
111  85  +
112  93  .
113  00  0
114  00  0
115  07  7
116  55  ÷
117  43 RCL
118  07  07
119  95  =
120  42 STO
121  12  12
122  93  .
123  00  0
124  07  7
125  85  +
126  93  .
127  05  5
128  55  ÷
129  43 RCL
130  07  07
131  75  -
132  43 RCL
133  14  14
134  66 PAU
135  95  =
136  22 INV
137  77  GE
138  67  EQ
139  45 YX
140  02  2
141  93  .
142  05  5
143  65  ×
144  53  (
145  01  1
146  93  .
147  06  6
148  75  -
149  43 RCL
150  07  07
151  35 1/X
```

152	54	)
153	45	Y^X
154	05	5
155	65	×
156	93	.
157	04	4
158	95	=
159	44	SUM
160	12	12
161	76	LBL
162	67	EQ
163	93	.
164	05	5
165	75	-
166	43	RCL
167	14	14
168	95	=
169	22	INV
170	77	GE
171	68	NOP
172	45	Y^X
173	01	1
174	93	.
175	05	5
176	65	×
177	53	(
178	93	.
179	00	0
180	00	0
181	09	9
182	85	+
183	93	.
184	00	0
185	03	3
186	04	4
187	55	÷
188	43	RCL
189	07	07
190	95	=
191	22	INV
192	44	SUM
193	12	12
194	76	LBL
195	68	NOP
196	43	RCL
197	14	14
198	75	-
199	93	.
200	07	7
201	95	=
202	22	INV
203	77	GE
204	69	OP
205	45	Y^X
206	02	2
207	93	.
208	05	5
209	65	×
210	53	(
211	06	6
212	05	5
213	55	÷
214	43	RCL
215	07	07
216	33	X^2
217	85	+
218	03	3
219	54	)
220	95	=
221	44	SUM
222	12	12
223	76	LBL
224	69	OP
225	01	1
226	05	5
227	52	EE
228	06	6
229	94	+/-
230	42	STO
231	49	49
232	32	X:T
233	43	RCL
234	12	12
235	65	×
236	02	2
237	65	×
238	43	RCL
239	14	14
240	85	+
241	43	RCL
242	13	13
243	65	×
244	43	RCL
245	14	14
246	45	Y^X
247	05	5
248	65	×
249	06	6
250	95	=
251	42	STO
252	48	48
253	43	RCL
254	12	12
255	65	×
256	43	RCL
257	14	14
258	33	X^2
259	85	+
260	43	RCL
261	13	13
262	65	×
263	43	RCL
264	14	14
265	45	Y^X
266	06	6
267	95	=
268	55	÷
269	53	(
270	01	1
271	85	+
272	43	RCL
273	49	49
274	65	×
275	53	(
276	08	8
277	03	3
278	00	0
279	75	-
280	05	5
281	52	EE
282	03	3
283	65	×
284	43	RCL
285	14	14
286	85	+
287	09	9
288	52	EE
289	03	3
290	65	×
291	43	RCL
292	14	14
293	33	X^2
294	75	-
295	04	4
296	02	2
297	00	0
298	00	0
299	65	×
300	43	RCL
301	14	14
302	45	Y^X
303	03	3
304	85	+
305	05	5
306	03	3
307	00	0
308	55	÷
309	43	RCL
310	07	07
311	34	$\sqrt{X}$
312	54	)
313	42	STO
314	49	49
315	54	)
316	95	=
317	42	STO
318	11	11
319	22	INV
320	52	EE
321	87	IFF
322	01	01

323	25	CLR
324	75	-
325	43	RCL
326	01	01
327	95	=
328	55	÷
329	43	RCL
330	48	48
331	95	=
332	22	INV
333	44	SUM
334	14	14
335	50	I×I
336	77	GE
337	22	INV
338	43	RCL
339	14	14
340	92	RTN

CALC F_R

341	76	LBL
342	14	D
343	43	RCL
344	14	14
345	45	Y^X
346	04	4
347	65	×
348	93	.
349	03	3
350	05	5
351	85	+
352	93	.
353	04	4
354	01	1
355	95	=
356	65	×
357	43	RCL
358	06	06
359	55	÷
360	03	3
361	09	9
362	93	.
363	06	6
364	55	÷
365	43	RCL
366	08	08
367	55	÷
368	53	(
369	43	RCL
370	04	04
371	85	+
372	01	1
373	05	5
374	54	)
375	95	=
376	94	+/-
377	85	+
378	01	1
379	95	=
380	22	INV
381	49	PRD
382	01	01
383	43	RCL
384	14	14
385	65	×
386	43	RCL
387	07	07
388	95	=
389	33	X^2
390	65	×
391	43	RCL
392	49	49
393	65	×
394	43	RCL
395	09	09
396	55	÷
397	04	4
398	93	.
399	04	4
400	02	2
401	55	÷
402	43	RCL
403	02	02
404	85	+
405	01	1
406	95	=
407	22	INV
408	49	PRD
409	01	01
410	92	RTN

MAIN PROGRAM
ENTER DATA

411	76	LBL
412	11	A
413	29	CP
414	93	.
415	07	7
416	42	STO
417	14	14
418	01	1
419	42	STO
420	01	01
421	02	2
422	09	9
423	42	STO
424	48	48
425	16	A'
426	19	D'
427	19	D'
428	16	A'
429	10	E'
430	22	INV
431	86	STF
432	00	00

CALC $K_o\beta^2$

433	76	LBL
434	43	RCL
435	43	RCL
436	02	02
437	55	÷
438	43	RCL
439	07	07
440	33	X^2
441	55	÷
442	53	(
443	03	3
444	05	5
445	08	8
446	93	.
447	05	5
448	85	+
449	93	.
450	00	0
451	00	0
452	07	7
453	65	×
454	43	RCL
455	03	03
456	54	)
457	55	÷
458	53	(
459	43	RCL
460	05	05
461	65	×
462	43	RCL
463	06	06
464	54	)
465	34	$\sqrt{X}$
466	95	=
467	42	STO
468	01	01
469	42	STO
470	10	10

CALC β

471	12	B
472	14	D
473	12	B
474	43	RCL
475	10	10
476	42	STO
477	01	01

```
478  14  D
479  12  B
480  99  PRT
```

CALC d

```
481  43  RCL
482  42  42
483  17  B'
484  43  RCL
485  14  14
486  65  ×
487  43  RCL
488  07  07
489  95  =
490  99  PRT
491  32  X:T
492  16  A'
493  98  ADV
494  32  X:T
495  91  R/S
```

ENTER REQD ORIFICE

```
496  76  LBL
497  13  C
498  32  X:T
499  86  STF
500  01  01
501  43  RCL
502  43  43
503  17  B'
504  32  X:T
505  91  R/S
506  99  PRT
```

CALC β

```
507  55  ÷
508  43  RCL
509  07  07
510  95  =
511  42  STO
512  14  14
513  43  RCL
514  41  41
515  17  B'
516  43  RCL
517  14  14
518  99  PRT
```

CALC FLOW

```
519  61  GTO
520  12  B
521  76  LBL
522  25  CLR
523  22  INV
524  86  STF
525  01  01
526  43  RCL
527  44  44
528  17  B'
529  43  RCL
530  11  11
531  55  ÷
532  43  RCL
533  01  01
534  65  ×
535  43  RCL
536  02  02
537  61  GTO
538  04  04
539  89  89
```

RE-ENTER VARIABLES

```
540  76  LBL
541  15  E
542  99  PRT
543  85  +
544  01  1
545  95  =
546  42  STO
547  01  01
548  73  RC*
549  01  01
550  91  R/S
551  72  ST*
552  01  01
553  99  PRT
554  98  ADV
555  86  STF
556  00  00
557  91  R/S
558  61  GTO
559  43  RCL
```

Program 10: HP 41CV Data Sheet

```
************

ORIFICE   GAS
FLANGE   TAPS

************

ENTER FLOW  PPH
      2,500.0000    ***
ENTER TEMP DEG F
        366.0000    ***
ENTER PRSS PSIG
        150.0000    ***
ENTER DENSITY PPCF
          0.3640    ***
ENTER DIFF RANGE INS H2O
        100.0000    ***
ENTER PIPE ID INS
          2.0670    ***
ENTER CP/CV
          1.3320    ***
ENTER VISCOSITY cP
          0.0150    ***
CALC   BETA
RATIO
          0.6366    ***
CALC  ORIFICE
 BORE    INS
          1.3160    ***

************

                    1.3160

ENTER REQD ORIFICE  INS
          1.3750    ***
CALC   BETA
RATIO
          0.6652    ***
CALC    FLOW
PPH
      2,781.2064    ***

************
```

Program 10: HP 41CV Register Loading

SIZE 080

```
R00=  0.000000
R01=  0.000000
R02=  0.000000
R03=  0.000000
R04=  0.000000
R05=  0.000000
R06=  0.000000
R07=  0.000000
R08=  0.000000
R09=  0.000000
R10=  0.000000
R11=  0.000000
R12=  0.000000
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  0.000000
R17=  0.000000
R18=  0.000000
R19=  0.000000
R20=  0.000000
R21=  0.000000
R22=  0.000000
R23=  0.000000
R24=  0.000000
R25= "ORIFIC"
R26= "E  GAS"
R27= "FLANGE"
R28= "  TAPS"
R29= "FLOW  "
R30=  0.000000
R31=  25.262728
R32=  57.295000
R33=  57.515200
R34=  57.535400
R35=  57.606100
R36=  57.626364
R37=  57.656600
R38=  57.670000
R39=  57.686900
R40=  0.000000
R41=  56.707100
R42=  75.767273
R43=  57.747673
R44=  0.000000
R45=  56.707100
R46=  56.295000
R47=  0.000000
R48=  0.000000
R49=  0.000000
R50= "PPH   "
R51= "TEMP D"
R52= "EG F  "
R53= "PRSS P"
R54= "SIG   "
R55= "******"
R56= "CALC  "
R57= "ENTER "
R58=  0.000000
R59=  0.000000
R60= "DENSIT"
R61= "Y PPCF"
R62= "DIFF R"
R63= "ANGE I"
R64= "NS H2O"
R65= "PIPE I"
R66= "D INS "
R67= "CP/CV "
R68= "VISCOS"
R69= "ITY cP"
R70= "BETA  "
R71= "RATIO "
R72= " BORE "
R73= "  INS "
R74= "REQD O"
R75= "CALC O"
R76= "RIFICE"
R77=  0.000000
R78=  0.000000
R79=  0.000000
```

Program 10: HP 41CV Listing

SUBROUTINES

```
01♦LBL "FT GAS"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 GTO d
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53 .7
54 STO 14
55 RCL IND 01
56♦LBL 01
57 XEQ J
58 GTO e
```

RE-ENTER VARIABLES

```
59♦LBL "REENTER"
60 ADV
```

```
61 1
62 +
63 STO 01
64 RCL IND 01
65 XEQ J
66 STOP
67 XEQ J
68 STO IND 01
69 ADV
70 SF 00
71 SF 02
72 STOP
73 GTO 02
```

BYPASS PRINTER

```
74♦LBL J
75 FC? 55
76 GTO 01
77 PRX
78 RTN
79♦LBL 01
80 VIEW X
81 RTN
```

ITERATE FOR β

```
82♦LBL B
83 .076
84 RCL 07
85 SQRT
86 /
87 .364
88 +
89 STO 13
90♦LBL F
91 .007
92 RCL 07
93 /
94 .5993
95 +
96 STO 12
97 .5
98 RCL 07
99 /
100 .07
101 +
102 RCL 14
103 PSE
104 -
105 0
106 X<>Y
107 X<=Y?
108 GTO 01
109 2.5
110 Y↑X
111 1.6
112 RCL 07
113 1/X
114 -
115 5
116 Y↑X
117 .4
118 *
119 *
120 ST+ 12
121♦LBL 01
122 .5
123 RCL 14
124 -
125 0
126 X<>Y
127 X<=Y?
128 GTO 01
129 1.5
130 Y↑X
131 .09034
132 RCL 07
133 /
134 +
135 *
136 ST- 12
137♦LBL 01
138 RCL 14
139 .7
140 -
141 0
142 X<>Y
143 X<=Y?
144 GTO 01
145 2.5
146 Y↑X
147 65
148 RCL 07
149 X↑2
150 /
151 3
152 +
153 *
154 ST+ 12
155♦LBL 01
156 RCL 12
157 2
158 *
159 RCL 14
160 *
161 RCL 14
162 5
163 Y↑X
164 6
165 *
166 RCL 13
167 *
168 +
169 STO 23
170 RCL 12
171 RCL 14
172 X↑2
173 *
174 RCL 13
175 RCL 14
176 6
177 Y↑X
178 *
179 +
180 830
181 RCL 14
182 5000
183 *
184 -
185 9000
186 RCL 14
187 X↑2
188 *
189 +
190 4200
191 RCL 14
192 X↑2
193 *
194 RCL 14
195 *
196 -
197 530
198 RCL 07
199 SQRT
200 /
201 +
202 STO 24
203 .000015
204 *
205 1
206 +
207 /
208 STO 11
209 FS? 01
210 GTO G
211 RCL 16
212 -
213 RCL 23
214 /
215 ST- 14
216 ABS
217 .000015
218 X<>Y
219 X>Y?
220 GTO F
221 RCL 14
222 RTN
```

CALC F_R

```
223♦LBL D
224 RCL 14
225 4
226 Y↑X
```

```
227 .35
228 *
229 .41
230 +
231 RCL 06
232 *
233 39.6
234 /
235 RCL 08
236 /
237 RCL 04
238 15
239 +
240 /
241 CHS
242 1
243 +
244 ST/ 16
245 RCL 14
246 RCL 07
247 *
248 X↑2
249 RCL 24
250 *
251 RCL 09
252 *
253 4.42
254 /
255 RCL 02
256 /
257 1
258 +
259 ST/ 16
260 RTN
```

MAIN PROGRAM ENTER DATA

```
261♦LBL A
262 1
263 STO 01
264 30
265 STO 58
266 XEQ a
267 XEQ d
268 XEQ a
269 XEQ e
270 CF 00
271♦LBL 02
272 41
273 STO 58
```

CALC $K_o\beta^2$

```
274 RCL 02
275 RCL 07
276 X↑2
277 /
278 358.5
279 RCL 03
280 .007
281 *
282 +
283 /
284 RCL 05
285 RCL 06
286 *
287 SQRT
288 /
289 STO 16
290 STO 10
```

CALC β

```
291 XEQ B
292 XEQ D
293 XEQ B
294 RCL 10
295 STO 16
296 XEQ D
297 XEQ B
298 XEQ J
```

CALC d

```
299 XEQ d
300 RCL 14
301 RCL 07
302 *
303 STO 19
304 GTO 01
```

ENTER REQD BORE

```
305♦LBL "EVEN SZ"
306 SF 01
307 14
308 STO 01
309 42
310 STO 58
311 XEQ e
```

CALC β

```
312 RCL 15
313 RCL 07
314 /
315 STO 14
316 XEQ J
```

CALC FLOW

```
317 GTO B
318♦LBL C
319 CF 01
320 XEQ d
321 RCL 11
322 RCL 16
323 /
324 RCL 02
325 *
326 STO 19
327♦LBL 01
328 XEQ J
329 FS? 00
330 STOP
331 XEQ a
332 CF 02
333 RCL 19
334 VIEW X
335 BEEP
336 ADV
337 STOP
338 .END.
```

Program 10: Sequence of Calculations

1. Calculate $K_o\beta^2$ value.

$$K_o\beta^2 = \frac{W_m}{D^2(358.5 + .007T_f)\sqrt{\gamma_f h_m}}$$

2. Iterate to find uncorrected beta ratio.

$$K_o\beta^2 = \beta^2\left[\left(0.5993 + \frac{0.007}{D}\right) + \left(0.364 + \frac{0.076}{\sqrt{D}}\right)\beta^4\right.$$

$$+ 0.4\left(1.6 - \frac{1}{D}\right)^5$$

$$\left(0.07 + \frac{0.5}{D} - \beta\right)^{5/2}\left(0.009 + \frac{0.034}{D}\right)$$

$$(0.5 - \beta)^{3/2} + \left(\frac{65}{D^2} + 3\right)$$

$$\left.(\beta - 0.7)^{5/2}\right] \div \left[1 + 0.000015\,(830 - 5000\beta + 9000\beta^2\right.$$

$$\left.\left. - 4200\beta^3 + \frac{530}{\sqrt{D}}\right)\right]$$

Any negative factor, such as $(\beta - 0.7)^{5/2}$ when β is less than 0.7, shall be taken as equal to zero, and thus the whole term $(65/D^2 + 3)(\beta - 0.7)^{5/2}$ will drop out of the equation.

Let fx equal the equation in step 2—$K_o\beta^2$, and let

$$f^1x = 2\left(\left(.5993 + \frac{.007}{D}\right) + 4\left(1.6 - \frac{1}{D}\right)^5\right.$$

$$\left(.07 + \frac{5}{D} - \beta\right)^{5/2} - \left(.009 + \frac{.034)}{D}\right)$$

$$(0.5 - \beta)^{3/2} + \left(\frac{65}{D^2} + 3\right)(\beta - .7)^{5/2}\,\beta$$

$$+ 6\left(.364 + \frac{.076}{\sqrt{D}}\right)\beta^6$$

Start with $\beta = 0.7$ and calculate fx/f^1x. If greater than 0.000015, subtract fx/f^1x from current value of β and repeat until the error is less than 0.000015.

3. Calculate the expansion factor.

$$Y = 1 - \frac{(.41 + .35\beta^4)h_m}{39.6\ kP_f}$$

4. Divide $K_o\beta^2$ by Y.
5. Calculate the Reynolds number correction factor.

$$F_r = 1 + \left(830 - 5000\beta + 9000\beta^3 - 4200\ \beta^3 + \frac{530}{\sqrt{D}}\right)$$

$$\cdot \frac{(D\beta)^2 \mu_{cp}}{4.42\ W_m}$$

6. Divide $K_o\beta^2$ by F_r.
7. Repeat step 2 to find corrected beta ratio.
8. Repeat steps 3, 4, 5, and 6 using corrected beta ratio.
9. Repeat step 2 for final beta ratio.
10. Calculate orifice bore.

$$d = BD \text{ inches}$$

11. Calculate flowrate for an even-sized orifice bore.

$$\beta = \frac{d}{D}$$

Calculate $K_o\beta^2$ using the equation in step 2.

$$\text{new flow} = \frac{\text{new } K_o\beta^2}{\text{original } K_o\beta^2} \times \text{original flow, pounds per hour}$$

Program 10: Nomenclature

D Inside diameter of pipe, inches
d Bore diameter of primary device, inches
F_r Reynolds number correction factor for steam, vapor, or gas, dimensionless
h_m Maximum differential or range of differential gauge, inches of water, dry calibrated

K_o Coefficient of discharge, including velocity of approach at a hypothetical Reynolds number of infinity, dimensionless
k Ratio of specific heats C_p/C_r, dimensionless
P_f Flowing pressure, PSIA
T_f Flowing temperature, °F
W_m Maximum rate of flow, pounds per hour
Y Expansion factor, dimensionless
β Diameter ratio d/D, dimensionless
γ_f Specific weight at flowing conditions, pounds per cubic foot
μ_{cp} Absolute viscosity, centipoises

References

L. K. Spink, *The Principles and Practice of Flowmeter Engineering*, The Foxboro Company.

Program 11
Gas or Vapor Flow—Orifice Plate, Pipe Taps

Program 11: User Instructions

a) For the TI program, enter 5 OP 17 for nonstandard partitioning (559.49).
b) Initiate program, press A.
c) Enter:
   1. Flowrate, pounds per hour — Press R/S
   2. Flow temperature, °F — Press R/S
   3. Flow pressure, PSIG — Press R/S
   4. Specific weight, pounds per cubic foot — Press R/S
   5. Differential range, inches of water — Press R/S
   6. Pipe inside diameter, inches — Press R/S
   7. Specific heat ratio C_p/C_v, dimensionless — Press R/S
   8. Absolute viscosity, centipoises — Press R/S
d) Program calculates beta ratio (dimensionless) and orifice bore (inches).
e) If an even-sized orifice bore is required, press C and enter:
   9. Required orifice bore, inches — Press R/S
f) Program calculates beta ratio (dimensionless) and new flowrate (pounds per hour).

Notes:
1. The E subroutine is available to change data and recalculate.
2. If the orifice plate material is not 316SS or 304SS see Table of Equal Thermal Expansion Temperatures for Various Orifice Plate Materials, page 162.
3. See Program 16 for specific weight calculation.

Program 11: TI 59 Data Sheet

```
********************

  GAS ORIFICE  CALC
     PIPE  TAPS

********************

ENTR FLOW   PPH
        2500.
ENTR  TEMP   °F
         366.
ENTR PRSS PSIG
         150.
ENTR SPCFC   WT PPCF
        0.364
ENTR DIFF RANGE IN W
         100.
ENTR PIPE    ID  INS
        2.067
ENTR CP/CV
        1.332
ENTR  VISC   CP
        0.015
CALC BETA
 .5798120941
CALC  ORIFICE    INS
 1.198471598

********************

ENTR  ORIFICE    INS
         1.25
CALC BETA
 .6047411708
CALC FLOW    PPH
 2817.176663

********************
```

Program 11: TI 59 Register Loading

PARTITIONING
479.59

0.	00	1417371300.	15
0.	01	42243615.	16
0.	02	1533631542.	17
0.	03	3324331700.	18
0.	04	24310043.	19
0.	05	3513312217.	20
0.	06	1624212100.	21
0.	07	33331521.	22
0.	08	3633152115.	23
0.	09	3336242200.	24
0.	10	3335363600.	25
0.	11	37133336.	26
0.	12	3324331700.	27
0.	13	2415170000.	28
0.	14	32352421.	29
		32.292846	30
		0.2726	31

221336.4039	32	46.15	41
243136.3837	33	46.292833	42
2416.2524	34	47.292833	43
1533.233622	35	46.4039	44
4337.212019	36	5151515151.	45
7321.183433	37	1513271500.	46
37173033.17	38	1731373500.	47
333323.1635	39	0.	48
2127324300.	40	0.	49

Program 11: TI 59 Listing

SUBROUTINES PRINT & STORE VARIABLES

```
000  76 LBL
001  10 E'
002  01  1
003  44 SUM
004  48  48
005  73 RC*
006  48  48
007  22 INV
008  59 INT
009  52 EE
010  22 INV
011  52 EE
012  67  EQ
013  19 D'
014  85  +
015  04  4
016  07  7
017  95  =
018  17 B'
019  69 OP
020  21  21
021  73 RC*
022  01  01
023  87 IFF
024  00  00
025  00  00
026  30  30
027  91 R/S
028  72 ST*
029  01  01
030  99 PRT
031  61 GTO
032  10 E'
```

PRINT LINES

```
033  76 LBL
034  19 D'
035  01  1
036  44 SUM
037  48  48
038  73 RC*
039  48  48
040  76 LBL
041  17 B'
042  42 STO
043  49  49
044  73 RC*
045  49  49
046  69 OP
047  01  01
048  18 C'
049  69 OP
050  02  02
051  18 C'
052  69 OP
053  03  03
054  18 C'
055  69 OP
056  04  04
057  69 OP
058  05  05
059  92 RTN
```

DECODE LINES

```
060  76 LBL
061  18 C'
062  01  1
063  00  0
064  00  0
065  48 EXC
066  49  49
067  22 INV
068  59 INT
069  49 PRD
070  49  49
071  73 RC*
072  49  49
073  92 RTN
```

PRINT LINE OF STARS

```
074  76 LBL
075  16 A'
076  93  .
077  00  0
078  02  2
079  02  2
080  35 1/X
081  98 ADV
082  17 B'
083  98 ADV
084  92 RTN
```

ITERATE FOR β

```
085  76 LBL
086  12  B
087  93  .
088  09  9
089  03  3
090  05  5
091  85  +
092  93  .
093  02  2
094  02  2
095  05  5
096  55  ÷
097  43 RCL
098  07  07
099  95  =
100  42 STO
101  13  13
102  76 LBL
103  22 INV
104  29 CP
105  93  .
106  05  5
107  09  9
108  02  2
109  05  5
110  85  +
111  93  .
112  00  0
113  01  1
114  08  8
115  02  2
116  55  ÷
117  43 RCL
118  07  07
119  95  =
120  42 STO
```

121	12	12	179	43	RCL	237	93	.
122	93	.	180	14	14	238	03	3
123	02	2	181	45	Y^X	239	05	5
124	05	5	182	01	1	240	65	×
125	75	-	183	03	3	241	43	RCL
126	43	RCL	184	85	+	242	14	14
127	14	14	185	43	RCL	243	45	Y^X
128	66	PAU	186	48	48	244	01	1
129	95	=	187	65	×	245	04	4
130	22	INV	188	04	4	246	95	=
131	77	GE	189	65	×	247	55	÷
132	68	NOP	190	43	RCL	248	53	(
133	45	Y^X	191	14	14	249	01	1
134	02	2	192	45	Y^X	250	85	+
135	93	.	193	03	3	251	43	RCL
136	05	5	194	85	+	252	49	49
137	65	×	195	43	RCL	253	65	×
138	01	1	196	12	12	254	53	(
139	93	.	197	65	×	255	09	9
140	04	4	198	02	2	256	00	0
141	03	3	199	65	×	257	05	5
142	55	÷	200	43	RCL	258	75	-
143	43	RCL	201	14	14	259	05	5
144	07	07	202	85	+	260	00	0
145	34	√X	203	43	RCL	261	00	0
146	95	=	204	13	13	262	00	0
147	44	SUM	205	65	×	263	65	×
148	12	12	206	43	RCL	264	43	RCL
149	76	LBL	207	14	14	265	14	14
150	68	NOP	208	45	Y^X	266	85	+
151	93	.	209	06	6	267	09	9
152	04	4	210	65	×	268	00	0
153	04	4	211	07	7	269	00	0
154	75	-	212	95	=	270	00	0
155	93	.	213	48	EXC	271	65	×
156	00	0	214	48	48	272	43	RCL
157	06	6	215	65	×	273	14	14
158	55	÷	216	43	RCL	274	33	X²
159	43	RCL	217	14	14	275	75	-
160	07	07	218	45	Y^X	276	04	4
161	95	=	219	04	4	277	02	2
162	42	STO	220	85	+	278	00	0
163	48	48	221	43	RCL	279	00	0
164	93	.	222	12	12	280	65	×
165	00	0	223	65	×	281	43	RCL
166	00	0	224	43	RCL	282	14	14
167	00	0	225	14	14	283	45	Y^X
168	00	0	226	33	X²	284	03	3
169	01	1	227	85	+	285	85	+
170	05	5	228	43	RCL	286	08	8
171	42	STO	229	13	13	287	07	7
172	49	49	230	65	×	288	05	5
173	32	X:T	231	43	RCL	289	55	÷
174	01	1	232	14	14	290	43	RCL
175	08	8	233	45	Y^X	291	07	07
176	93	.	234	07	7	292	54	)
177	09	9	235	85	+	293	42	STO
178	65	×	236	01	1	294	49	49

295	54	)
296	95	=
297	42	STO
298	11	11
299	87	IFF
300	01	01
301	25	CLR
302	75	-
303	43	RCL
304	01	01
305	95	=
306	55	÷
307	43	RCL
308	48	48
309	95	=
310	22	INV
311	44	SUM
312	14	14
313	50	I×I
314	77	GE
315	22	INV
316	43	RCL
317	14	14
318	92	RTN

CALC F_R

319	76	LBL
320	14	D
321	43	RCL
322	14	14
323	45	Y^X
324	04	4
325	65	×
326	93	.
327	03	3
328	05	5
329	85	+
330	93	.
331	04	4
332	01	1
333	95	=
334	65	×
335	43	RCL
336	06	06
337	55	÷
338	03	3
339	09	9
340	93	.
341	06	6
342	55	÷
343	43	RCL
344	08	08
345	55	÷
346	53	(
347	43	RCL
348	04	04
349	85	+
350	01	1
351	05	5
352	54	)
353	95	=
354	94	+/-
355	85	+
356	01	1
357	95	=
358	22	INV
359	49	PRD
360	01	01
361	43	RCL
362	14	14
363	65	×
364	43	RCL
365	07	07
366	95	=
367	33	X^2
368	65	×
369	43	RCL
370	49	49
371	65	×
372	43	RCL
373	09	09
374	55	÷
375	04	4
376	93	.
377	04	4
378	02	2
379	55	÷
380	43	RCL
381	02	02
382	85	+
383	01	1
384	95	=
385	22	INV
386	49	PRD
387	01	01
388	92	RTN

MAIN PROGRAM
ENTER DATA

389	76	LBL
390	11	A
391	29	CP
392	87	IFF
393	00	00
394	44	SUM
395	93	.
396	07	7
397	42	STO
398	14	14
399	76	LBL
400	44	SUM
401	01	1
402	42	STO
403	01	01
404	02	2
405	09	9
406	42	STO
407	48	48
408	16	A'
409	19	D'
410	19	D'
411	16	A'
412	10	E'
413	22	INV
414	86	STF
415	00	00

CALC $K_o\beta^2$

416	76	LBL
417	43	RCL
418	43	RCL
419	02	02
420	55	÷
421	43	RCL
422	07	07
423	33	X^2
424	55	÷
425	53	(
426	03	3
427	05	5
428	08	8
429	93	.
430	05	5
431	85	+
432	93	.
433	00	0
434	00	0
435	07	7
436	65	×
437	43	RCL
438	03	03
439	54	)
440	55	÷
441	53	(
442	43	RCL
443	05	05
444	65	×
445	43	RCL
446	06	06
447	54	)
448	34	$\sqrt{X}$
449	95	=
450	42	STO
451	01	01
452	42	STO
453	10	10

CALC β

```
454  12  B
455  14  D
456  12  B
457  43  RCL
458  10  10
459  42  STO
460  01  01
461  14  D
462  12  B
463  99  PRT
```

CALC d

```
464  43  RCL
465  42  42
466  17  B'
467  43  RCL
468  14  14
469  65  ×
470  43  RCL
471  07  07
472  95  =
473  99  PRT
474  32  X:T
475  16  A'
476  98  ADV
477  32  X:T
478  91  R/S
```

ENTER REQD ORIFICE

```
479  76  LBL
480  13  C
481  32  X:T
482  86  STF
483  01  01
484  43  RCL
485  43  43
486  17  B'
487  32  X:T
488  91  R/S
489  99  PRT
```

CALC β

```
490  55  ÷
491  43  RCL
492  07  07
493  95  =
494  42  STO
495  14  14
496  43  RCL
497  41  41
498  17  B'
499  43  RCL
500  14  14
501  99  PRT
```

CALC FLOW

```
502  61  GTO
503  12  B
504  76  LBL
505  25  CLR
506  22  INV
507  86  STF
508  01  01
509  43  RCL
510  44  44
511  17  B'
512  43  RCL
513  11  11
514  55  ÷
515  43  RCL
516  01  01
517  65  ×
518  43  RCL
519  02  02
520  61  GTO
521  04  04
522  72  72
```

RE-ENTER VARIABLES

```
523  76  LBL
524  15  E
525  99  PRT
526  85  +
527  01  1
528  95  =
529  42  STO
530  01  01
531  73  RC*
532  01  01
533  91  R/S
534  72  ST*
535  01  01
536  99  PRT
537  98  ADV
538  86  STF
539  00  00
540  91  R/S
541  61  GTO
542  43  RCL
```

Program 11: HP 41CV Data Sheet

```
************

ORIFICE  GAS
*PIPE  TAPS*

************

ENTER FLOW PPH
      2,500.0000    ***
ENTER TEMP DEG F
        366.0000    ***
ENTER PRSS PSIG
        150.0000    ***
ENTER DENSITY PPCF
          0.3640    ***

ENTER DIFF RANGE INS H2O
        100.0000    ***
ENTER PIPE ID INS
          2.0670    ***
ENTER CP/CV
          1.3320    ***
ENTER VISCOSITY cP
          0.0150    ***
CALC  BETA
RATIO
          0.5798    ***
CALC ORIFICE
 BORE    INS
          1.1985    ***

*************

              1.1985

ENTER REQD ORIFICE  INS
          1.2500    ***
CALC  BETA
RATIO
          0.6047    ***
CALC  FLOW
PPH
      2,817.1767    ***

*************
```

Program 11: HP 41CV Register Loading

SIZE 080

```
R00=  0.000000
R01=  0.000000
R02=  0.000000
R03=  0.000000
R04=  0.000000
R05=  0.000000
R06=  0.000000
R07=  0.000000
R08=  0.000000
R09=  0.000000
R10=  0.000000
R11=  0.000000
R12=  0.000000
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  0.000000
R17=  0.000000
R18=  0.000000
R19=  0.000000
R20=  0.000000
R21=  0.000000
R22=  0.000000
R23=  0.000000
R24=  0.000000
R25= "ORIFIC"
R26= "E  GAS"
R27= "*PIPE "
R28= " TAPS*"
R29= "FLOW  "
R30=  0.000000
R31=  25.262728
R32=  57.295000
R33=  57.515200
R34=  57.535400
R35=  57.606100
R36=  57.626364
R37=  57.656600
R38=  57.670000
R39=  57.686900
R40=  0.000000
R41=  56.707100
R42=  75.767273
R43=  57.747673
R44=  0.000000
R45=  56.707100
R46=  56.295000
R47=  0.000000
R48=  0.000000
R49=  0.000000
R50= "PPH   "
R51= "TEMP D"
R52= "EG F  "
R53= "PRSS P"
R54= "SIG   "
R55= "******"
R56= "CALC  "
R57= "ENTER "
R58=  0.000000
R59=  0.000000
R60= "DENSIT"
R61= "Y PPCF"
R62= "DIFF R"
R63= "ANGE I"
R64= "NS H2O"
R65= "PIPE I"
R66= "D INS "
R67= "CP/CV "
R68= "VISCOS"
R69= "ITY cP"
R70= "BETA  "
R71= "RATIO "
R72= " BORE "
R73= "  INS "
R74= "REQD O"
R75= "CALC O"
R76= "RIFICE"
R77=  0.000000
R78=  0.000000
R79=  0.000000
```

Program 11: HP 41CV Listing

SUBROUTINES

```
01♦LBL "PT GAS"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 GTO d
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53 .7
54 STO 14
55 RCL IND 01
56♦LBL 01
57 XEQ J
58 GTO e
```

RE-ENTER VARIABLES

```
59♦LBL "REENTER"
60 ADV
61 1
62 +
```

```
63 STO 01
64 RCL IND 01
65 XEQ J
66 STOP
67 XEQ J
68 STO IND 01
69 ADV
70 SF 00
71 SF 02
72 STOP
73 GTO 02
```

BYPASS PRINTER

```
74♦LBL J
75 FC? 55
76 GTO 01
77 PRX
78 RTN
79♦LBL 01
80 VIEW X
81 RTN
```

ITERATE FOR β

```
82♦LBL B
83 .225
84 RCL 07
85 /
86 .935
87 +
88 STO 13
89♦LBL F
90 .0182
91 RCL 07
92 /
93 .5925
94 +
95 STO 12
96 .25
97 RCL 14
98 PSE
99 -
100 0
101 X<>Y
102 X<=Y?
103 GTO 01
104 2.5
105 Y↑X
106 1.43
107 *
108 RCL 07
109 SQRT
110 /
111 ST+ 12
112♦LBL 01
113 .06
114 RCL 07
115 /
116 CHS
117 .44
118 +
119 STO 23
120 18.9
121 RCL 14
122 13
123 Y↑X
124 *
125 RCL 14
126 3
127 Y↑X
128 RCL 23
129 *
130 4
131 *
132 +
133 RCL 12
134 2
135 *
136 RCL 14
137 *
138 +
139 RCL 14
140 6
141 Y↑X
142 7
143 *
144 RCL 13
145 *
146 +
147 STO 20
148 RCL 14
149 4
150 Y↑X
151 RCL 23
152 *
153 RCL 12
154 RCL 14
155 X↑2
156 *
157 +
158 RCL 14
159 7
160 Y↑X
161 RCL 13
162 *
163 +
164 RCL 14
165 14
166 Y↑X
167 1.35
168 *
169 +
170 9000
171 RCL 14
172 X↑2
173 *
174 905
175 +
176 5000
177 RCL 14
178 *
179 -
180 RCL 14
181 3
182 Y↑X
183 4200
184 *
185 -
186 875
187 RCL 07
188 /
189 +
190 STO 24
191 .000015
192 *
193 1
194 +
195 /
196 STO 11
197 FS? 01
198 GTO G
199 RCL 16
200 -
201 RCL 20
202 /
203 ST- 14
204 ABS
205 .000015
206 X<>Y
207 X>Y?
208 GTO F
209 RCL 14
210 RTN
```

CALC F_R

```
211♦LBL D
212 RCL 14
213 4
214 Y↑X
215 .35
216 *
217 .41
218 +
219 RCL 06
220 *
221 39.6
222 /
223 RCL 08
224 /
225 RCL 04
226 15
227 +
228 /
229 CHS
230 1
231 +
```

```
232 ST/ 16
233 RCL 14
234 RCL 07
235 *
236 X↑2
237 RCL 24
238 *
239 RCL 09
240 *
241 4.42
242 /
243 RCL 02
244 /
245 1
246 +
247 ST/ 16
248 RTN
```

MAIN PROGRAM
ENTER DATA

```
249♦LBL A
250 1
251 STO 01
252 30
253 STO 58
254 XEQ a
255 XEQ d
256 XEQ a
257 XEQ e
258 CF 00
259♦LBL 02
260 41
261 STO 58
```

CALC $K_o\beta^2$

```
262 RCL 02
263 RCL 07
264 X↑2
265 /
266 358.5
267 RCL 03
268 .007
269 *
270 +
271 /
272 RCL 05
273 RCL 06
274 *
275 SQRT
276 /
277 STO 16
278 STO 10
```

CALC β

```
279 XEQ B
280 XEQ D
281 XEQ B
282 RCL 10
283 STO 16
284 XEQ D
285 XEQ B
286 XEQ J
```

CALC d

```
287 XEQ d
288 RCL 14
289 RCL 07
290 *
291 STO 19
292 GTO 01
```

ENTER REQD BORE

```
293♦LBL "EVEN SZ"
294 SF 01
295 14
296 STO 01
297 42
298 STO 58
299 XEQ e
```

CALC β

```
300 RCL 15
301 RCL 07
302 /
303 STO 14
304 XEQ J
```

CALC FLOW

```
305 GTO B
306♦LBL G
307 CF 01
308 XEQ d
309 RCL 11
310 RCL 16
311 /
312 RCL 02
313 *
314 STO 19
315♦LBL 01
316 XEQ J
317 FS? 00
318 STOP
319 XEQ a
320 CF 02
321 RCL 19
322 VIEW X
323 BEEP
324 ADV
325 STOP
326 .END.
```

Program 11: Sequence of Calculations

1. Calculate $K_o\beta^2$ value.

$$K_o\beta^2 = \frac{W_m}{D^2\,(358.5 + .007T_f)\,\sqrt{\gamma_f h_m}}$$

2. Iterate to find uncorrected beta ratio, β.

$$K_o\beta^2 = \beta^2\left[0.5925 + \frac{0.0182}{D} + \left(0.440 - \frac{0.06}{D}\right)\beta^2\right.$$

$$+ \left(0.935 + \frac{0.225}{D}\right) \beta^5$$

$$+ 1.35\beta^{14} + \frac{1.43}{\sqrt{D}} (0.25 - \beta)^{5/2} \Bigg] \div \Bigg[1 + 0.000015$$

$$\left(905 - 5000\beta + 9000\beta^2 - 4200\beta^3 + \frac{875}{D}\right)\Bigg]$$

If $(.25 - \beta)$ is negative, the function is taken as zero. Let fx equal the equation in step 2 $-K_o\beta^2$, and let

$$f^1x = 2\left(.5925 + \frac{.0182}{D}\right)\beta + 7\left(.935 + \frac{.225}{D}\right)\beta^6$$

$$+ 4\left(.44 - \frac{.06}{D}\right)\beta^3 + \frac{1.43}{\sqrt{D}}(.25 - \beta)^{5/2}\beta^3 + 18.9\beta^{13}$$

Start with $\beta = 0.7$ and calculate fx/f^1x. If greater than 0.000015, subtract fx/f^1x from the current value of β and repeat until the error is less than 0.000015.

3. Calculate the expansion factor.

$$Y = 1 - \frac{(.41 + .35\beta^4)\, h_m}{39.6\, k\, P_f}$$

4. Divide $K_o\beta^2$ by Y.

5. Calculate the Reynolds number correction factor.

$$F_r = 1 + \left(905 - 5000\beta + 9000\beta^2 - 4200\beta^3 + \frac{875}{D}\right)$$

$$\cdot \frac{(DB)^2\, \mu_{cp}}{4.42\, W_m}$$

6. Divide $K_o\beta^2$ by F_r.
7. Repeat step 2 to find corrected beta ratio.
8. Repeat steps 3, 4, 5, and 6 using corrected beta ratio.
9. Repeat step 2 for final beta ratio.
10. Calculate orifice bore.

$$d = \beta D \text{ inches}$$

11. Calculate flowrate for an even-sized orifice bore.

$$\beta = \frac{d}{D}$$

Calculate $K_o\beta^2$ using the equation in step 2.

$$\text{new flow} = \frac{\text{new } K_o\beta^2}{\text{original } K_o\beta^2} \times \text{original flow, pounds per hour}$$

Program 11: Nomenclature

- D Inside diameter of pipe, inches
- d Bore diameter of primary device, inches
- F_r Reynolds number correction for steam, vapor, or gas, dimensionless
- h_m Maximum differential or range of differential gauge, inches of water, dry calibrated.
- K_o Coefficient of discharge, including velocity of approach at a hypothetical Reynolds number of infinity, dimensionless
- k Ratio of specific heats C_p/C_v, dimensionless
- P_f Flowing pressure, PSIA
- T_f Flowing temperature, °F
- W_m Maximum rate of flow, pounds per hour
- Y Expansion factor, dimensionless
- β Diameter ratio d/D dimensionless
- γ_f Specific weight at flowing conditions, pounds per cubic foot
- μ_{cp} Absolute viscosity, centipoises

References

L. K. Spink, *The Principles and Practice of Flowmeter Engineering*, The Foxboro Company.

Program 12
Gas or Vapor Flow—Orifice Plate, Corner Taps

Program 12: User Instructions

a) For the TI program, enter 5OP 17 for nonstandard partitioning.

b) Initiate program, press A.

c) Enter:

1. Flowrate, pounds per hour	Press R/S
2. Flow temperature, °F	Press R/S
3. Flow pressure, PSIG	Press R/S
4. Specific weight, pounds per cubic foot	Press R/S
5. Differential range, inches of water	Press R/S
6. Pipe inside diameter, inches	Press R/S
7. Specific heat ratio C_p/C_v, dimensionless	Press R/S
8. Absolute viscosity, centipoises	Press R/S

d) Program calculates beta ratio (dimensionless) and orifice bore (inches).

e) If an even-sized orifice bore is required, press C and enter:

9. Required orifice bore, inches	Press R/S

f) Program calculates beta ratio (dimensionless) and new flowrate (pounds per hour).

Notes:

1. The E subroutine is available to change data and recalculate.
2. If the orifice plate material is not 316SS or 304SS, see Table of Equal Thermal Expansion Temperatures for Various Orifice Plate Materials, page 162.
3. See Program 16 for specific weight calculation.

Program 12: TI 59 Data Sheet

```
********************

  GAS ORIFICE  CALC
     CORNR TAPS

********************

ENTR FLOW    PPH
        2500.
ENTR  TEMP    °F
         366.
ENTR PRSS PSIG
         150.
ENTR SPCFC   WT PPCF
        0.364
ENTR DIFF RANGE IN W
         100.
ENTR PIPE     ID  INS
        2.067

ENTR CP/CV
        1.332
ENTR  VISC    CP
        0.015
CALC BETA
 .6400921702
CALC  ORIFICE     INS
 1.323070516

********************

ENTR  ORIFICE     INS
        1.375
CALC BETA
 .6652152879
CALC FLOW    PPH
 2740.165873

********************
```

Program 12: TI 59 Register Loading

PARTITIONING
559.49

0.	00	3336242200.	24
0.	01	3335363600.	25
0.	02	37133336.	26
0.	03	1532353135.	27
0.	04	2415170000.	28
0.	05	32352421.	29
0.	06	32.292846	30
0.	07	0.2726	31
0.	08	221336.4039	32
0.	09	243136.3837	33
0.	10	2416.2524	34
0.	11	1533.233622	35
0.	12	4337.212019	36
0.	13	7321.183433	37
0.	14	37173033.17	38
1417371300.	15	333323.1635	39
42243615.	16	2127324300.	40
1533631542.	17	46.15	41
3324331700.	18	46.292833	42
24310043.	19	47.292833	43
3513312217.	20	46.4039	44
1624212100.	21	5151515151.	45
33331521.	22	1513271500.	46
3633152115.	23	1731373500.	47
		0.	48
		0.	49

Program 12: TI 59 Listing

SUBROUTINES
PRINT & STORE VARIABLES

```
000  76 LBL
001  10 E'
002  01  1
003  44 SUM
004  48  48
005  73 RC*
006  48  48
007  22 INV
008  59 INT
009  52 EE
010  22 INV
011  52 EE
012  67  EQ
013  19 D'
014  85  +
015  04  4
016  07  7
017  95  =
018  17 B'
019  69 OP
020  21  21
021  73 RC*
022  01  01
023  87 IFF
024  00  00
025  00  00
026  30  30
027  91 R/S
028  72 ST*
029  01  01
030  99 PRT
031  61 GTO
032  10 E'
```

PRINT LINES

```
033  76 LBL
034  19 D'
035  01  1
036  44 SUM
037  48  48
038  73 RC*
039  48  48
040  76 LBL
041  17 B'
042  42 STO
043  49  49
044  73 RC*
045  49  49
046  69 OP
047  01  01
048  18 C'
049  69 OP
050  02  02
051  18 C'
052  69 OP
053  03  03
054  18 C'
055  69 OP
056  04  04
057  69 OP
058  05  05
059  92 RTN
```

DECODE LINES

```
060  76  LBL
061  18  C'
062  01   1
063  00   0
064  00   0
065  48  EXC
066  49   49
067  22  INV
068  59  INT
069  49  PRD
070  49   49
071  73  RC*
072  49   49
073  92  RTN
```

PRINT LINE OF STARS

```
074  76  LBL
075  16  A'
076  93   .
077  00   0
078  02   2
079  02   2
080  35  1/X
081  98  ADV
082  17  B'
083  98  ADV
084  92  RTN
```

ITERATE FOR β

```
085  76  LBL
086  12   B
087  29  CP
088  93   .
089  06   6
090  00   0
091  00   0
092  04   4
093  42  STO
094  12   12
095  93   .
096  05   5
097  75   -
098  43  RCL
099  14   14
100  95   =
101  22  INV
102  77   GE
103  68  NOP
104  45  YX
105  01   1
106  93   .
107  05   5
108  65   ×
109  93   .
110  00   0
111  05   5
112  02   2
113  95   =
114  22  INV
115  44  SUM
116  12   12
117  76  LBL
118  68  NOP
119  43  RCL
120  14   14
121  75   -
122  93   .
123  07   7
124  95   =
125  22  INV
126  77   GE
127  69  OP
128  45  YX
129  53   (
130  05   5
131  55   ÷
132  03   3
133  54   )
134  65   ×
135  93   .
136  06   6
137  02   2
138  95   =
139  44  SUM
140  12   12
141  76  LBL
142  69  OP
143  93   .
144  00   0
145  00   0
146  00   0
147  00   0
148  01   1
149  05   5
150  32  X:T
151  43  RCL
152  12   12
153  65   ×
154  02   2
155  65   ×
156  43  RCL
157  14   14
158  66  PAU
159  85   +
160  02   2
161  93   .
162  01   1
163  65   ×
164  43  RCL
165  14   14
166  45  YX
167  05   5
168  95   =
169  42  STO
170  48   48
171  43  RCL
172  12   12
173  65   ×
174  43  RCL
175  14   14
176  33  X²
177  85   +
178  93   .
179  03   3
180  05   5
181  65   ×
182  43  RCL
183  14   14
184  45  YX
185  06   6
186  95   =
187  42  STO
188  11   11
189  87  IFF
190  01   01
191  25  CLR
192  75   -
193  43  RCL
194  01   01
195  95   =
196  55   ÷
197  43  RCL
198  48   48
199  95   =
200  22  INV
201  44  SUM
202  14   14
203  50  I×I
204  77   GE
205  12   B
206  43  RCL
207  11   11
208  55   ÷
209  43  RCL
210  14   14
211  45  YX
212  03   3
213  55   ÷
214  43  RCL
215  07   07
216  65   ×
217  53   (
218  93   .
```

```
219  00   0
220  00   0
221  02   2
222  85   +
223  93   .
224  00   0
225  02   2
226  06   6
227  65   ×
228  43  RCL
229  14   14
230  45  Y×
231  04   4
232  54   )
233  95   =
234  42  STO
235  49   49
236  43  RCL
237  14   14
238  92  RTN
```

CALC F_R

```
239  76  LBL
240  14   D
241  43  RCL
242  14   14
243  45  Y×
244  04   4
245  65   ×
246  93   .
247  03   3
248  05   5
249  85   +
250  93   .
251  04   4
252  01   1
253  95   =
254  65   ×
255  43  RCL
256  06   06
257  55   ÷
258  03   3
259  09   9
260  93   .
261  06   6
262  55   ÷
263  43  RCL
264  08   08
265  55   ÷
266  53   (
267  43  RCL
268  04   04
269  85   +
270  01   1
271  05   5
272  54   )
273  95   =
274  94  +/-
275  85   +
276  01   1
277  95   =
278  22  INV
279  49  PRD
280  01   01
281  43  RCL
282  14   14
283  65   ×
284  43  RCL
285  07   07
286  95   =
287  33  X²
288  65   ×
289  43  RCL
290  49   49
291  65   ×
292  43  RCL
293  09   09
294  55   ÷
295  04   4
296  93   .
297  04   4
298  02   2
299  55   ÷
300  43  RCL
301  02   02
302  85   +
303  01   1
304  95   =
305  22  INV
306  49  PRD
307  01   01
308  92  RTN
```

MAIN PROGRAM
ENTER DATA

```
309  76  LBL
310  11   A
311  29  CP
312  87  IFF
313  00   00
314  44  SUM
315  93   .
316  07   7
317  42  STO
318  14   14
319  76  LBL
320  44  SUM
321  01   1
322  42  STO
323  01   01
324  02   2
325  09   9
326  42  STO
327  48   48
328  16  A'
329  19  D'
330  19  D'
331  16  A'
332  10  E'
333  22  INV
334  86  STF
335  00   00
```

CALC $K_o\beta^2$

```
336  76  LBL
337  43  RCL
338  43  RCL
339  02   02
340  55   ÷
341  43  RCL
342  07   07
343  33  X²
344  55   ÷
345  53   (
346  03   3
347  05   5
348  08   8
349  93   .
350  05   5
351  85   +
352  93   .
353  00   0
354  00   0
355  07   7
356  65   ×
357  43  RCL
358  03   03
359  54   )
360  55   ÷
361  53   (
362  43  RCL
363  05   05
364  65   ×
365  43  RCL
366  06   06
367  54   )
368  34  √X
369  95   =
370  42  STO
371  01   01
372  42  STO
373  10   10
```

CALC β

```
374  12  B
375  14  D
376  12  B
377  43  RCL
378  10  10
379  42  STO
380  01  01
381  14  D
382  12  B
383  99  PRT
```

CALC d

```
384  43  RCL
385  42  42
386  17  B'
387  43  RCL
388  14  14
389  65  ×
390  43  RCL
391  07  07
392  95  =
393  99  PRT
394  32  X⇌T
395  16  A'
396  98  ADV
397  32  X⇌T
398  91  R/S
```

ENTER REQD ORIFICE

```
399  76  LBL
400  13  C
401  32  X⇌T
402  86  STF
403  01  01
404  43  RCL
405  43  43
406  17  B'
407  32  X⇌T
408  91  R/S
409  99  PRT
```

CALC β

```
410  55  ÷
411  43  RCL
412  07  07
413  95  =
414  42  STO
415  14  14
416  43  RCL
417  41  41
418  17  B'
419  43  RCL
420  14  14
421  99  PRT
```

CALC FLOW

```
422  61  GTO
423  12  B
424  76  LBL
425  25  CLR
426  22  INV
427  86  STF
428  01  01
429  43  RCL
430  44  44
431  17  B'
432  43  RCL
433  11  11
434  55  ÷
435  43  RCL
436  01  01
437  65  ×
438  43  RCL
439  02  02
440  61  GTO
441  03  03
442  92  92
```

RE-ENTER VARIABLES

```
443  76  LBL
444  15  E
445  99  PRT
446  85  +
447  01  1
448  95  =
449  42  STO
450  01  01
451  73  RC*
452  01  01
453  91  R/S
454  72  ST*
455  01  01
456  99  PRT
457  98  ADV
458  86  STF
459  00  00
460  91  R/S
461  61  GTO
462  43  RCL
```

Program 12: HP 41CV Data Sheet

```
************

ORIFICE  GAS
CORNER  TAPS

************

ENTER FLOW  PPH
      2,500.0000    ***
ENTER TEMP DEG F
        366.0000    ***
ENTER PRSS PSIG
        150.0000    ***
ENTER DENSITY PPCF
          0.3640    ***
ENTER DIFF RANGE INS H2O
        100.0000    ***
ENTER PIPE ID INS
          2.0670    ***
ENTER CP/CV
          1.3320    ***
ENTER VISCOSITY cP
          0.0150    ***
CALC  BETA
RATIO
          0.6401    ***
CALC ORIFICE
BORE   INS
          1.3231    ***

************

                1.3231

ENTER REQD ORIFICE  INS
          1.3750    ***
CALC  BETA
RATIO
          0.6652    ***
CALC  FLOW
PPH
      2,740.1659    ***

************
```

Program 12: HP 41CV Register Loading

SIZE 080

```
R00=  0.000000
R01=  0.000000
R02=  0.000000
R03=  0.000000
R04=  0.000000
R05=  0.000000
R06=  0.000000
R07=  0.000000
R08=  0.000000
R09=  0.000000
R10=  0.000000
R11=  0.000000
R12=  0.000000
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  0.000000
R17=  0.000000
R18=  0.000000
R19=  0.000000
R20=  0.000000
R21=  0.000000
R22=  0.000000
R23=  0.000000
R24=  0.000000
R25= "ORIFIC"
R26= "E  GAS"
R27= "CORNER"
R28= "  TAPS"
R29= "FLOW  "
R30=  0.000000
R31=  25.262728
R32=  57.295000
R33=  57.515200
R34=  57.535400
R35=  57.606100
R36=  57.626364
R37=  57.656600
R38=  57.670000
R39=  57.686900
R40=  0.000000
R41=  56.707100
R42=  75.767273
R43=  57.747673
R44=  0.000000
R45=  56.707100
R46=  56.295000
R47=  0.000000
R48=  0.000000
R49=  0.000000
R50= "PPH   "
R51= "TEMP D"
R52= "EG F  "
R53= "PRSS P"
R54= "SIG   "
R55= "******"
R56= "CALC  "
R57= "ENTER "
R58=  46.000000
R59=  0.000000
R60= "DENSIT"
R61= "Y PPCF"
R62= "DIFF R"
R63= "ANGE I"
R64= "NS H2O"
R65= "PIPE I"
R66= "D INS "
R67= "CP/CV "
R68= "VISCOS"
R69= "ITY cP"
R70= "BETA  "
R71= "RATIO "
R72= " BORE "
R73= "  INS "
R74= "REQD O"
R75= "CALC O"
R76= "RIFICE"
R77=  0.000000
R78=  0.000000
R79=  0.000000
```

Program 12: HP 41CV Listing

SUBROUTINES

```
01♦LBL "CT GAS"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 GTO d
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53 .7
54 STO 14
55 RCL IND 01
56♦LBL 01
57 XEQ J
58 GTO e
```

RE-ENTER VARIABLES

```
59♦LBL "REENTER"
60 ADV
61 1
62 +
63 STO 01
```

```
64 RCL IND 01
65 XEQ J
66 STOP
67 XEQ J
68 STO IND 01
69 ADV
70 SF 00
71 SF 02
72 STOP
73 GTO 02
```

BYPASS PRINTER

```
74♦LBL J
75 FC? 55
76 GTO 01
77 PRX
78 RTN
79♦LBL 01
80 VIEW X
81 RTN
```

ITERATE FOR β

```
82♦LBL B
83 .6004
84 STO 12
85 .5
86 RCL 14
87 -
88 0
89 X<>Y
90 X<=Y?
91 GTO 01
92 1.5
93 Y↑X
94 .052
95 *
96 ST- 12
97♦LBL 01
98 RCL 14
99 .7
100 -
101 0
102 X<>Y
103 X<=Y?
104 GTO 01
105 .6
106 1/X
107 Y↑X
108 .62
109 *
110 ST+ 12
111♦LBL 01
112 RCL 12
113 2
114 *
115 RCL 14
116 PSE
117 *
118 RCL 14
119 5
120 Y↑X
121 2.1
122 *
123 +
124 STO 23
125 RCL 12
126 RCL 14
127 X↑2
128 *
129 RCL 14
130 6
131 Y↑X
132 .35
133 *
134 +
135 STO 11
136 FS? 01
137 GTO G
138 RCL 16
139 -
140 RCL 23
141 /
142 ST- 14
143 ABS
144 .000015
145 X<>Y
146 X>Y?
147 GTO B
148 RCL 11
149 RCL 14
150 3
151 Y↑X
152 /
153 RCL 07
154 /
155 RCL 14
156 4
157 Y↑X
158 .026
159 *
160 .002
161 +
162 *
163 STO 24
164 RCL 14
165 RTN
```

CALC F_R

```
166♦LBL D
167 RCL 14
168 4
169 Y↑X
170 .35
171 *
172 .41
173 +
174 RCL 06
175 *
176 39.6
177 /
178 RCL 08
179 /
180 RCL 04
181 15
182 +
183 /
184 CHS
185 1
186 +
187 ST/ 16
188 RCL 14
189 RCL 07
190 *
191 X↑2
192 RCL 24
193 *
194 RCL 09
195 *
196 4.42
197 /
198 RCL 02
199 /
200 1
201 +
202 ST/ 16
203 RTN
```

MAIN PROGRAM
ENTER DATA

```
204♦LBL A
205 1
206 STO 01
207 30
208 STO 58
209 XEQ a
210 XEQ d
211 XEQ a
212 XEQ e
213 CF 00
```

CALC $K_o\beta^2$

```
214♦LBL 02
215 41
216 STO 58
217 RCL 02
218 RCL 07
219 X↑2
220 /
221 358.5
222 RCL 03
223 .007
224 *
```

```
225 +
226 /
227 RCL 05
228 RCL 06
229 *
230 SQRT
231 /
232 STO 16
233 STO 10
```

CALC β

```
234 XEQ B
235 XEQ D
236 XEQ B
237 RCL 10
238 STO 16
239 XEQ D
240 XEQ B
241 XEQ J
```

CALC d

```
242 XEQ d
243 RCL 14
244 RCL 07
245 *
246 STO 19
247 GTO 01

248♦LBL "EVEN SZ"
249 SF 01
250 14
251 STO 01
252 42
253 STO 58
254 XEQ e
```

CALC β

```
255 RCL 15
256 RCL 07
257 /
258 STO 14
259 XEQ J
```

CALC FLOW

```
260 GTO B
261♦LBL G
262 CF 01
263 XEQ d
264 RCL 11
265 RCL 16
266 /
267 RCL 02
268 *
269 STO 19
270♦LBL 01
271 XEQ J
272 FS? 00
273 STOP
274 XEQ a
275 CF 02
276 RCL 19
277 VIEW X
278 BEEP
279 ADV
280 STOP
281 .END.
```

Program 12: Sequence of Calculations

1. Calculate $K_o\beta^2$:

$$K_o\beta^2 = \frac{W_m}{D^2\,(358.5 + .007T_f)\,\sqrt{\gamma_f h_m}}$$

2. Iterate to find the uncorrected beta ratio, β.

$$K_o\beta^2 = \beta^2\,(.6004 + .35\beta^4 - .052\,(.5 - \beta)^{3/2} + .62(\beta - .7)^{5/3}$$

If $(.5 - \beta)$ or $(\beta - .7)$ is negative, the function is taken as zero. Let

$$fx = \beta^2\,(.6004 + .35\beta^4 - .052\,(.5 - \beta)^{3/2} + .62\,(\beta - 7)^{5/3})$$
$$- K_o\beta^2$$

and

$$f^1x = 2.1\,\beta^5 + 2\beta\,(.6004 - .052\,(.5 - \beta)^{3/2} + .62(\beta - 7)^{5/3})$$

Start with $\beta = 0.7$ and calculate fx/f^1x. If greater than 0.000015, subtract fx/f^1x from current value of β and repeat until the error is less than 0.000015.

3. Calculate the expansion factor.

$$Y = 1 - \frac{(.41 + .35\beta^4)h_m}{39.6\, k\, P_f}$$

4. Divide $K_o\beta^2$ by Y.
5. Calculate the Reynolds number correction factor.

$$F_r = 1 + (.002 + .026\beta^4)\, K_o \frac{D\, \mu_{cp}}{4.42\, W_m}$$

6. Divide $K_o\beta^2$ by F_r.
7. Repeat step 2 to find corrected beta ratio.
8. Repeat steps 3, 4, 5, and 6 using corrected beta ratio.
9. Repeat step 2 for final beta ratio.
10. Calculate orifice bore.

$$d = \beta D \text{ inches}$$

11. Calculate flowrate for an even-sized orifice bore.

$$\beta = \frac{d}{D}$$

Calculate $K_o\beta^2$ using equation in step 2.

$$\text{new flow} = \frac{\text{new } K_o\beta^2}{\text{original } K_o\beta^2} \times \text{original flow, pounds per hour}$$

Program 12: Nomenclature

D Inside diameter of pipe, inches
d Bore diameter of primary device, inches
F_r Reynolds number correction for steam, vapor, or gas, dimensionless
h_m Maximum differential or range of differential gauge, inches of water, dry calibrated
K_o Coefficient of discharge, including velocity of approach at a hypothetical Reynolds number of infinity, dimensionless
k Ratio of specific heats C_p/C_v, dimensionless
P_f Flowing pressure, PSIA
T_f Flowing temperature, °F

W_m Maximum rate of flow, pounds per hour
Y Expansion factor, dimensionless
β Diameter ratio d/D, dimensionless
γ_f Specific weight at flowing conditions, pounds per cubic foot
μ_{cp} Absolute viscosity, centipoises

References

L. K. Spink, *The Principles and Practice of Flowmeter Engineering*, The Foxboro Company.

Program 13
Gas or Vapor Flow—Flow Nozzle and Venturi

Program 13: User Instructions

a) Initiate program, press A.
b) Enter:

1. Flowrate, pounds per hour	Press R/S
2. Flow temperature, °F	Press R/S
3. Flow pressure, PSIG	Press R/S
4. Specific weight, pounds per cubic foot	Press R/S
5. Absolute viscosity, centipoises	Press R/S
6. Ratio of specific heats C_p/C_v, dimensionless	Press R/S
7. Differential range, inches of water	Press R/S
8. Pipe inside diameter, inches	Press R/S

c) Program calculates preliminary beta ratio (dimensionless) and Reynolds number (dimensionless).
d) Enter, from appropriate F_c chart:

9. Reynolds number correction factor F_c, dimensionless	Press R/S

e) Calculate beta ratio (dimensionless) and nozzle bore (inches).
f) If an even-sized nozzle bore is required, press C and enter:

10. Required nozzle bore, inches	Press R/S

g) Program calculates beta ratio (dimensionless) and new flowrate (pounds per hour).

Notes:

1. The E subroutine is available to change data and recalculate.

2. If the orifice plate material is not 316SS or 304SS, see Table of Equal Thermal Expansion Temperatures for Various Orifice Plate Materials, page 162.
3. See Program 16 for specific weight calculation.

Program 13: TI 59 Data Sheet

```
*******************

FLOW NZZLE GAS CALC

*******************

ENTR FLOW    PPH
        2500.
ENTR TEMP      °F
         366.
ENTR PRSS  PSIG
         150.
ENTR SPCFC    WT PPCF
        0.364
ENTR VISC      CP
        0.015
ENTR CP/CV
        1.332
ENTR DIFF RANGE IN W
         100.
ENTR PIPE     ID  INS
        2.067
CALC PRELM BETA
 .5149997578
CALC REYNLDS N°
 692027.7623
ENTR     FC
      1.0115
CALC  BETA
 .5122708115
CALC NZZLE         INS
 1.058363767

*******************


ENTR NZZLE  INS
          1.
CALC  BETA
 .4837929366
CALC FLOW    PPH
 2213.122473

*******************
```

Program 13: TI 59 Register Loading

PARTITIONING
479.59

0.	00	0.	14
0.	01	0.	15
0.	02	0.	16
0.	03	0.	17
0.	04	0.	18
0.	05	0.	19
0.	06	0.	20
0.	07	0.	21
0.	08	56.4945	22
0.	09	57.2743	23
0.	10	4224361500.	24
0.	11	23362422.	25
0.	12	22133600.	26
0.	13	3146462717.	27
		1636003173.	28
		3517453127.	29

3335172730.	30	333323.2444	45
3324331700.	31	14173713.35	46
24310043.	32	4337.343332	47
3513312217.	33	7321.314143	48
1624212100.	34	2127324300.	49
1533631542.	35	56.3046	50
33331521.	36	56.2928	51
3633152115.	37	57.42	52
3335363600.	38	56.46	53
3717303300.	39	56.270043	54
49.272656	40	5151515151.	55
2416.4945	41	1513271500.	56
2115.3948	42	1731373500.	57
243136.3825	43	0.	58
1533.374736	44	0.	59

Program 13: TI 59 Listing

SUBROUTINES PRINT & STORE VARIABLES

```
000   76 LBL
001   10 E'
002   01   1
003   44 SUM
004   58  58
005   73 RC*
006   58  58
007   22 INV
008   59 INT
009   52 EE
010   22 INV
011   52 EE
012   67  EQ
013   19 D'
014   85   +
015   05   5
016   07   7
017   95   =
018   17 B'
019   69 DP
020   21  21
021   73 RC*
022   01  01
023   87 IFF
024   00  00
025   00  00
026   30  30
027   91 R/S
028   72 ST*
029   01  01
030   73 RC*
031   01  01
032   99 PRT
033   61 GTO
034   10 E'
```

PRINT LINES

```
035   76 LBL
036   19 D'
037   01   1
038   44 SUM
039   58  58
040   73 RC*
041   58  58
042   76 LBL
043   17 B'
044   42 STO
045   59  59
046   73 RC*
047   59  59
048   69 DP
049   01  01
050   18 C'
051   69 DP
052   02  02
053   18 C'
054   69 DP
055   03  03
056   18 C'
057   69 DP
058   04  04
059   69 DP
060   05  05
061   92 RTN
```

DECODE LINES

```
062   76 LBL
063   18 C'
064   01   1
065   00   0
066   00   0
067   48 EXC
068   59  59
069   22 INV
070   59 INT
071   49 PRD
072   59  59
073   73 RC*
074   59  59
075   92 RTN
```

PRINT LINE OF STARS

```
076   76 LBL
077   16 A'
078   93   .
079   00   0
080   01   1
081   08   8
082   35 1/X
083   98 ADV
084   17 B'
085   98 ADV
086   92 RTN
```

RE-ENTER VARIABLES

```
087   76 LBL
088   15   E
089   99 PRT
090   85   +
091   01   1
092   95   =
093   42 STO
```

094	01	01
095	73	RC*
096	01	01
097	91	R/S
098	72	ST*
099	01	01
100	99	PRT
101	22	INV
102	86	STF
103	01	01
104	98	ADV
105	86	STF
106	00	00
107	61	GTO
108	22	INV

ITERATE FOR β

109	76	LBL
110	12	B
111	93	.
112	00	0
113	00	0
114	00	0
115	00	0
116	01	1
117	32	X⇌T
118	76	LBL
119	25	CLR
120	71	SBR
121	44	SUM
122	75	-
123	43	RCL
124	14	14
125	95	=
126	55	÷
127	53	(
128	43	RCL
129	13	13
130	66	PAU
131	45	Y^X
132	03	3
133	65	×
134	04	4
135	54	)
136	45	Y^X
137	93	.
138	05	5
139	65	×
140	93	.
141	04	4
142	09	9
143	95	=
144	22	INV
145	44	SUM
146	13	13
147	50	I×I
148	77	GE
149	25	CLR
150	92	RTN

CALC S FROM β

151	76	LBL
152	44	SUM
153	53	(
154	53	(
155	43	RCL
156	13	13
157	45	Y^X
158	04	4
159	55	÷
160	53	(
161	01	1
162	75	-
163	43	RCL
164	13	13
165	45	Y^X
166	04	4
167	54	)
168	54	)
169	34	√X
170	65	×
171	93	.
172	09	9
173	08	8
174	54	)
175	92	RTN

CALC Y

176	76	LBL
177	14	D
178	93	.
179	04	4
180	01	1
181	85	+
182	93	.
183	03	3
184	05	5
185	65	×
186	43	RCL
187	13	13
188	45	Y^X
189	04	4
190	95	=
191	65	×
192	43	RCL
193	08	08
194	55	÷
195	05	5
196	05	5
197	93	.
198	04	4
199	55	÷
200	43	RCL
201	07	07
202	55	÷
203	53	(
204	43	RCL
205	04	04
206	85	+
207	01	1
208	05	5
209	95	=
210	94	+/-
211	85	+
212	01	1
213	95	=
214	92	RTN

MAIN PROGRAM
ENTER DATA

215	76	LBL
216	11	A
217	29	CP
218	01	1
219	42	STO
220	01	01
221	93	.
222	05	5
223	42	STO
224	13	13
225	03	3
226	09	9
227	42	STO
228	58	58
229	16	A'
230	19	D'
231	16	A'
232	10	E'
233	22	INV
234	86	STF
235	00	00

CALC S FROM
PROCESS DATA

236	76	LBL
237	22	INV
238	43	RCL
239	02	02
240	55	÷
241	53	(
242	03	3

```
243  05   5
244  08   8
245  93   .
246  05   5
247  85   +
248  93   .
249  00   0
250  00   0
251  07   7
252  65   ×
253  43  RCL
254  03   03
255  54   )
256  55   ÷
257  43  RCL
258  09   09
259  33  X²
260  55   ÷
261  53   (
262  43  RCL
263  05   05
264  65   ×
265  43  RCL
266  08   08
267  54   )
268  34  √X
269  95   =
270  42  STO
271  14   14
272  42  STO
273  15   15
```

CALC PRELIM β

```
274  12   B
275  14   D
276  22  INV
277  49  PRD
278  14   14
279  12   B
280  14   D
281  35  1/X
282  65   ×
283  43  RCL
284  15   15
285  95   =
286  42  STO
287  14   14
288  12   B
289  43  RCL
290  13   13
291  99  PRT
```

CALC R_D

```
292  05   5
293  00   0
294  42  STO
295  58   58
296  19  D'
297  04   4
298  93   .
299  04   4
300  02   2
301  65   ×
302  43  RCL
303  02   02
304  55   ÷
305  43  RCL
306  13   13
307  55   ÷
308  43  RCL
309  06   06
310  55   ÷
311  43  RCL
312  09   09
313  95   =
314  99  PRT
```

ENTER F_c

```
315  19  D'
316  43  RCL
317  10   10
318  87  IFF
319  01   01
320  43  RCL
321  91  R/S
322  86  STF
323  01   01
324  42  STO
325  10   10
326  76  LBL
327  43  RCL
328  99  PRT
329  87  IFF
330  00   00
331  33  X²
332  22  INV
333  86  STF
334  01   01
335  76  LBL
336  33  X²
```

CALC β

```
337  43  RCL
338  10   10
339  22  INV
340  49  PRD
341  14   14
342  12   B
343  19  D'
344  43  RCL
345  13   13
346  99  PRT
```

CALC d

```
347  19  D'
348  43  RCL
349  13   13
350  65   ×
351  43  RCL
352  09   09
353  95   =
354  76  LBL
355  23  LNX
356  99  PRT
357  32  X:T
358  16  A'
359  98  ADV
360  98  ADV
361  32  X:T
362  91  R/S
```

ENTER REQD NOZZLE

```
363  76  LBL
364  13   C
365  32  X:T
366  43  RCL
367  23   23
368  17  B'
369  32  X:T
370  91  R/S
371  99  PRT
```

CALC β

```
372  55   ÷
373  43  RCL
374  09   09
375  95   =
376  42  STO
377  13   13
378  43  RCL
379  53   53
380  17  B'
381  43  RCL
382  13   13
383  99  PRT
```

CALC FLOW

```
384  71  SBR
```

```
385  44  SUM
386  55   ÷
387  43  RCL
388  14   14
389  65   ×
390  43  RCL
391  02   02
392  95   =
393  32  X⇄T
394  43  RCL
395  22   22
396  17  B'
397  32  X⇄T
398  61  GTO
399  23  LNX
```

Program 13: HP 41CV Data Sheet

```
************

FLOW  NOZZLE
   GAS

************

ENTER FLOW  PPH
      2,500.0000    ***
ENTER TEMP DEG F
        366.0000    ***
ENTER PRSS PSIG
        150.0000    ***
ENTER DENSITY PPCF
          0.3640    ***
ENTER VISCOSITY cP
          0.0150    ***
ENTER CP/CV
          1.3320    ***
ENTER DIFF RANGE INS H2O
        100.0000    ***
ENTER PIPE ID INS
          2.0670    ***
CALC  PRELIM
BETA  RATIO
          0.5150    ***
CALC  REYNOL
DS NO
     692,027.7620   ***
ENTER FC
          1.0115    ***
CALC  BETA
RATIO
          0.5123    ***
CALC  NOZZLE
 BORE INS
          1.0589    ***

************
             1.0589

ENTER NOZZLE BORE INS
          1.0000    ***
CALC  BETA
RATIO
          0.4838    ***
CALC  FLOW
PPH
      2,213.1225    ***

************
```

Program 13: HP 41CV Register Loading

```
SIZE 080
R00=  0.000000
R01=  0.000000
R02=  0.000000
R03=  0.000000
R04=  0.000000
R05=  0.000000
R06=  0.000000
R07=  0.000000
R08=  0.000000
R09=  0.000000
R10=  0.000000
R11=  0.000000
R12=  0.000000
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  0.000000
R17=  0.000000
R18=  0.000000
R19=  0.000000
R20=  0.000000
R21=  0.000000
R22=  0.000000
R23=  0.000000
R24=  0.000000
R25= "NOZZLE"
R26= "   GAS"
R27= "FLOW  "
R28= "PPH   "
R29= "PRELIM"
R30=  0.000000
R31=  27.252600
R32=  57.272800
R33=  57.515200
R34=  57.535400
R35=  57.606100
R36=  57.686900
R37=  57.670000
R38=  57.626364
R39=  57.656600
R40=  0.000000
R41=  56.297071
R42=  56.767700
R43=  57.780000
R44=  0.000000
R45=  56.707100
R46=  56.257273
R47=  57.257273
R48=  0.000000
R49=  56.707100
R50=  56.272800
R51= "TEMP D"
R52= "EG F  "
R53= "PRSS P"
R54= "SIG   "
R55= "******"
R56= "CALC  "
R57= "ENTER "
R58=  50.000000
R59=  0.000000
R60= "DENSIT"
R61= "Y PPCF"
R62= "DIFF R"
R63= "ANGE I"
R64= "NS H2O"
R65= "PIPE I"
R66= "D INS "
R67= "CP/CV "
R68= "VISCOS"
R69= "ITY cP"
R70= "BETA  "
R71= "RATIO "
R72= " BORE "
R73= "INS   "
R74=  0.000000
R75=  0.000000
R76= "REYNOL"
R77= "DS NO "
R78= "FC    "
R79=  0.000000
```

SUBROUTINES

```
01♦LBL "FN GAS"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 GTO d
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53 .5
54 STO 13
55 RCL IND 01
56♦LBL 01
57 XEQ J
58 GTO e
```

RE-ENTER VARIABLES

```
59♦LBL "REENTER"
60 ADV
61 1
62 +
63 STO 01
64 RCL IND 01
65 XEQ J
66 STOP
67 XEQ J
68 STO IND 01
69 ADV
70 SF 00
71 SF 02
72 STOP
73 GTO 02
```

BYPASS PRINTER

```
74♦LBL J
75 FC? 55
76 GTO 01
77 PRX
78 RTN
79♦LBL 01
80 VIEW X
81 RTN
```

ITERATE FOR β

```
82♦LBL B
83 XEQ G
84 RCL 14
85 -
86 RCL 13
87 PSE
88 3
89 Y↑X
90 4
91 *
92 SQRT
93 /
94 .49
95 *
96 ST- 13
97 ABS
98 .00001
99 X<>Y
100 X>Y?
101 GTO B
102 RTN
```

CALC S

```
103♦LBL G
104 RCL 13
105 4
106 Y↑X
107 ENTER↑
108 CHS
109 1
110 +
111 /
112 SQRT
113 .98
114 *
115 RTN
```

CALC Y

```
116♦LBL D
117 RCL 13
118 4
119 Y↑X
120 .35
121 *
122 .41
123 +
124 RCL 08
125 *
126 55.4
127 /
128 RCL 07
129 /
130 RCL 04
131 15
132 +
133 /
134 CHS
135 1
136 +
137 RTN
```

MAIN PROGRAM ENTER DATA

```
138♦LBL A
139 1
140 STO 01
141 30
142 STO 58
143 XEQ a
144 XEQ d
145 XEQ a
```

```
146 XEQ e
147 CF 02
```

CALC S

```
148♦LBL 02
149 9
150 STO 01
151 41
152 STO 58
153 RCL 02
154 358.5
155 RCL 03
156 .007
157 *
158 +
159 /
160 RCL 09
161 X↑2
162 /
163 RCL 05
164 RCL 08
165 *
166 SQRT
167 /
168 STO 14
169 STO 15
```

CALC PRELIM β

```
170 XEQ B
171 XEQ D
172 ST/ 14
173 XEQ B
174 XEQ D
175 1/X
176 RCL 15
177 *
178 STO 14
179 XEQ B
180 RCL 13
181 XEQ J
```

CALC R_D

```
182 XEQ d
183 4.42
184 RCL 02
185 *
186 RCL 13
187 /
188 RCL 06
189 /
190 RCL 09
191 /
192 XEQ J
```

ENTER F_c

```
193 XEQ e
```

CALC β

```
194 RCL 10
195 ST/ 14
196 XEQ B
197 RCL 13
198 XEQ J
```

CALC d

```
199 XEQ d
200 RCL 13
201 RCL 09
202 *
203 STO 19
204 GTO I
```

ENTER REQD NOZZLE

```
205♦LBL "EVEN SZ"
206 10
207 STO 01
208 46
209 STO 58
210 XEQ e
```

CALC β

```
211 RCL 11
212 RCL 09
213 /
214 STO 13
215 XEQ J
```

CALC FLOW

```
216 XEQ d
217 XEQ G
218 RCL 14
219 /
220 RCL 02
221 *
222 STO 19
223♦LBL I
224 XEQ J
225 FS? 02
226 STOP
227 XEQ a
228 CF 00
229 RCL 19
230 VIEW X
231 BEEP
232 ADV
233 STOP
234 .END.
```

Program 13: Sequence of Calculations

1. Calculate S factor.

$$S = \frac{W_m}{D^2 (358.5 + .007T_f) \sqrt{\gamma_f h_m}}$$

2. Iterate to find the uncorrected beta ratio, β.

$$S = .98 \sqrt{\frac{\beta^4}{1 - \beta^4}}$$

Let

$$fx = .98\sqrt{\frac{\beta^4}{1 - \beta^4}} - S$$

and

$$f^1x = .49\sqrt{4\beta^3}$$

Start with $\beta = 0.5$ and calculate fx/f^1x. If greater than 0.00001, subtract fx/f^1x from current value of β and repeat until the error is less than 0.00001.

3. Calculate the expansion factor.

$$Y = 1 - \frac{(.41 + .35\beta^4)h_m}{55.4\, k\, P_f}$$

4. Divide S by Y.
5. Repeat step 2 to find the corrected beta ratio.
6. Calculate Reynolds number.

$$R_D = \frac{4.42\, W_m}{\beta\, D\, \mu_{cp}}$$

7. Divide S by F_c.
8. Repeat step 2.
9. Calculate bore.

$$d = \beta\, D \text{ inches}$$

10. Calculate flowrate for an even-sized bore.

$$\beta = \frac{d}{D}$$

Calculate S using equation in step 2.

$$\text{new flow} = \frac{\text{new } S}{\text{original } S} \times \text{original flow, pounds per hour}$$

Program 13: Nomenclature

D Inside diameter of pipe, inches
d Bore diameter of primary device, inches
F_c Reynolds number correction, dimensionless
h_m Maximum differential or range of differential gauge, inches of water, dry calibrated
k Ratio of specific heats C_p/C_v, dimensionless
P_f Flowing pressure, PSIA
S Beta ratio index for d/D, dimensionless
T_f Flowing temperature, °F
W_m Maximum rate of flow, pounds per hour
Y Expansion factor, dimensionless
β Diameter ratio d/D, dimensionless
γ_f Specific weight at flowing conditions, pounds per cubic foot
μ_{cp} Absolute viscosity, centipoises

References

L. K. Spink, *The Principles and Practice of Flowmeter Engineering,* The Foxboro Company.

Typical Data

Table of Equal Thermal Expansion Temperatures °F for Various Orifice Plate Materials

Type 316 or Type 304	Alu-minum	Copper	Type 430	2% CRMO	5% CRMO	Bronze	Steel	Monel
	−298					−360		
	−230	−378				−273		
−325	−178	−266				−216		
−226	−131	−194				−163		−281
−152	−85	−132				−111		−191
−86	−41	−72				−60		−108
−24	+3	−15				−8		−33
+38	+47	+42	+24	+28	+27	+43	+31	+38
+101	+91	+99	+112	+108	+110	+95	+106	+104
+158			+202	+184	+191	+149	+181	+168
213			290	260	272	200	254	230
266			374	331	352	249	324	290
318			456	400	426	297	392	348
367			531	468	493	345	457	405
414			604	534	560	393	520	461
463			677	597	628	440	542	516
512			749	660	696		644	571
560			817	720	763		705	626
607			884	780	827		765	680
655			952	842	888		823	733
703			1020	899	948		879	785
750			1087	956	1009		934	835
796			1155	1011	1071		988	886
840			1223	1065	1133		1041	935

The program is written for 316SS and 304SS. If another material is used, move down the scale for the selected material, then across (left) to the equivalent 316SS/304SS temperature. Enter this value. For example, if the material selected for orifice plate was Monel, with a flow temperature of 405°F, enter 367°F. (The temperature is only entered in the program for orifice plate thermal expansion. It does not affect any other calculation.)

Physical Properties

	Gas	Liquid	
	k^* C_p/C_v	Water = 1 Sp. Gr	Sp. Gr. @ °F
Acetaldehyde	1.14	.783	64
Acetic Acid	1.15	1.049	68
Acetone	—	.791	66
Acetylene	1.26	—	—
Air	1.40	—	—
Ammonia	1.33	.817	−110
Argon	1.67	1.65	−387
Benzene	1.12	.879	68
Butadiene 1.3	1.12	.621	68
Butane *n*-	1.094	.579	68
Butane iso-	1.094	.557	68
Carbon Dioxide	1.30	1.101	−35
Carbon Disulfide	1.21	1.263	68
Carbon Monoxide	1.40	.814	−318
Chlorine	1.36	1.56	−29
Cyclohexane	1.09	.779	68
n-Decane	1.03	.734	60
Dowtherm A	1.046	.997	212
Dowtherm E	—	1.181	212
Ethane	1.22	.546	−126
Ethyl Alcohol	1.13	.789	68
Ethyl Chloride	1.19	.903	50
Ethylene (Ethene)	1.26	.566	−152
Freon 11	1.14	1.494	63
Freon 12	1.14	1.486	−22
Freon 22	1.18	1.419	−42
Freon 114	1.09	1.538	30
Gasoline	—	.75**	68
Helium	1.66	—	—
n-Hexane	1.06	.659	68
Hydrogen Chloride	1.41	—	—
Hydrogen	1.41	.0709	−423
Hydrogen Sulfide	1.32	—	—
Kerosene	—	.815**	60
Methane	1.31	.415	−263
Methyl Alcohol	1.20	.792	68
Methyl Butane	1.08	.625	60
Methyl Chloride	1.20	.952	32
Natural Gas	1.27	—	—
Nitric Acid (HNO_3)	—	1.502	60
Nitric Oxide	1.40	1.269	−239
Nitrogen	1.40	1.026	−422

*Values at 14.7 pounds per square inch, absolute and 60°F.
**Typical value.

(table continued on next page)

Physical Properties (continued)

	Gas	Liquid	
	k* C_p/C_v	Water = 1 Sp. Gr	Sp. Gr. @ °F
Nitrous Oxide	1.30	1.226	−128
Nonane	1.04	.718	68
n-Octane	1.05	.707	68
Oils			
Fuel, Bunker C	—	1.014	60
Fuel, No. 3	—	.899	60
Fuel, No. 5 & 6	—	.993	60
Lube	—	.910	60
Mineral	—	.910	60
Oxygen	1.40	1.426	−422
n-Pentane	1.07	.631	60
Propane	1.13	.585	−49
Propylene	1.15	.609	−53
Steam	1.324	1.00	39
Styrene	1.07	.906	68
Sulfur Dioxide	1.29	1.434	32
Sulfuric Acid	—	1.834	60
Toluene	1.09	.866	68

*Values at 14.7 pounds per square inch, absolute and 60°F.
**Typical value.

Pipe Data*

Nominal Pipe Size, Inches	Outside Diameter, Inches	Identification: Steel: Iron Pipe Size	Identification: Steel: Sched. No.	Identification: Stainless Steel Sched. No.	Wall Thickness (t) Inches	Inside Diameter (D) Inches
		—	—	10S	.049	.307
⅛	0.405	STD	40	40S	.068	.269
		XS	80	80S	.095	.215
		—	—	10S	.065	.410
¼	0.540	STD	40	40S	.088	.364
		XS	80S	80S	.119	.302
		—	—	10S	.065	.545
⅜	0.675	STD	40	40S	.091	.493
		XS	80	80S	.126	.423
		—	—	5S	.065	.710
		—	—	10S	.083	.674
½	0.840	STD	40	40S	.109	.622
		XS	80	80S	.147	.546
		—	160	—	.187	.466
		XXS	—	—	.294	.252
		—	—	5S	.065	.920
		—	—	10S	.083	.884
¾	1.505	STD	40	40S	.113	.824
		XS	80	80S	.154	.742
		—	160	—	.219	.612
		XXS	—	—	.308	.434
		—	—	5S	.065	1.185
		—	—	10S	.109	1.097
1	1.315	STD	40	40S	.133	1.049
		XS	80	80S	.179	.957
		—	160	—	.250	.815
		XXS	—	—	.358	.599
		—	—	5S	.065	1.530
		—	—	10S	.109	1.442
1¼	1.660	STD	40	40S	.140	1.380
		XS	80	80S	.191	1.278
		—	160	—	.250	1.160
		XXS	—	—	.382	.896
		—	—	5S	.065	1.770
		—	—	10S	.109	1.682
1½	1.900	STD	40	40S	.154	1.610
		XS	80	80S	.200	1.500

*Identification, wall thickness, and weights are extracted from ANSI B36 19. The notations STD, XS, and XXS indicate standard, extra strong, and double extra strong pipe, respectively.
(Table continued on next page)

Pipe Data* (continued)

Nominal Pipe Size, Inches	Outside Diameter, Inches	Identification: Steel: Iron Pipe Size	Identification: Steel: Sched. No.	Identification: Stainless Steel Sched. No.	Wall Thickness (t), Inches	Inside Diameter (D) Inches
		—	160	—	.218	1.338
		XXS	—	—	.400	1.100
2	2.375	—	—	5S	.065	2.245
		—	—	10S	.109	2.157
		STD	40	40S	.154	2.067
		XS	80	80S	.218	1.939
		—	160	—	.344	1.687
		XXS	—	—	.436	1.503
2½	2.875	—	—	5S	.083	2.709
		—	—	10S	.120	2.635
		STD	40	40S	.203	1.469
		XS	80	80S	.276	2.323
		—	160	—	.375	2.125
		XXS	—	—	.552	1.771
3	3.500	—	—	5S	.083	3.334
		—	—	10S	.120	3.260
		STD	40	40S	.216	3.068
		XS	80	80S	.300	2.900
		—	160	—	.438	2.624
		XXS	—	—	.600	2.300
3½	4.000	—	—	5S	.083	3.834
		—	—	10S	.120	3.760
		STD	40	40S	.226	3.548
		XS	80	80S	.318	3.364
4	4.500	—	—	5S	.083	4.334
		—	—	10S	.120	4.260
		STD	40	40S	.237	4.026
		XS	80	80S	.337	3.826
		—	120	—	.438	3.624
		—	160	—	.531	3.438
		XXS	—	—	.674	3.152
5	5.563	—	—	5S	.109	5.345
		—	—	10S	.134	5.295
		STD	40	40S	.258	5.047
		XS	80	80S	.375	4.813
		—	120	—	.500	4.563
		—	160	—	.625	4.313
		XXS	—	—	.750	4.063

*Identification, wall thickness, and weights are extracted from ANSI B36 19. The notations STD, XS, and XXS indicate standard, extra strong, and double extra strong pipe, respectively. (Table continued on next page)

Pipe Data* (continued)

Nominal Pipe Size, Inches	Outside Diameter, Inches	Identification: Steel: Iron Pipe Size	Steel: Sched. No.	Stainless Steel Sched. No.	Wall Thickness (t), Inches	Inside Diameter (D) Inches
		—	—	5S	.109	6.407
		—	—	10S	.134	6.357
		STD	40	40S	.280	6.065
6	6.625	XS	80	80S	.432	5.761
		—	120	—	.562	5.501
		—	160	—	.719	5.187
		XXS	—	—	.864	4.897
		—	—	5S	.109	8.407
		—	—	10S	.148	8.329
		—	20	—	.250	8.125
		—	30	—	.277	8.071
		STD	40	40S	.322	7.981
8	8.625	—	60	—	.406	7.813
		XS	80	80S	.500	7.625
		—	100	—	.594	7.437
		—	120	—	.719	7.187
		—	140	—	.812	7.001
		XXS	—	—	.875	6.875
		—	160	—	.906	6.813
		—	—	5S	.134	10.482
		—	—	10S	.165	10.420
		—	20	—	.250	10.250
		—	30	—	.307	10.136
		STD	40	40S	.365	10.020
10	10.750	XS	60	80S	.500	9.750
		—	80	—	.594	9.562
		—	100	—	.719	9.312
		—	120	—	.844	9.062
		XXS	140	—	1.000	8.750
		—	160	—	1.125	8.500
		—	—	5S	.156	12.438
		—	—	10S	.180	12.390
		—	20	—	.250	12.250
		—	30	—	.330	12.090
		STD	—	40S	.375	12.000
		—	40	—	.406	11.938
12	12.75	XS	—	80S	.500	11.750
		—	60	—	.562	11.626
		—	80	—	.688	11.374
		—	100	—	.844	11.062

*Identification, wall thickness, and weights are extracted from ANSI B36 19. The notations STD, XS, and XXS indicate standard, extra strong, and double extra strong pipe, respectively. (Table continued on next page)

Pipe Data* (continued)

		Identification				
		Steel				
Nominal Pipe Size, Inches	Outside Diameter, Inches	Iron Pipe Size	Sched. No.	Stainless Steel Sched. No.	Wall Thickness (t) Inches	Inside Diameter (D) Inches
		XXS	120	—	1.000	10.750
		—	140	—	1.125	10.500
		—	160	—	1.312	10.126
14	14.00	—	—	5S	.156	13.688
		—	—	10S	.188	13.624
		—	10	—	.250	13.500
		—	20	—	.312	13.376
		STD	30	—	.375	13.250
		—	40	—	.438	13.124
		XS	—	—	.500	13.000
		—	60	—	.594	12.812
		—	80	—	.750	12.500
		—	100	—	.938	12.124
		—	120	—	1.094	11.812
		—	140	—	1.250	11.500
		—	160	—	1.406	11.188
16	16.00	—	—	5S	.165	15.670
		—	—	10S	.188	15.624
		—	10	—	.250	15.500
		—	20	—	.312	15.376
		STD	30	—	.375	15.250
		XS	40	—	.500	15.000
		—	60	—	.656	14.688
		—	80	—	.844	14.312
		—	100	—	1.031	13.938
		—	120	—	1.219	13.562
		—	140	—	1.438	13.124
		—	160	—	1.594	12.812
18	18.00	—	—	5S	.165	17.670
		—	—	10S	.188	17.624
		—	10	—	.250	17.500
		—	20	—	.312	17.376
		STD	—	—	.375	17.250
		—	30	—	.438	17.124
		XS	—	—	.500	17.000
		—	40	—	.562	16.876
		—	60	—	.750	16.500
		—	80	—	.938	16.124
		—	100	—	1.156	15.688

*Identification, wall thickness, and weights are extracted from ANSI B36 19. The notations STD, XS, and XXS indicate standard, extra strong, and double extra strong pipe, respectively.
(Table continued on next page)

Pipe Data* (continued)

Nominal Pipe Size, Inches	Outside Diameter, Inches	Identification: Steel: Iron Pipe Size	Identification: Steel: Sched. No.	Identification: Stainless Steel Sched. No.	Wall Thickness (t) Inches	Inside Diameter (D) Inches
		—	120	—	1.375	15.250
		—	140	—	1.562	14.876
		—	160	—	1.781	14.438
		—	—	5S	.188	19.624
		—	—	10S	.218	19.564
		—	10	—	.250	19.500
		STD	20	—	.375	19.250
		XS	30	—	.500	19.000
20	20.00	—	40	—	.594	18.812
		—	60	—	.812	18.376
		—	80	—	1.031	17.938
		—	100	—	1.281	17.438
		—	120	—	1.500	17.000
		—	140	—	1.750	16.500
		—	160	—	1.969	16.062
			—			
		—	—	5S	.188	21.624
		—	10	10S	.218	21.564
		—	20	—	.250	21.500
		STD	30	—	.375	21.250
22	22.00	XS	40	—	.500	21.000
		—	60	—	.875	20.250
		—	80	—	1.125	19.75
		—	100	—	1.375	19.25
		—	120	—	1.625	18.75
		—	140	—	1.875	18.25
		—	160	—	2.125	17.75
		—	—	5S	.218	23.564
		—	10	10S	.250	23.500
		STD	20	—	.375	23.250
		XS	—	—	.500	23.000
		—	30	—	.562	22.876
24	24.00	—	40	—	.688	22.624
		—	60	—	.969	22.062
		—	80	—	1.219	21.562
		—	100	—	1.531	20.938
		—	120	—	1.812	20.376
		—	140	—	2.062	19.876
		—	160	—	2.344	19.312

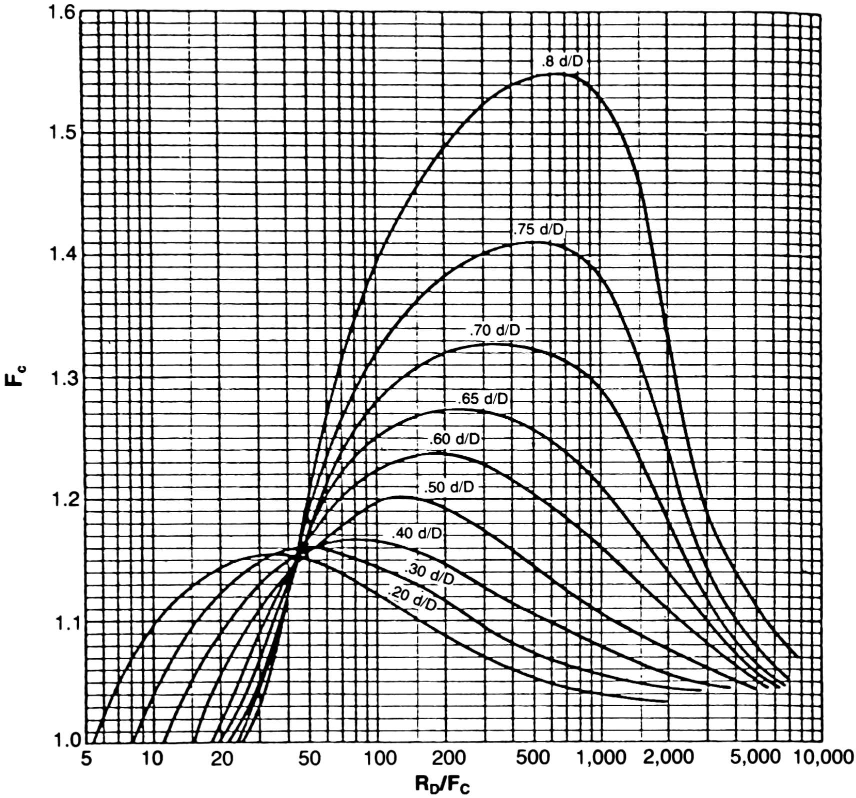
*Identification, wall thickness, and weights are extracted from ANSI B36 19. The notations STD, XS, and XXS indicate standard, extra strong, and double extra strong pipe, respectively. (Table continued on next page)

Pipe Data* (continued)

Nominal Pipe Size, Inches	Outside Diameter, Inches	Identification: Steel — Iron Pipe Size	Identification: Steel — Sched. No.	Identification: Stainless Steel Sched. No.	Wall Thickness (t) Inches	Inside Diameter (D) Inches
		—	10	—	.312	25.376
26	26.00	STD	—	—	.375	25.250
		XS	20	—	.500	25.000
		—	10	—	.312	27.376
28	28.00	STD	—	—	.375	27.250
		XS	20	—	.500	27.000
		—	30	—	.625	26.750
		—	—	5S	.250	29.500
		—	10	10S	.312	29.376
30	30.00	STD	—	—	.375	29.250
		XS	20	—	.500	29.000
		—	30	—	.625	28.750
		—	10	—	.312	31.376
		STD	—	—	.375	31.250
32	32.00	XS	20	—	.500	31.000
		—	30	—	.625	30.750
		—	40	—	.688	30.624
		—	10	—	.344	33.312
		STD	—	—	.375	33.250
34	34.00	XS	20	—	.500	33.000
		—	30	—	.625	32.750
		—	40	—	.688	32.624
		—	10	—	.312	35.376
		STD	—	—	.375	35.250
36	36.00	XS	20	—	.500	35.000
		—	30	—	.625	34.750
		—	40	—	.750	34.500

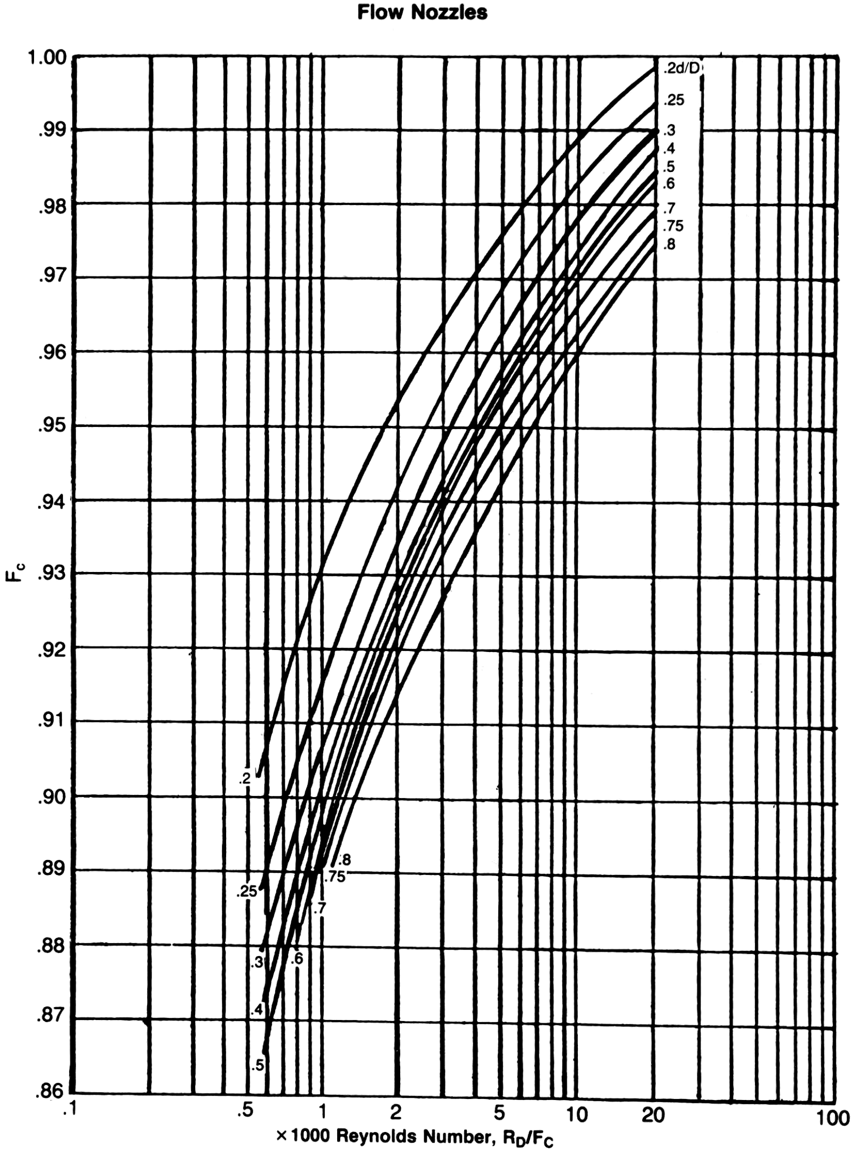
*Identification, wall thickness, and weights are extracted from ANSI B36 19. The notations STD, XS, and XXS indicate standard, extra strong, and double extra strong pipe, respectively.

Viscosity Corrections for Concentric Orifices



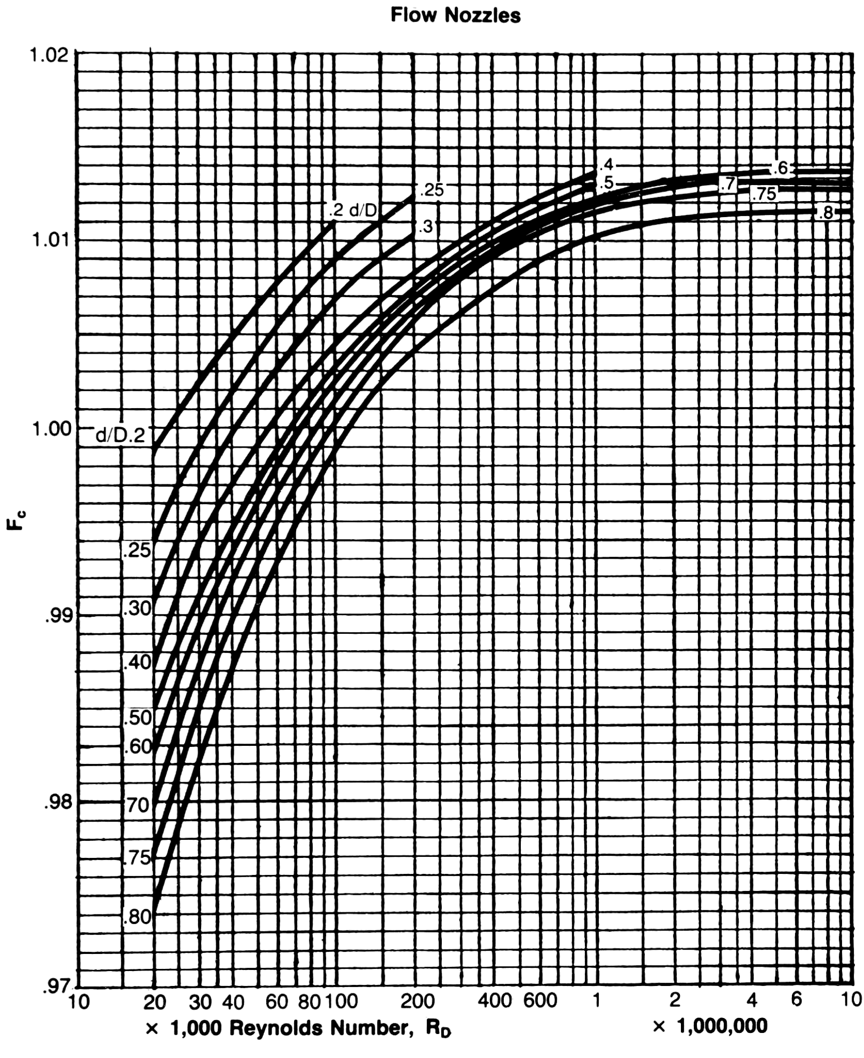
(Reprinted from *Principles and Practice of Flow Meter Engineering*, by L.P. Spink, The Foxboro Co.)

Viscosity Corrections for Flow Nozzles (Taps at 1D and ½D)



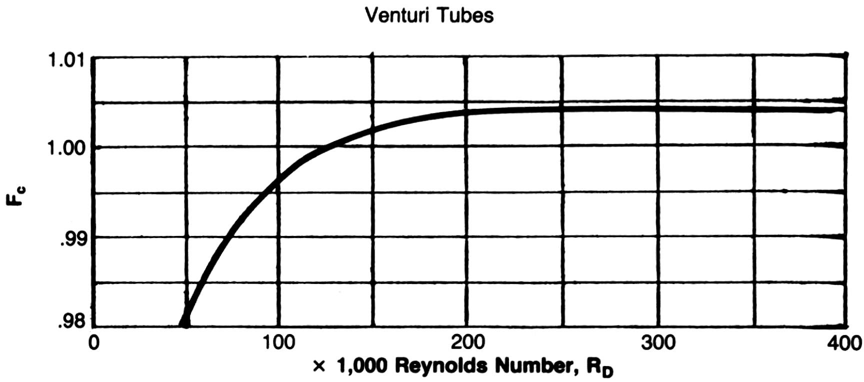
(Reprinted from *Principles and Practice of Flow Meter Engineering*, by L.P. Spink, The Foxboro Co.)

Reynolds Number Corrections for Flow Nozzles (Taps at 1D and ½D)



(Reprinted from *Principles and Practice of Flow Meter Engineering*, by L.P. Spink, The Foxboro Co.)

Reynolds Number Corrections for Venturi Tubes



(Reprinted from *Principles and Practice of Flow Meter Engineering*, by L.P. Spink, The Foxboro Co.)

CHAPTER FIVE

Restriction Orifices

Program 14 Liquid Flow
Program 15 Gas or Vapor Flow

Restriction orifices regulate noncritical flows such as purges. The larger ones (four inches) are mounted between flanges, and the small ones (one inch) in a restriction orifice union.

The liquid calculation is based on the orifice sizing procedure, with an adjustment for pressure recovery. The gas calculation assumes sonic flow, i.e. discharge pressure less than half the absolute inlet pressure. If that is not the case, use the gas orifice calculation, Program 10.

Program 14
Liquid Flow

Program 14: User Instructions

To calculate bore, press A.

a) Enter:

1. Pipe inside diameter, inches	Press R/S
2. Specific gravity at flow temperature, dimensionless	Press R/S
3. Flow temperature, °F	Press R/S
4. Flowrate, pounds per hour	Press R/S
5. Pressure drop across orifice, PSI	Press R/S

b) Program calculates orifice bore, inches.

To calculate flowrate, press B.

a) Enter:

1. Pipe inside diameter, inches	Press R/S
2. Specific gravity at flow temperature, dimensionless	Press R/S
3. Flow temperature, °F	Press R/S

4. Pressure drop across orifice, PSI — Press R/S
5. Orifice bore, inches — Press R/S

b) Program calculates flowrate, pounds per hour.

To calculate pressure drop, press C.

a) Enter:
1. Pipe inside diameter, inches — Press R/S
2. Specific gravity at flow temperature, dimensionless — Press R/S
3. Flow temperature, °F — Press R/S
4. Flowrate, pounds per hour — Press R/S
5. Orifice bore, inches — Press R/S

b) Program calculates pressure drop, PSI.

Program 14: TI 59 Data Sheet

A

```
*LIQ**LIQ**LIQ**LIQ*

 RESTRICTN ORIFICE
     CALC  BORE

ENTER PIPE I.D.  INS
       4.026
ENTER SPEC GRAVITY
        1.12
ENTER FLOW TEMP   °F
        100.
ENTER FLOW RATE  PPH
       23700.
ENTER PRSS DROP PSIG
        150.
CALC  ORIF BORE  INS
 .4526300192

*LIQ**LIQ**LIQ**LIQ*
```

B

```
*LIQ**LIQ**LIQ**LIQ*

 RESTRICTN ORIFICE
     CALC  FLOW

ENTER PIPE I.D.  INS
       4.026
ENTER SPEC GRAVITY
        1.12
ENTER FLOW TEMP   °F
        100.
ENTER PRSS DROP PSIG
        150.
ENTER ORIF BORE  INS
      0.45263
CALC  FLOW RATE  PPH
 23699.99796

*LIQ**LIQ**LIQ**LIQ*
```

C

```
*LIQ**LIQ**LIQ**LIQ*

 RESTRICTN ORIFICE
     CALC  PRSS DROP

ENTER PIPE I.D.  INS
       4.026
ENTER SPEC GRAVITY
        1.12
ENTER FLOW TEMP   °F
        100.
ENTER FLOW RATE  PPH
       23700.
ENTER ORIF BORE  INS
      0.45263
CALC  DROP PRSS PSIG
 150.0000258

*LIQ**LIQ**LIQ**LIQ*
```

Program 14: TI 59 Register Loading

PARTITIONING
479.59

0.	00	512724345 1.	29
0.	01	42.414	30
0.	02	37.393836	31
0.	03	59.585655	32
0.	04	2437450000.	33
0.	05	22351342.	34
0.	06	36331715.	35
0.	07	3200000000.	36
0.	08	1513271500.	37
0.	09	35133724.	38
0.	10	14173713.	39
0.	11	3235000000.	40
0.	12	21131537.	41
0.	13	33232400.	42
0.	14	243136.	43
39.3836	15	24401640.	44
56.5443	16	33243317.	45
45.4443	17	33362422.	46
35.3433	18	16353233.	47
52.4746	19	7321.	48
53.4948	20	37173033.	49
53.515	21	333323.	50
0.	22	35133717.	51
29.	23	33353636.	52
29.292929	24	21273243.	53
37.475246	25	14323517.	54
37.53515	26	2415170000.	55
37.565443	27	32352421.	56
37.42414	28	1731371735.	57
		3524153731.	58
		35173637.	59

Program 14: TI 59 Listing

SUBROUTINES
PRINT & STORE DATA

```
000  76  LBL
001  42  STO
002  42  STO
003  23   23
004  43  RCL
005  57   57
006  69  OP
007  01   01
008  73  RC*
009  23   23
010  69  OP
011  02   02
012  71  SBR
013  43  RCL
014  69  OP
015  03   03
016  71  SBR
017  43  RCL
018  69  OP
019  04   04
020  69  OP
021  05   05
022  69  OP
023  21   21
024  73  RC*
025  01   01
026  91  R/S
027  99  PRT
028  72  ST*
029  01   01
030  92  RTN
```

DECODE LINES

```
031  76  LBL
032  43  RCL
033  43  RCL
034  23   23
035  22  INV
036  59  INT
037  65   ×
038  01   1
039  00   0
040  00   0
041  95   =
042  42  STO
043  23   23
044  73  RC*
045  23   23
046  92  RTN
```

PRINT LINES

```
047  76  LBL
048  61  GTO
049  42  STO
050  23   23
```

```
051  73 RC*
052  23  23
053  69 OP
054  01  01
055  71 SBR
056  43 RCL
057  69 OP
058  02  02
059  71 SBR
060  43 RCL
061  69 OP
062  03  03
063  71 SBR
064  43 RCL
065  69 OP
066  04  04
067  69 OP
068  05  05
069  92 RTN
```

PRINT HEADING

```
070  76 LBL
071  90 LST
072  01  1
073  42 STO
074  01  01
075  98 ADV
076  43 RCL
077  24  24
078  71 SBR
079  61 GTO
080  98 ADV
081  43 RCL
082  32  32
083  71 SBR
084  61 GTO
085  92 RTN
```

STORE COMMON DATA

```
086  76 LBL
087  97 DSZ
088  43 RCL
089  17  17
090  71 SBR
091  42 STO
092  43 RCL
093  18  18
094  71 SBR
095  42 STO
096  43 RCL
097  20  20
098  71 SBR
099  42 STO
```

CALC F$_a$

```
100  53  (
101  43 RCL
102  04  04
103  75  -
104  06  6
105  08  8
106  54  )
107  65  ×
108  93  .
109  00  0
110  00  0
111  00  0
112  00  0
113  02  2
114  85  +
115  01  1
116  95  =
117  42 STO
118  12  12
119  92 RTN
```

MAIN PROGRAM TO CALC BORE ENTER DATA

```
120  76 LBL
121  11  A
122  71 SBR
123  90 LST
124  93  .
125  03  3
126  07  7
127  05  5
128  04  4
129  71 SBR
130  61 GTO
131  98 ADV
132  71 SBR
133  97 DSZ
134  43 RCL
135  21  21
136  71 SBR
137  42 STO
138  43 RCL
139  19  19
140  71 SBR
141  42 STO
142  43 RCL
143  27  27
144  71 SBR
145  61 GTO
```

CALC ϕ

```
146  43 RCL
147  05  05
148  55  ÷
149  01  1
150  04  4
151  09  9
152  02  2
153  00  0
154  55  ÷
155  43 RCL
156  02  02
157  33 X²
158  55  ÷
159  43 RCL
160  12  12
161  55  ÷
162  53  (
163  43 RCL
164  06  06
165  65  ×
166  43 RCL
167  03  03
168  54  )
169  34 √X
170  95  =
```

ϕ< .05 CALC β

```
171  32 X:T
172  93  .
173  00  0
174  05  5
175  32 X:T
176  77  GE
177  22 INV
178  45 Y^X
179  93  .
180  04  4
181  09  9
182  04  4
183  65  ×
184  01  1
185  93  .
186  02  2
187  05  5
188  06  6
189  61 GTO
190  23 LNX
```

.05 <ϕ< .4 CALC β

```
191  76 LBL
192  22 INV
193  32 X:T
194  93  .
195  04  4
196  32 X:T
```

```
197  77   GE
198  24  CE
199  45  Yˣ
200  93   .
201  04   4
202  00   0
203  07   7
204  65   ×
205  93   .
206  09   9
207  06   6
208  08   8
209  61  GTO
210  23  LNX
```

.4 <φ< .7 CALC β

```
211  76  LBL
212  24  CE
213  32  X⇌T
214  93   .
215  07   7
216  32  X⇌T
217  77   GE
218  25  CLR
219  45  Yˣ
220  93   .
221  01   1
222  04   4
223  04   4
224  65   ×
225  93   .
226  07   7
227  06   6
```

CALC d

```
228  61  GTO
229  23  LNX
230  76  LBL
231  25  CLR
232  00   0
233  35  1/X
234  91  R/S
235  76  LBL
236  23  LNX
237  65   ×
238  43  RCL
239  02   02
240  95   =
241  42  STO
242  10   10
243  99  PRT
244  76  LBL
245  95   =
246  98  ADV
247  43  RCL
248  24   24
249  71  SBR
250  61  GTO
251  98  ADV
252  98  ADV
253  98  ADV
254  43  RCL
255  10   10
256  91  R/S
```

CALC FLOW ENTER DATA

```
257  76  LBL
258  12   B
259  71  SBR
260  90  LST
261  93   .
262  03   3
263  07   7
264  05   5
265  03   3
266  71  SBR
267  61  GTO
268  98  ADV
269  71  SBR
270  97  DSZ
271  43  RCL
272  19   19
273  71  SBR
274  42  STO
275  43  RCL
276  16   16
277  71  SBR
278  42  STO
279  43  RCL
280  26   26
281  71  SBR
282  61  GTO
```

CALC FLOW

```
283  71  SBR
284  44  SUM
285  65   ×
286  01   1
287  04   4
288  09   9
289  02   2
290  00   0
291  65   ×
292  43  RCL
293  02   02
294  33  X²
295  65   ×
296  43  RCL
297  12   12
298  65   ×
299  53   (
300  43  RCL
301  05   05
302  65   ×
303  43  RCL
304  03   03
305  54   )
306  34  √X
307  95   =
308  42  STO
309  10   10
310  99  PRT
311  61  GTO
312  95   =
```

CALC PRESSURE DROP ENTER DATA

```
313  76  LBL
314  13   C
315  71  SBR
316  90  LST
317  93   .
318  03   3
319  07   7
320  05   5
321  02   2
322  04   4
323  07   7
324  71  SBR
325  61  GTO
326  98  ADV
327  71  SBR
328  97  DSZ
329  43  RCL
330  21   21
331  71  SBR
332  42  STO
333  43  RCL
334  16   16
335  71  SBR
336  42  STO
337  43  RCL
338  25   25
339  71  SBR
340  61  GTO
```

CALC ΔP

```
341  71  SBR
342  44  SUM
343  95   95
344  35  1/X
```

```
345   65   ×
346   43  RCL
347   05   05
348   55   ÷
349   01   1
350   04   4
351   09   9
352   02   2
353   00   0
354   55   ÷
355   43  RCL
356   02   02
357   33  X²
358   55   ÷
359   43  RCL
360   12   12
361   95   =
362   33  X²
363   55   ÷
364   43  RCL
365   03   03
366   95   =
367   42  STO
368   10   10
369   99  PRT
370   61  GTO
371   95   =
```

SUBROUTINE TO CALCφ CALCβ

```
372   76  LBL
373   44  SUM
374   43  RCL
375   06   06
376   55   ÷
377   43  RCL
378   02   02
379   95   =
```

β< .285 CALC φ

```
380   32  X⇌T
381   93   .
382   02   2
383   08   8
384   05   5
385   32  X⇌T
386   77   GE
387   52  EE
388   55   ÷
389   01   1
390   93   .
391   02   2
392   05   5
393   06   6
394   95   =
395   45  Yˣ
396   93   .
397   04   4
398   09   9
399   04   4
400   35  1/X
401   61  GTO
402   71  SBR
```

.285 <β< .666 CALC φ

```
403   76  LBL
404   52  EE
405   32  X⇌T
406   93   .
407   06   6
408   06   6
409   06   6
410   32  X⇌T
411   77   GE
412   53   (
413   55   ÷
414   93   .
415   09   9
416   06   6
417   08   8
418   95   =
419   45  Yˣ
420   93   .
421   04   4
422   00   0
423   07   7
424   35  1/X
425   61  GTO
426   71  SBR
```

.666 <β< .72 CALC φ

```
427   76  LBL
428   53   (
429   32  X⇌T
430   93   .
431   07   7
432   02   2
433   32  X⇌T
434   77   GE
435   25  CLR
436   55   ÷
437   93   .
438   07   7
439   06   6
440   95   =
441   45  Yˣ
442   93   .
443   01   1
444   04   4
445   04   4
446   35  1/X
447   76  LBL
448   71  SBR
449   92  RTN
```

Program 14: HP 41CV Data Sheet

```
*************

*RO LIQUID*
*CALC BORE*

*************

ENTER PIPE ID INS
           4.026    ***
ENTER SG
           1.120    ***
ENTER TEMP DEG F
           100.000    ***
ENTER FLOW  PPH
        23,700.000    ***
ENTER dP PSI
           150.000    ***
CALC ORIFICE
 BORE   INS
             0.453    ***

*************
```

```
*************

*RO LIQUID*
*CALC FLOW*

*************

ENTER PIPE ID INS
           4.026    ***
ENTER SG
           1.120    ***
```

```
ENTER TEMP DEG F
        100.000    ***
ENTER dP PSI
        150.000    ***
ENTER ORIFICE BORE INS
          0.453    ***
CALC   FLOW
PPH
     23,700.000    ***

************
```

```
************

*RO LIQUID*
*CALC dP PSI

************

ENTER PIPE ID INS
          4.026    ***
ENTER SG
          1.120    ***
```

```
ENTER TEMP DEG F
        100.000    ***
ENTER FLOW  PPH
     23,700.000    ***
ENTER ORIFICE BORE INS
          0.453    ***
CALC   dP PSI
        150.000    ***

************
```

Program 14: HP 41CV Register Loading

SIZE 080

```
R00=  0.000000
R01=  0.000000
R02=  0.000000
R03=  0.000000
R04=  0.000000
R05=  0.000000
R06=  0.000000
R07=  0.000000
R08=  0.000000
R09=  0.000000
R10=  0.000000
R11=  0.000000
R12=  0.000000
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  0.000000
R17=  0.000000
R18=  0.000000
R19=  0.000000
R20=  0.000000
R21=  0.000000
R22=  0.000000
R23=  0.000000
R24=  0.000000
R25= "*RO LI"
R26= "QUID* "
R27= "BORE* "
R28= "FLOW* "
R29= "dP PSI"
R30=  25.266729
R31=  57.686900
R32=  57.500000
R33=  57.515200
R34=  0.000000
R35=  57.535400
R36=  57.290000
R37=  0.000000
R38=  70.717262
R39=  57.290000
R40=  57.606162
R41=  0.000000
R42=  56.535400
R43=  57.535400
R44=  0.000000
R45=  57.606162
R46=  0.000000
R47=  56.290000
R48=  0.000000
R49=  0.000000
R50= "SG    "
R51= "TEMP D"
R52= "EG F  "
R53= "FLOW  "
R54= "PPH   "
R55= "******"
R56= "CALC  "
R57= "ENTER "
R58=  47.000000
R59=  0.000000
R60= "ORIFIC"
R61= "E BORE"
R62= " INS  "
R63=  0.000000
R64=  0.000000
R65=  0.000000
R66=  0.000000
R67= "*CALC "
R68= "PIPE I"
R69= "D INS "
R70= "CALC O"
R71= "RIFICE"
R72= " BORE "
R73=  0.000000
R74=  0.000000
R75=  0.000000
R76=  0.000000
R77=  0.000000
R78=  0.000000
R79=  0.000000
```

Program 14: HP 41CV Listing

SUBROUTINES

```
01♦LBL "RO LIQD"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
```

```
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 RTN
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53♦LBL 01
54 XEQ J
55 GTO e
```

RE-ENTER VARIABLES

```
56♦LBL "REENTER"
57 ADV
58 1
59 +
60 STO 01
61 4
62 X<>Y
63 X<=Y?
64 GTO 01
65 FS? 02
66 GTO 02
67 FC? 03
68 GTO 01
69 RCL 01
70 5
71 X=Y?
72 GTO 01
73♦LBL 02
74 1
75 ST+ 01
76♦LBL 01
77 RCL IND 01
78 XEQ J
79 STOP
80 XEQ J
81 STO IND 01
82 ADV
83 SF 00
84 STOP
85 FS? 01
86 GTO "AA"
87 FS? 02
88 GTO B
89 FS? 03
90 GTO C
```

BYPASS PRINTER

```
91♦LBL J
92 FC? 55
93 GTO 01
94 PRX
95 RTN
96♦LBL 01
97 VIEW X
98 RTN
```

COMMON CALC

```
99♦LBL F
100 RCL 04
101 68
102 -
103 .00002
104 *
105 1
106 +
107 14920
108 *
109 RCL 02
110 X↑2
111 *
112 RCL 03
113 SQRT
114 *
115 RTN
```

CALC ϕ

```
116♦LBL G
117 .05
118 RCL 09
119 X<=Y?
120 GTO 01
121 .4
122 RCL 09
123 X<=Y?
124 GTO 02
125 .7
126 RCL 09
127 X<=Y?
128 GTO 03
129 0
130 1/X
131♦LBL 01
132 .494
133 Y↑X
134 1.256
135 *
136 RTN
137♦LBL 02
138 .407
139 Y↑X
140 .968
141 *
142 RTN
143♦LBL 03
144 .144
145 Y↑X
146 .76
147 *
148 RTN
```

CALC β

```
149♦LBL H
150 .285
151 RCL 08
152 X<=Y?
153 GTO 01
154 .666
155 RCL 08
156 X<=Y?
157 GTO 02
158 .72
159 RCL 08
160 X<=Y?
161 GTO 03
162 0
163 1/X
164♦LBL 01
165 1.256
166 /
167 .494
168 1/X
169 Y↑X
170 RTN
171♦LBL 02
172 .968
173 /
174 .407
175 1/X
176 Y↑X
177 RTN
178♦LBL 03
179 .76
180 /
181 .144
182 1/X
183 Y↑X
184 RTN
```

COMMON ENTRIES

```
185♦LBL I
186 1
```

```
187 STO 01
188 29
189 STO 58
190 XEQ a
191 XEQ d
192 XEQ a
193 XEQ e
194 RTN
```

MAIN PROGRAM TO CALC BORE

```
195♦LBL A
196 FS? 00
197 GTO 01
198 CF 02
199 CF 03
200♦LBL 01
201 FS? 02
202 GTO "FLOW="
203 FS? 03
204 GTO "PRESS="
205 SF 01
206 25.266727
207 STO 30
208 XEQ I
209 XEQ e
210 XEQ d
211 CF 00
212♦LBL "AA"
213 RCL 05
214 XEQ F
215 /
216 RCL 06
217 SQRT
218 /
219 STO 09
220 XEQ G
221 RCL 02
222 *
223 STO 07
224 GTO D
```

CALC FLOW

```
225♦LBL "FLOW="
226 FS? 00
227 GTO 01
228 CF 01
229 CF 03
230♦LBL 01
231 FS? 01
232 GTO A
233 FS? 03
234 GTO "dP="
235 SF 02
236 25.266728
237 STO 30
238 XEQ I
239 1
240 ST+ 01
241 38
242 STO 58
243 XEQ e
244 XEQ d
245 CF 00
246♦LBL B
247 RCL 07
248 RCL 02
249 /
250 STO 08
251 XEQ H
252 XEQ F
253 *
254 RCL 06
255 SQRT
256 *
257 STO 05
258 GTO D
```

CALC dP

```
259♦LBL "dP="
260 FS? 00
261 GTO 01
262 CF 01
263 CF 02
264♦LBL 01
265 FS? 01
266 GTO A
267 FS? 02
268 GTO "FLOW="
269 SF 03
270 25.266729
271 STO 30
272 XEQ I
273 42
274 STO 58
275 XEQ e
276 1
277 ST+ 01
278 XEQ e
279 XEQ d
280 CF 00
281♦LBL C
282 RCL 07
283 RCL 02
284 /
285 STO 08
286 XEQ H
287 XEQ F
288 *
289 1/X
290 RCL 05
291 *
292 X↑2
293 STO 06
294♦LBL D
295 STO 09
296 XEQ J
297 FS? 00
298 STOP
299 XEQ a
300 RCL 09
301 VIEW X
302 BEEP
303 ADV
304 STOP
305 END
```

Program 14: Sequence of Calculations

To calculate bore.

1. Calculate ϕ:

$$\phi = \frac{W_m}{14{,}920\,(1 + .00002\,(T_f - 68))D^2\sqrt{G_f\,\Delta P}}$$

When ϕ is less than .05:

$$\beta = 1.256\ \phi^{.494}$$

When ϕ is less than .4 and greater than .05:

$$\beta = .968\ \phi^{.407}$$

When ϕ is less than .7 and greater than .4:

$$\beta = .76\ \phi^{.144}$$

If ϕ is greater than .7, an error exists.

2. Calculate orifice bore.

$$d = \beta D \text{ inches}$$

To calculate flow or pressure drop.

1. When β is less than .285:

$$\phi = {\frac{\beta}{1.256}}^{1/.494}$$

When β is less than .666 and greater than .285:

$$\phi = {\frac{\beta}{.968}}^{1/.407}$$

When β is less than .72 and greater than .666:

$$\phi = {\frac{\beta}{.76}}^{1/.144}$$

If β is greater than .72, an error exists.

2. Flow $W_m = 14{,}920\ D^2\ \phi\ \sqrt{G_f \Delta P}\ (1 - .00002\ (T_f - 68))$ pounds per hour

$$\text{pressure drop} = \left(\frac{W_m}{14{,}920\ D^2\ \phi\ \sqrt{G_f}\ (1 - .00002(T_f - 68))}\right)^2 \text{PSI}$$

Program 14: Nomenclature

D Inside diameter of pipe, inches
d Bore of restriction orifice, inches
G_f Specific gravity of the liquid at flowing temperature, dimensionless
ΔP Pressure drop across orifice, PSI

T_f Flowing temperature, °F
W_m Maximum rate of flow, pounds per hour
β Diameter ratio, dimensionless
ϕ Index for β

Program 15
Gas or Vapor Flow

Program 15: User Instructions

To calculate bore, press A.

a) Enter:

1. Pipe inside diameter, inches	Press R/S
2. Specific weight, pounds per cubic foot	Press R/S
3. Flow temperature, °F	Press R/S
4. Flowrate, pounds per hour	Press R/S
5. Inlet pressure, PSIG	Press R/S

b) Program calculates orifice bore, inches.

To calculate flowrate, press B.

a) Enter:

1. Pipe inside diameter, inches	Press R/S
2. Specific weight, pounds per cubic foot	Press R/S
3. Flow temperature, °F	Press R/S
4. Inlet pressure, PSIG	Press R/S
5. Orifice bore, inches	Press R/S

b) Program calculates flowrate, pounds per hour.

To calculate inlet pressure, press C.

a) Enter:

1. Pipe inside diameter, inches	Press R/S
2. Specific weight, pounds per cubic foot	Press R/S
3. Flow temperature, °F	Press R/S
4. Flowrate, pounds per hour	Press R/S
5. Orifice bore, inches	Press R/S

b) Program calculates inlet pressure, PSIG.

Note: See Program 16 for specific weight calculation.

Program 15: TI 59 Data Sheet

```
*GAS**GAS**GAS**GAS*

 RESTRICTN ORIFICE
     CALC  BORE

ENTER PIPE I.D.  INS
        1.5
ENTER SPEC WGHT PPCF
       0.21
ENTER FLOW TEMP   °F
        78.
ENTER FLOW RATE  PPH
       160.
ENTER INLT PRSS PSIG
        14.
CALC  ORIF BORE  INS
 .3039758147

*GAS**GAS**GAS**GAS*

*GAS**GAS**GAS**GAS*

 RESTRICTN ORIFICE
     CALC  FLOW

ENTER PIPE I.D.  INS
        1.5
ENTER SPEC WGHT PPCF
       0.21
ENTER FLOW TEMP   °F
        78.
ENTER INLT PRSS PSIG
        14.
ENTER ORIF BORE  INS
      0.304
CALC  FLOW RATE  PPH
 160.0258806

*GAS**GAS**GAS**GAS*

*GAS**GAS**GAS**GAS*

 RESTRICTN ORIFICE
     CALC  PRSS

ENTER PIPE I.D.  INS
        1.5
ENTER SPEC WGHT PPCF
       0.21
ENTER FLOW TEMP   °F
        78.
ENTER FLOW RATE  PPH
       160.
ENTER ORIF BORE  INS
      0.304
CALC  INLT PRSS PSIG
  13.9907176

*GAS**GAS**GAS**GAS*
```

Program 15: TI 59 Register Loading

PARTITIONING
479.59

0.	00	0.	12
0.	01	0.	13
0.	02	0.	14
0.	03	39.3836	15
0.	04	56.5443	16
0.	05	45.4443	17
0.	06	35.3433	18
0.	07	47.5246	19
0.	08	53.4948	20
0.	09	53.515	21
0.	10	0.	22
0.	11	29.	23
		29.292929	24
		37.475246	25
		37.53515	26

```
  37.565443    27
   37.42414    28
5122133651.    29
     42.414    30
   37.39414    31
  59.585655    32
  33331521.    33
  43222337.    34
  36331715.    35
3200000000.    36
1513271500.    37
  35133724.    38
  14173713.    39
3235000000.    40
  21131537.    41
  45373633.    42
    243136.    43
  24401640.    44
  33243317.    45
  33362422.    46
  24312737.    47
      7321.    48
  37173033.    49
    333323.    50
  35133717.    51
  33353636.    52
  21273243.    53
  14323517.    54
2415170000.    55
  32352421.    56
1731371735.    57
3524153731.    58
  35173637.    59
```

Program 15: TI 59 Listing

SUBROUTINES PRINT & STORE DATA

```
000  76  LBL
001  42  STO
002  42  STO
003  23   23
004  43  RCL
005  57   57
006  69  OP
007  01   01
008  73  RC*
009  23   23
010  69  OP
011  02   02
012  71  SBR
013  43  RCL
014  69  OP
015  03   03
016  71  SBR
017  43  RCL
018  69  OP
019  04   04
020  69  OP
021  05   05
022  69  OP
023  21   21
024  73  RC*
025  01   01
026  91  R/S
027  99  PRT
028  72  ST*
029  01   01
030  92  RTN
```

DECODE LINES

```
031  76  LBL
032  43  RCL
033  43  RCL
034  23   23
035  22  INV
036  59  INT
037  65   ×
038  01   1
039  00   0
040  00   0
041  95   =
042  42  STO
043  23   23
044  73  RC*
045  23   23
046  92  RTN
```

PRINT LINES

```
047  76  LBL
048  61  GTO
049  42  STO
050  23   23
051  73  RC*
052  23   23
053  69  OP
054  01   01
055  71  SBR
056  43  RCL
057  69  OP
058  02   02
059  71  SBR
060  43  RCL
061  69  OP
062  03   03
063  71  SBR
064  43  RCL
065  69  OP
066  04   04
067  69  OP
068  05   05
069  92  RTN
```

PRINT HEADING

```
070  76  LBL
071  90  LST
072  01   1
073  42  STO
074  01   01
075  98  ADV
076  43  RCL
077  24   24
078  71  SBR
079  61  GTO
080  98  ADV
081  43  RCL
082  32   32
083  71  SBR
084  61  GTO
085  92  RTN
```

STORE COMMON DATA

```
086  76  LBL
087  97  DSZ
088  43  RCL
089  17   17
090  71  SBR
091  42  STO
```

```
092   43  RCL
093   18   18
094   71  SBR
095   42  STO
096   43  RCL
097   20   20
098   71  SBR
099   42  STO
```

CALC F_a

```
100   53   (
101   43  RCL
102   04   04
103   75   -
104   06   6
105   08   8
106   54   )
107   65   ×
108   93   .
109   00   0
110   00   0
111   00   0
112   00   0
113   02   2
114   85   +
115   01   1
116   95   =
117   42  STO
118   12   12
119   92  RTN
```

MAIN PROGRAM TO CALC BORE

ENTER DATA

```
120   76  LBL
121   11   A
122   71  SBR
123   90  LST
124   93   .
125   03   3
126   07   7
127   05   5
128   04   4
129   71  SBR
130   61  GTO
131   98  ADV
132   71  SBR
133   97  DSZ
134   43  RCL
135   21   21
136   71  SBR
137   42  STO
138   43  RCL
139   19   19
140   71  SBR
141   42  STO
142   43  RCL
143   27   27
144   71  SBR
145   61  GTO
```

CALC Y_TS_P

```
146   43  RCL
147   05   05
148   55   ÷
149   03   3
150   05   5
151   09   9
152   55   ÷
153   43  RCL
154   02   02
155   33   X²
156   55   ÷
157   43  RCL
158   12   12
159   55   ÷
160   53   (
161   53   (
162   43  RCL
163   06   06
164   85   +
165   01   1
166   04   4
167   93   .
168   07   7
169   54   )
170   65   ×
171   43  RCL
172   03   03
173   54   )
174   34   √X
175   95   =
```

CALC d

```
176   45   Y^X
177   93   .
178   04   4
179   09   9
180   01   1
181   09   9
182   65   ×
183   93   .
184   06   6
185   09   9
186   09   9
187   01   1
188   95   =
189   65   ×
190   43  RCL
191   02   02
192   95   =
193   42  STO
194   10   10
195   99  PRT
196   76  LBL
197   95   =
198   98  ADV
199   43  RCL
200   24   24
201   71  SBR
202   61  GTO
203   98  ADV
204   98  ADV
205   98  ADV
206   43  RCL
207   10   10
208   91  R/S
```

CALC FLOW

ENTER DATA

```
209   76  LBL
210   12   B
211   71  SBR
212   90  LST
213   93   .
214   03   3
215   07   7
216   05   5
217   03   3
218   71  SBR
219   61  GTO
220   98  ADV
221   71  SBR
222   97  DSZ
223   43  RCL
224   19   19
225   71  SBR
226   42  STO
227   43  RCL
228   16   16
229   71  SBR
230   42  STO
231   43  RCL
232   26   26
233   71  SBR
234   61  GTO
```

CALC Y_TS_P

```
235   43  RCL
236   06   06
237   55   ÷
238   43  RCL
239   02   02
240   95   =
241   55   ÷
242   93   .
243   06   6
```

```
244  09  9
245  09  9
246  01  1
247  95  =
248  45  YX
249  93  .
250  04  4
251  09  9
252  01  1
253  09  9
254  35  1/X
```

CALC FLOW

```
255  65  ×
256  03  3
257  05  5
258  09  9
259  65  ×
260  43  RCL
261  02  02
262  33  X²
263  65  ×
264  43  RCL
265  12  12
266  65  ×
267  53  (
268  53  (
269  43  RCL
270  05  05
271  85  +
272  01  1
273  04  4
274  93  .
275  07  7
276  54  )
277  65  ×
278  43  RCL
279  03  03
280  54  )
281  34  √X
282  95  =
283  42  STO
284  10  10
285  99  PRT
286  61  GTO
287  95  =
```

CALC INLET PRES ENTER DATA

```
288  76  LBL
289  13  C
290  71  SBR
291  90  LST
292  93  .
293  03  3
294  07  7
295  05  5
296  02  2
297  71  SBR
298  61  GTO
299  98  ADV
300  71  SBR
301  97  DSZ
302  43  RCL
303  21  21
304  71  SBR
305  42  STO
306  43  RCL
307  16  16
308  71  SBR
309  42  STO
310  43  RCL
311  25  25
312  71  SBR
313  61  GTO
```

CALC Y_TS_P

```
314  43  RCL
315  06  06
316  55  ÷
317  43  RCL
318  02  02
319  95  =
320  55  ÷
321  93  .
322  06  6
323  09  9
324  09  9
325  01  1
326  95  =
327  45  YX
328  93  .
329  04  4
330  09  9
331  01  1
332  09  9
333  35  1/X
334  95  =
```

CALC PRESS

```
335  35  1/X
336  65  ×
337  43  RCL
338  05  05
339  55  ÷
340  03  3
341  05  5
342  09  9
343  55  ÷
344  43  RCL
345  02  02
346  33  X²
347  55  ÷
348  43  RCL
349  12  12
350  95  =
351  33  X²
352  55  ÷
353  43  RCL
354  03  03
355  75  -
356  01  1
357  04  4
358  93  .
359  07  7
360  95  =
361  42  STO
362  10  10
363  99  PRT
364  61  GTO
365  95  =
```

(Program 15: HP 41CV Data Sheet on next page)

Program 15: HP 41CV Data Sheet

```
************         ************         ************

 *RO   GAS*           *RO   GAS*           *RO   GAS*
*CALC BORE*          *CALC FLOW*          *CALC PRSS*

************         ************         ************

ENTER PIPE ID INS    ENTER PIPE ID INS    ENTER PIPE ID INS
      1.500   ***          1.500   ***          1.500   ***
ENTER DENSITY PPCF   ENTER DENSITY PPCF   ENTER DENSITY PPCF
      0.210   ***          0.210   ***          0.210   ***
ENTER TEMP DEG F     ENTER TEMP DEG F     ENTER TEMP DEG F
     78.000   ***         78.000   ***         78.000   ***
ENTER FLOW  PPH      ENTER INLET PRSS PSIG ENTER FLOW  PPH
    160.000   ***         14.000   ***        160.000   ***
ENTER INLET PRSS PSIG ENTER ORIFICE BORE INS ENTER ORIFICE BORE INS
     14.000   ***          0.303   ***          0.303   ***
CALC ORIFICE         CALC   FLOW          CALC   INLET
 BORE   INS          PPH                  PRSS PSIG
      0.303   ***        160.000   ***         14.000   ***

************         ************         ************
```

Program 15: HP 41CV Register Loading

SIZE 080

```
R00=  0.000000     R26= "GAS*  "      R53= "FLOW  "
R01=  0.000000     R27= "BORE* "      R54= "PPH   "
R02=  0.000000     R28= "FLOW* "      R55= "******"
R03=  0.000000     R29= "PRSS* "      R56= "CALC  "
R04=  0.000000     R30=  25.266729    R57= "ENTER "
R05=  0.000000     R31=  57.686900    R58=  47.000000
R06=  0.000000     R32=  57.495000    R59=  0.000000
R07=  0.000000     R33=  57.515200    R60= "ORIFIC"
R08=  0.000000     R34=  0.000000     R61= "E BORE"
R09=  0.000000     R35=  57.535400    R62= " INS  "
R10=  0.000000     R36=  57.636465    R63= "INLET "
R11=  0.000000     R37=  0.000000     R64= "PRSS P"
R12=  0.000000     R38=  70.717262    R65= "SIG   "
R13=  0.000000     R39=  57.636465    R66=  0.000000
R14=  0.000000     R40=  57.606162    R67= "*CALC "
R15=  0.000000     R41=  0.000000     R68= "PIPE I"
R16=  0.000000     R42=  56.535400    R69= "D INS "
R17=  0.000000     R43=  57.535400    R70= "CALC O"
R18=  0.000000     R44=  0.000000     R71= "RIFICE"
R19=  0.000000     R45=  57.606162    R72= " BORE "
R20=  0.000000     R46=  0.000000     R73=  0.000000
R21=  0.000000     R47=  56.636465    R74=  0.000000
R22=  0.000000     R48=  0.000000     R75=  0.000000
R23=  0.000000     R49= "DENSIT"      R76=  0.000000
R24=  0.000000     R50= "Y PPCF"      R77=  0.000000
R25= "  *RO "      R51= "TEMP D"      R78=  0.000000
                   R52= "EG F  "      R79=  0.000000
```

Program 15: HP 41CV Listing

SUBROUTINES

```
01♦LBL "RO GAS"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 RTN
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53♦LBL 01
54 XEQ J
55 GTO e
```

RE-ENTER VARIABLES

```
56♦LBL "REENTER"
57 ADV
58 1
59 +
60 STO 01
61 4
62 X<>Y
63 X<=Y?
64 GTO 01
65 FS? 02
66 GTO 02
67 FC? 03
68 GTO 01
69 RCL 01
70 5
71 X=Y?
72 GTO 01
73♦LBL 02
74 1
75 ST+ 01
76♦LBL 01
77 RCL IND 01
78 XEQ J
79 STOP
80 XEQ J
81 STO IND 01
82 ADV
83 SF 00
84 STOP
85 FS? 01
86 GTO "AA"
87 FS? 02
88 GTO B
89 FS? 03
90 GTO C
```

BYPASS PRINTER

```
91♦LBL J
92 FC? 55
93 GTO 01
94 PRX
95 RTN
96♦LBL 01
97 VIEW X
98 RTN
```

COMMON CALC

```
99♦LBL F
100 RCL 04
101 68
102 -
103 .00002
104 *
105 1
106 +
107 359
108 *
109 RCL 02
110 X↑2
111 *
112 RCL 03
113 SQRT
114 *
115 RTN
```

COMMON ENTRIES

```
116♦LBL I
117 1
118 STO 01
119 29
120 STO 58
121 XEQ a
122 XEQ d
123 XEQ a
124 XEQ e
125 RTN
```

MAIN PROGRAM CALC BORE

```
126♦LBL A
127 FS? 00
128 GTO 01
129 CF 02
130 CF 03
131♦LBL 01
132 FS? 02
133 GTO "FLOW="
134 FS? 03
135 GTO "PRESS="
136 SF 01
137 25.266727
138 STO 30
139 XEQ I
140 XEQ e
141 XEQ d
142 CF 00
143♦LBL "AA"
144 RCL 05
145 XEQ F
146 /
```

```
147 RCL 06
148 15
149 +
150 SQRT
151 /
152 .4919
153 Y↑X
154 .6991
155 *
156 RCL 02
157 *
158 STO 07
159 GTO D
```

CALC FLOW

```
160♦LBL "FLOW="
161 FS? 00
162 GTO 01
163 CF 01
164 CF 03
165♦LBL 01
166 FS? 01
167 GTO A
168 FS? 03
169 GTO "PRESS="
170 SF 02
171 25.266728
172 STO 30
173 XEQ I
174 1
175 ST+ 01
176 38
177 STO 58
178 XEQ e
179 XEQ d
180 CF 00
181♦LBL B
182 RCL 07
183 RCL 02
184 /
185 .6991
186 /
187 .4919
188 1/X
189 Y↑X
190 XEQ F
191 *
192 RCL 06
193 15
194 +
195 SQRT
196 *
197 STO 05
198 GTO D
```

CALC PRESSURE

```
199♦LBL "PRESS="
200 FS? 00
201 GTO 01
202 CF 01
203 CF 02
204♦LBL 01
205 FS? 01
206 GTO A
207 FS? 02
208 GTO "FLOW="
209 SF 03
210 25.266729
211 STO 30
212 XEQ I
213 42
214 STO 58
215 XEQ e
216 1
217 ST+ 01
218 XEQ e
219 XEQ d
220 CF 00
221♦LBL C
222 RCL 07
223 RCL 02
224 /
225 .6991
226 /
227 .4919
228 1/X
229 Y↑X
230 XEQ F
231 *
232 1/X
233 RCL 05
234 *
235 X↑2
236 15
237 -
238 STO 06
239♦LBL D
240 STO 09
241 XEQ J
242 FS? 00
243 STOP
244 XEQ a
245 RCL 09
246 VIEW X
247 BEEP
248 ADV
249 STOP
250 .END.
```

Program 15: Sequence of Calculations

To calculate bore:

1. Calculate $Y_T S_P$ index.

$$Y_T S_P = \frac{W_m}{359\, D^2\, (1 + .00002\, (T_f - 68))\, \sqrt{\gamma_f P_f}}$$

2. Calculate beta ratio.

$$\beta = .6991\, (Y_T S_P)^{.4919}$$

3. Calculate orifice bore.

$$d = \beta D \text{ inches}$$

To calculate flow and inlet pressure:

1. Calculate $Y_T S_P$ index.

$$Y_T S_P = \frac{\beta}{.6991}^{1/.4919}$$

2. Flow $= 359 (Y_T S_P) D^2 (1 + .00002 (T_f - 68)) \sqrt{\gamma_f P_f}$ pounds per hour

3. Inlet pressure $= \dfrac{\left(\dfrac{W_m}{359 D^2 (Y_T S_P)(1 + .00002 (T_f - 68))}\right)^2}{\gamma_f} - 14.7$ PSIG

Program 15: Nomenclature

D	Inside diameter of pipe, inches
d	Bore of restriction orifice, inches
P_f	Inlet pressure, PSIA
T_f	Flow temperature, °F
W_m	Maximum rate of flow, pounds per hour
$Y_T S_P$	Index for β, dimensionless
β	Diameter ratio, dimensionless
γ_f	Specific weight at flowing conditions, pounds per cubic foot

References

L. K. Spink, *The Principles and Practices of Flowmeter Engineering*, The Foxboro Company.

CHAPTER SIX

Properties of Gas and Vapor

Program 16 Gas Properties
Typical Data

This program is not an instrument engineering program. With a stream analysis and a table of physical constants of mixtures which follows the mixture laws (see table on page 205), the program will provide most of the gas property data that are required for the instrument calculations in this book.

Program 16 will provide

1. The compressibility factor Z, dimensionless.
2. The specific weight (or density) γ, pounds per cubic foot.
3. The mixture molecular weight M, dimensionless.
4. The mixture critical temperature T_c, °R.
5. The mixture critical pressure P_c, PSIA.
6. The mixture ratio of specific heats C_p/C_v, dimensionless.
7. The mixture normal boiling point latent heat of vaporization ΔHV, Btu per pound.

Caution must be exercised when using the information in number 7. For mixtures having components with widely different values, the answer may be of limited value.

The program defaults to a compressibility factor and specific weight calculation if the first component volume % entry is 100. Any number of components can be handled by the program. It loops until 100% value is reached.

Program 16
Gas Properties

Program 16: User Instructions

Two programs are available. Program A calculates items 1–5; Program B calculates items 1–7.

a) Initiate program required, press A or B.
b) Enter:
   1. Flow pressure, PSIG — Press R/S
   2. Flow temperature, °F — Press R/S
   3. Component-number volume % (*Note:* When the volume % is 100, the program goes immediately to the calculation. When the volume % is not 100, it continues.) — Press R/S
   4. Critical pressure, PSIA — Press R/S
   5. Critical temperature, °R — Press R/S
   6. Molecular weight, dimensionless — Press R/S

   And, if program B is selected:

   7. Ratio of specific heats C_p/C_v, dimensionless — Press R/S
   8. Normal boiling point latent heat of vaporization, Btu per pound — Press R/S
c) Program calculates remaining volume %. If less than 100, it loops back to 3. If equal to 100, it continues and calculates:
   - Mixture critical pressure, PSIA
   - Mixture critical temperature, °R
   - Mixture molecular weight, dimensionless

   And, if program B was selected, it calculates:

   - Mixture ratio of specific heats C_p/C_v, dimensionless
   - Mixture normal boiling point latent heat of vaporization, Btu per pound

   And, finally, both programs calculate:

   - Compressibility factor *Z*, dimensionless, and specific weight (or density), pounds per cubic foot

---

Program 16: TI 59 Data Sheet

```
********************
         A
 GAS PROPERTIES

********************

ENTR   FLOW PRSS PSIG
          100.
ENTR   FLOW TEMP    °F
           60.

ENTR CMPNT N° 1 VOL%
          100.
ENTR  CRIT PRSS PSIA
          200.
ENTR  CRIT TEMP    °R
          500.
ENTR  MW
           20.

CALC       Z
 .8017328052
```

```
CALC DENSITY      PPCF
 .5128149689

********************
********************
```

A

```
 GAS PROPERTIES

********************

ENTR  FLOW PRSS PSIG
          100.
ENTR  FLOW TEMP    °F
           60.

ENTR CMPNT N° 1 VOL%
           50.
ENTR  CRIT PRSS PSIA
          300.
ENTR  CRIT TEMP    °R
          600.
ENTR  MW
           30.
CALC  VOL% TOGO
           50.

ENTR CMPNT N° 2 VOL%
           50.
ENTR  CRIT PRSS PSIA
          100.
ENTR  CRIT TEMP    °R
          400.
ENTR  MW
           10.

CALC MXTUR CRIT PRSS
          200.
CALC MXTUR CRIT TEMP
          500.
CALC MXTUR MW
           20.

CALC      Z
 .8017328052
CALC DENSITY      PPCF
 .5128149689

********************
********************
```

B

```
 GAS PROPERTIES

********************

ENTR  FLOW PRSS PSIG
          100.
ENTR  FLOW TEMP    °F
           60.

ENTR CMPNT N° 1 VOL%
           50.
ENTR  CRIT PRSS PSIA
          300.
ENTR  CRIT TEMP    °R
           30.
ENTR  MW
           30.
ENTR CP/CV
          1.6
ENTR  NBP ΔHV  BTU/P
          300.
CALC  VOL% TOGO
           50.

ENTR CMPNT N° 2 VOL%
           50.
ENTR  CRIT PRSS PSIA
          100.
ENTR  CRIT TEMP    °R
          970.
ENTR  MW
           10.
ENTR CP/CV
          1.2
ENTR  NBP ΔHV  BTU/P
          100.

CALC MXTUR CRIT PRSS
          200.
CALC MXTUR CRIT TEMP
          500.
CALC MXTUR MW
           20.
CALC MXTUR      CP/CV
          1.4
CALC MXTUR NBP ΔHV
          200.

CALC      Z
 .8017328052
CALC DENSITY      PPCF
 .5128149689

********************
```

Program 16: TI 59 Register Loading

PARTITIONING
479.59

0.	00	0.545352	29
0.	01	33331521.	30
0.	02	21273243.	31
0.	03	3745000000.	32
0.	04	1617313624.	33
0.	05	46.0866403	34
0.	06	3044374135.	35
0.	07	37322232.	36
0.	08	1437416333.	37
0.	09	7523420000.	38
0.	10	31143300.	39
0.	11	1533631542.	40
0.	12	30430000.	41
0.5633323	13	7335.	42
0.5634	14	33362413.	43
75.56353938	15	15352437.	44
0.5635004	16	42322761.	45
0.563541	17	31730002.	46
0.56354449	18	1530333137.	47
0.56354451	19	7321.00001	48
0.564536	20	37173033.	49
0.57393837	21	33362422.	50
0.574	22	33353636.	51
0.5741	23	3537241736.	52
0.57444942	24	3335323317.	53
0.57445143	25	22133600.	54
0.57475845	26	5151515151.	55
0.57314948	27	1513271500.	56
0.5731515	28	1731373500.	57
		0.	58
		0.	59

Program 16: TI 59 Listing

PRINT AND STORE VARIABLES

```
000  76 LBL
001  10 E'
002  19 D'
003  73 RC*
004  01  01
005  69 OP
006  21  21
007  91 R/S
008  99 PRT
009  72 ST*
010  01  01
011  92 RTN
```

PRINT LINES

```
012  76 LBL
013  19 D'
014  42 STO
015  59  59
016  18 C'
017  69 OP
018  01  01
019  18 C'
020  69 OP
021  02  02
022  18 C'
023  69 OP
024  03  03
025  18 C'
026  69 OP
027  04  04
028  69 OP
029  05  05
030  92 RTN
```

DECODE LINES

```
031  76 LBL
032  18 C'
033  01  1
034  00  0
035  00  0
036  48 EXC
037  59  59
038  22 INV
039  59 INT
040  49 PRD
041  59  59
042  73 RC*
043  59  59
044  92 RTN
```

CALC %

```
045  76 LBL
046  17 B'
047  19 D'
048  43 RCL
049  05  05
```

```
050   69  OP
051   21   21
052   91  R/S
053   99  PRT
054   65   ×
055   43  RCL
056   05   05
057   55   ÷
058   01   1
059   00   0
060   00   0
061   95   =
062   74  SM*
063   01   01
064   92  RTN
```

PRINT LINE OF STARS

```
065   76  LBL
066   16  A'
067   05   5
068   55   ÷
069   09   9
070   95   =
071   98  ADV
072   19  D'
073   98  ADV
074   92  RTN
```

PRINT %

```
075   76  LBL
076   42  STO
077   43  RCL
078   20   20
079   19  D'
080   43  RCL
081   04   04
082   99  PRT
083   01   1
084   44  SUM
085   58   58
086   04   4
087   42  STO
088   01   01
089   61  GTO
090   22  INV
091   04   4
092   42  STO
093   01   01
```

MAIN PROGRAM A—ENTER DATA

```
094   76  LBL
095   11   A
096   86  STF
097   01   01
```

PROGRAM B ENTER DATA

```
098   76  LBL
099   12   B
100   29  CP
101   01   1
102   42  STO
103   01   01
104   01   1
105   00   0
106   00   0
107   42  STO
108   04   04
109   43  RCL
110   46   46
111   42  STO
112   58   58
113   00   0
114   42  STO
115   06   06
116   42  STO
117   07   07
118   42  STO
119   08   08
120   42  STO
121   09   09
122   42  STO
123   10   10
124   16  A'
125   43  RCL
126   29   29
127   19  D'
128   16  A'
129   43  RCL
130   28   28
131   10  E'
132   43  RCL
133   27   27
134   10  E'
135   69  OP
136   21   21
137   76  LBL
138   22  INV
139   98  ADV
140   43  RCL
141   26   26
142   10  E'
143   43  RCL
144   25   25
145   17  B'
146   43  RCL
147   24   24
148   17  B'
149   43  RCL
150   23   23
151   17  B'
152   87  IFF
153   01   01
154   23  LNX
155   01   1
156   00   0
157   00   0
158   32  X:T
159   43  RCL
160   05   05
161   67   EQ
162   23  LNX
163   43  RCL
164   22   22
165   17  B'
166   43  RCL
167   21   21
168   17  B'
169   76  LBL
170   23  LNX
171   43  RCL
172   05   05
173   22  INV
174   44  SUM
175   04   04
176   29  CP
177   43  RCL
178   04   04
179   22  INV
180   67   EQ
181   42  STO
182   43  RCL
183   58   58
184   75   -
185   43  RCL
186   46   46
187   95   =
188   67   EQ
189   43  RCL
190   98  ADV
```

PRINT MIXTURE VALUES

```
191   43  RCL
192   19   19
193   19  D'
194   43  RCL
195   06   06
196   99  PRT
197   43  RCL
198   18   18
199   19  D'
200   43  RCL
201   07   07
202   99  PRT
```

```
203  43  RCL
204  17   17
205  19  D'
206  43  RCL
207  08   08
208  99  PRT
209  87  IFF
210  01   01
211  43  RCL
212  43  RCL
213  16   16
214  19  D'
215  43  RCL
216  09   09
217  99  PRT
218  43  RCL
219  15   15
220  19  D'
221  43  RCL
222  10   10
223  99  PRT
```

CALC P & T

```
224  76  LBL
225  43  RCL
226  22  INV
227  86  STF
228  01   01
229  98  ADV
230  01   1
231  04   4
232  93   .
233  07   7
234  44  SUM
235  02   02
236  04   4
237  06   6
238  00   0
239  44  SUM
240  03   03
241  43  RCL
242  14   14
243  19  D'
```

CALC B P_f

```
244  76  LBL
245  15   E
246  43  RCL
247  48   48
248  22  INV
249  59  INT
250  32  X:T
251  43  RCL
252  34   34
253  22  INV
254  59  INT
255  65   ×
256  43  RCL
257  07   07
258  55   ÷
259  43  RCL
260  06   06
261  65   ×
262  43  RCL
263  02   02
264  55   ÷
265  43  RCL
266  03   03
267  95   =
268  42  STO
269  11   11
```

CALC A²/B

```
270  43  RCL
271  07   07
272  55   ÷
273  43  RCL
274  03   03
275  95   =
276  45  Y^X
277  01   1
278  93   .
279  05   5
280  65   ×
281  04   4
282  93   .
283  09   9
284  03   3
285  03   3
286  09   9
287  06   6
288  95   =
289  42  STO
290  12   12
```

ITERATE FOR Z

```
291  01   1
292  42  STO
293  01   01
294  76  LBL
295  25  CLR
296  43  RCL
297  01   01
298  33  X²
299  65   ×
300  03   3
301  75   -
302  43  RCL
303  01   01
304  65   ×
305  02   2
306  85   +
307  53   (
308  43  RCL
309  11   11
310  65   ×
311  53   (
312  43  RCL
313  12   12
314  75   -
315  43  RCL
316  11   11
317  75   -
318  01   1
319  54   )
320  54   )
321  42  STO
322  59   59
323  95   =
324  42  STO
325  09   09
326  43  RCL
327  01   01
328  45  Y^X
329  03   3
330  75   -
331  43  RCL
332  01   01
333  33  X²
334  85   +
335  43  RCL
336  59   59
337  65   ×
338  43  RCL
339  01   01
340  75   -
341  43  RCL
342  12   12
343  65   ×
344  43  RCL
345  11   11
346  33  X²
347  95   =
348  55   ÷
349  43  RCL
350  09   09
351  95   =
352  22  INV
353  44  SUM
354  01   01
355  50  IxI
356  77   GE
```

```
357  25 CLR
358  43 RCL
359  01  01
360  99 PRT
361  42 STO
362  10  10
```

CALC DENSITY

```
363  43 RCL
364  13  13
365  19 D'
366  43 RCL
367  02  02
368  55  ÷
369  43 RCL
370  03  03
371  65  ×
372  43 RCL
373  08  08
374  55  ÷
375  43 RCL
376  10  10
377  55  ÷
378  01  1
379  00  0
380  93  .
381  07  7
382  03  3
383  95  =
384  99 PRT
385  42 STO
386  11  11
387  32 X⇌T
388  16 A'
389  98 ADV
390  98 ADV
391  98 ADV
392  32 X⇌T
393  91 R/S
```

Program 16: HP 41CV Data Sheet

```
************

    *GAS*
*PROPERTIES*

************


ENTER PRSS PSIG
     100.0000000    ***
ENTER TEMP DEG F
     60.00000000    ***
ENTER % COMPNT NO 1.
     100.0000000    ***
ENTER CRIT  PRSS PSIA
     200.0000000    ***
ENTER CRIT  TEMP DEG R
     500.0000000    ***
ENTER MW
     20.00000000    ***
CALC     Z
     0.801732805    ***
CALC DENSITY
 PPCF
     0.512814969    ***


************
```

```
************

    *GAS*
*PROPERTIES*

************

ENTER PRSS PSIG
     100.0000000    ***
ENTER TEMP DEG F
     60.00000000    ***
ENTER % COMPNT NO 1.
     25.00000000    ***
ENTER CRIT  PRSS PSIA
     200.0000000    ***
ENTER CRIT  TEMP DEG R
     500.0000000    ***
ENTER MW
     20.00000000    ***
ENTER CP/CV
     1.400000000    ***
ENTER NBP dHV BTU/P
     200.0000000    ***
CALC % TO GO
     75.00000000    ***

ENTER % COMPNT NO 2.
     75.00000000    ***
ENTER CRIT  PRSS PSIA
     200.0000000    ***
```

```
ENTER CRIT  TEMP DEG R
     500.0000000    ***
ENTER MW
     20.00000000    ***
ENTER CP/CV
     1.400000000    ***
ENTER NBP dHV BTU/P
     200.0000000    ***
CALC MIXTURE
CRIT   PRSS
     200.0000000    ***
CALC MIXTURE
CRIT   TEMP
     500.0000000    ***
CALC MIXTURE
MW
     20.00000000    ***
CALC MIXTURE
CP/CV
     1.400000000    ***
CALC MIXTURE
NBP dHV
     200.0000000    ***
CALC     Z
     0.801732805    ***
CALC DENSITY
 PPCF
     0.512814969    ***
************
```

Program 16: HP 41CV Register Loading

SIZE 080

```
R00=  0.000000
R01=  0.000000
R02=  0.000000
R03=  0.000000
R04=  0.000000
R05=  0.000000
R06=  0.000000
R07=  0.000000
R08=  0.000000
R09=  0.000000
R10=  0.000000
R11=  0.000000
R12=  0.000000
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  0.000000
R17=  0.000000
R18=  0.000000
R19=  0.000000
R20=  0.000000
R21=  0.000000
R22=  0.000000
R23=  0.000000
R24= "   *GA"
R25= "S*    "
R26= "*PROPE"
R27= "RTIES*"
R28= "CALC M"
R29=  24.252627
R30=  57.505100
R31=  57.525300
R32=  0.000000
R33=  57.546260
R34=  0.000000
R35=  57.635064
R36=  57.635265
R37=  57.660000
R38=  0.000000
R39=  57.670000
R40=  57.686970
R41=  0.000000
R42=  79.710000
R43=  28.726373
R44=  28.726374
R45=  28.726600
R46=  28.726700
R47=  28.726861
R48=  56.750000
R49=  76.777800
R50= "PRSS P"
R51= "SIG   "
R52= "TEMP D"
R53= "EG F  "
R54= "% COMP"
R55= "******"
R56= "CALC  "
R57= "ENTER "
R58=  49.000000
R59=  0.000000
R60=  1.000000
R61= "V     "
R62= "NT NO "
R63= "CRIT  "
R64= "SIA   "
R65= "EG R  "
R66= "MW    "
R67= "CP/CV"
R68= "NBP dH"
R69= "V BTU/"
R70= "P     "
R71= " TO GO"
R72= "IXTURE"
R73= "PRSS  "
R74= "TEMP  "
R75= " Z    "
R76= "CALC D"
R77= "ENSITY"
R78= " PPCF "
R79= "CALC %"
```

Program 16: HP 41CV Listing

SUBROUTINES

```
01♦LBL "GAS PRP"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 FIX 0
22 ARCL IND 59
23 FIX 9
24 RCL 59
25 FRC
26 100
27 *
28 STO 59
29 X≠0?
30 GTO c
31 FC? 55
32 GTO 01
33 PRA
34 CF 12
35 RTN
36♦LBL 01
37 CF 12
38 AVIEW
39 RTN
```

PRINT & STORE VARIABLES

```
40♦LBL e
41 1
42 ST+ 58
43 RCL IND 58
44 X=0?
45 RTN
46 XEQ b
47 1
48 ST+ 01
49 RCL IND 01
50 TONE 9
51 FS? 00
52 GTO 01
53 STOP
```

```
54 FC? 01
55 GTO 02
56 XEQ J
57 RCL 04
58 *
59 100
60 /
61 ST+ IND 01
62 GTO e
63♦LBL 02
64 STO IND 01
65♦LBL 01
66 XEQ J
67 GTO e
```

RE-ENTER VARIABLES

```
68♦LBL "REENTER"
69 ADV
70 1
71 +
72 STO 01
73 RCL IND 01
74 XEQ J
75 STOP
76 XEQ J
77 STO IND 01
78 ADV
79 SF 00
80 SF 02
81 100
82 STO 04
83 STOP
84 GTO C
```

BYPASS PRINTER

```
85♦LBL J
86 FC? 55
87 GTO 01
88 PRX
89 RTN
90♦LBL 01
91 VIEW X
92 RTN
```

MAIN PROGRAM INCLUDES CP/CV & dHV

```
93♦LBL "CP/CV"
94 SF 03
```

ENTER DATA

```
95♦LBL A
96 1
97 STO 01
98 STO 21
99 STO 60
100 28
101 STO 58
102 FS? 00
103 GTO 01
104 0
105 STO 05
106 STO 06
107 STO 07
108 STO 08
109 STO 09
110 100
111 STO 20
112 STO 04
113♦LBL 01
114 XEQ a
115 XEQ d
116 XEQ a
117 XEQ e
118 CF 02
119♦LBL B
120 3
121 STO 01
122 32
123 STO 58
124 FS? 00
125 GTO G
126 XEQ e
127 RCL 04
128 ST- 20
129 100
130 -
131 X=0?
132 GTO G
133 SF 01
134 XEQ e
135 FS? 03
136 XEQ e
137 RCL 20
138 0
139 X≠Y?
140 GTO 01
141 CF 00
142 CF 01
```

PRINT MIXTURE VALUES

```
143 42
144 STO 58
145 XEQ d
146 RCL 05
147 XEQ J
148 XEQ d
149 RCL 06
150 XEQ J
151 XEQ d
152 RCL 07
153 XEQ J
154 FC? 03
155 GTO C
156 XEQ d
157 RCL 08
158 XEQ J
159 XEQ d
160 RCL 09
161 XEQ J
162 GTO C
163♦LBL 01
164 RCL 20
165 STO 04
166 41
167 STO 58
168 XEQ d
169 CF 01
170 RCL 20
171 XEQ J
172 1
173 ST+ 60
174 ADV
175 GTO B
176♦LBL G
177 34
178 STO 58
179 4
180 STO 01
181 XEQ e
```

CALC BP_f

```
182♦LBL C
183 47
184 STO 58
185 XEQ d
186 .0866403
187 RCL 06
188 *
189 RCL 05
190 /
191 RCL 02
192 14.7
193 +
194 *
195 RCL 03
196 460
197 +
198 /
199 STO 11
```

CALC A^2/B

```
200 RCL 06
201 RCL 03
202 460
203 +
204 /
205 1.5
206 Y↑X
207 4.93396
208 *
209 STO 12
```

ITERATE FOR Z

```
210♦LBL F
211 RCL 21
212 X↑2
213 3
214 *
215 RCL 21
216 2
217 *
218 -
219 RCL 12
220 RCL 11
221 -
222 1
223 -
224 RCL 11
225 *
226 STO 22
227 +
228 STO 23
229 RCL 21
230 3
231 Y↑X
232 RCL 21
233 X↑2
234 -
235 RCL 22
236 RCL 21
237 *
238 +
239 RCL 12
240 RCL 11
241 X↑2
242 *
243 -
244 RCL 23
245 /
246 ST- ^1
247 ABS
248 PSE
249 .00001
250 X<>Y
251 X>Y?
252 GTO F
253 RCL 21
254 XEQ J
```

CALC DENSITY

```
255 XEQ d
256 RCL 02
257 14.7
258 +
259 RCL 03
260 460
261 +
262 /
263 RCL 07
264 *
265 RCL 21
266 /
267 10.73
268 /
269 STO 13
270 XEQ J
271 FS? 02
272 STOP
273 XEQ a
274 CF 00
275 CF 03
276 CF 04
277 RCL 21
278 RCL 13
279 VIEW X
280 BEEP
281 ADV
282 STOP
283 END
```

Program 16: Sequence of Calculations

1. Mixture values are calculated by the mixture law, which assumes that the property of the mixture is the sum of the partial fractions.
2. The compressibility factor is iterated from the Redlich-Kwong equation.

$$fx = Z^3 - Z^2 + BP_f\left(\left(\frac{A^2}{B}\right) - BP_f - 1\right)Z - \left(\left(\frac{A^2}{B}\right)BP_f\right)^2$$

$$f^1x = 3Z^2 - 2Z + BP_f\left(\left(\frac{A^2}{B}\right) - BP_f - 1\right)$$

where

$$A = \frac{.42748T_c^{2.5}}{P_cT_f^{2.5}}$$

$$BP_f = .0866403\,\frac{T_cP_f}{P_cT_f}$$

$$\frac{A^2}{B} = 4.93396\left(\frac{T_c}{T_f}\right)^{1.5}$$

Start with $Z = 1$ and calculate fx/f^1x. If greater than 0.00001, subtract fx/f^1x from the current value of Z and repeat until the error is less than 0.00001.

3. Calculate the specific weight.

$$\gamma_f = \frac{P_f}{T_f}\frac{M}{1.314Z} \quad \text{pounds per cubic foot}$$

Program 16: Nomenclature

A, B	Partial calculations for Z
M	Molecular weight, dimensionless
P_f	Flowing pressure, atmospheres
P_c	Critical pressure, atmospheres
T_f	Flowing temperature, °K
T_c	Critical temperature, °K
Z	Compressibility, dimensionless
γ_f	Specific weight, pounds per cubic foot

Note: These units do not correspond with the calculator input units. The program converts as necessary.

Typical Data

Physical Properties

No.	Compound	Formula	Critical Constants: Pressure, PSIA (P_c)	Critical Constants: Temperature, °R (T_c)	Molecular Weight (M)	Ratio of Specific Heats C_p/C_v at 14.7 PSIA and 60°F (k)	Heat of Vaporization, 14.696 PSIA at Boiling Point, Btu/lb ($NBP\ \Delta HV$)
1	Methane	CH_4	667.8	343.4	16.043	1.311	219.22
2	Ethane	C_2H_6	707.8	550.0	30.070	1.193	210.41
3	Propane	C_3H_8	616.3	666.0	44.097	1.136	183.05
4	*n*-Butane	C_4H_{10}	550.7	765.0	58.124	1.094	165.65
5	Isobutane	C_4H_{10}	529.1	735.0	58.124	1.097	157.53
6	*n*-Pentane	C_5H_{12}	488.6	845.7	72.151	1.074	153.59
7	Isopentane	C_5H_{12}	490.4	829.1	72.151	1.075	147.13
8	Neopentane	C_5H_{12}	464.0	781.0	72.151	1.074	135.58
9	*n*-Hexane	C_6H_{14}	436.9	913.7	86.178	1.062	143.95
10	2-Methylpentane	C_6H_{14}	436.6	895.8	86.178	1.063	138.67
11	3-Methylpentane	C_6H_{14}	453.1	908.3	86.178	1.064	140.09
12	Neohexane	C_6H_{14}	446.8	860.1	86.178	1.064	131.24
13	2,3-Dimethylbutane	C_6H_{14}	453.5	900.3	86.178	1.065	136.08
14	*n*-Heptane	C_7H_{16}	396.8	972.8	100.205	1.054	136.01
15	2-Methylhexane	C_7H_{16}	396.5	955.0	100.205	1.054	131.59
16	3-Methylhexane	C_7H_{16}	408.1	963.8	100.205	1.054	132.11
17	3-Ethylpentane	C_7H_{16}	419.3	973.5	100.205	1.054	132.83
18	2,2-Dimethylpentane	C_7H_{16}	402.2	937.2	100.205	1.053	125.13

(table continued on next page)

Physical Properties (continued)

No.	Compound	Formula	Critical Constants: Pressure, PSIA (P_c)	Critical Constants: Temperature, °R (T_c)	Molecular Weight (M)	Ratio of Specific Heats C_p/C_v at 14.7 PSIA and 60°F (k)	Heat of Vaporization, 14.696 PSIA at Boiling Point, Btu/lb ($NBP\ \Delta HV$)
19	*2,4*-Dimethylpentane	C_7H_{16}	396.9	936.0	100.205	1.053	126.58
20	*3,3*-Dimethylpentane	C_7H_{16}	427.2	965.9	100.205	1.053	127.21
21	Triptane	C_7H_{16}	428.4	956.4	100.205	1.055	124.21
22	*n*-Octane	C_8H_{18}	360.6	1024.2	114.232	1.046	129.53
23	Diisobutyl	C_8H_{18}	360.6	990.4	114.232	1.049	122.80
24	Isooctane	C_8H_{18}	372.4	979.5	114.232	1.049	116.71
25	*n*-Nonane	C_9H_{20}	332.0	1070.7	128.259	1.042	123.76
26	*n*-Decane	$C_{10}H_{22}$	304.0	1112.1	142.286	1.038	118.68
27	Cyclopentane	C_5H_{10}	653.8	921.5	70.135	1.117	167.34
28	Methylcyclopentane	C_6H_{12}	548.9	959.4	84.162	1.085	147.83
29	Cyclohexane	C_6H_{12}	591.0	996.7	84.162	1.089	153.00
30	Methylcyclohexane	C_7H_{14}	503.5	1030.3	98.189	1.068	136.30
31	Ethylene	C_2H_4	729.8	506.6	28.054	1.243	207.57
32	Propene	C_3H_6	669.0	656.9	42.081	1.154	188.18
33	*1*-Butene	C_4H_8	583.0	755.6	56.108	1.111	167.94
34	*cis-2*-Butene	C_4H_8	610.0	784.4	56.108	1.121	178.91
35	*trans-2*-Butene	C_4H_8	595.0	771.9	56.108	1.107	174.39
36	Isobutene	C_4H_8	580.0	752.6	56.108	1.106	169.48
37	*1*-Pentene	C_5H_{10}	590.0	836.9	70.135	1.084	154.46
38	*1,2*-Butadiene	C_4H_6	653.0	799.0	54.092	1.118	181.00
39	*1,3*-Butadiene	C_4H_6	628.0	766.0	54.092	1.120	174.00
40	Isoprene	C_5H_8	558.4	872.0	68.119	1.089	153.00

Physical Properties (continued)

No.	Compound	Formula	Critical Constants: Pressure, PSIA (P_c)	Critical Constants: Temperature, °R (T_c)	Molecular Weight (M)	Ratio of Specific Heats C_p/C_v at 14.7 PSIA and 60°F (k)	Heat of Vaporization, 14.696 PSIA at Boiling Point, Btu/lb ($NBP\ \Delta HV$)
41	Acetylene	C_2H_2	890.4	555.3	26.038	1.238	—
42	Benzene	C_6H_6	710.4	1012.2	78.114	1.117	169.31
43	Toluene	C_7H_8	595.9	1065.6	92.141	1.091	154.84
44	Ethylbenzene	C_8H_{10}	523.5	1111.2	106.168	1.072	144.00
45	*o*-Xylene	C_8H_{10}	541.4	1135.0	106.168	1.069	149.10
46	*m*-Xylene	C_8H_{10}	513.6	1111.0	106.168	1.072	147.20
47	*p*-Xylene	C_8H_{10}	509.2	1109.6	106.168	1.072	144.52
48	Styrene	C_8H_8	580.0	1166.0	104.152	1.076	151.00
49	Isopropylbenzene	C_9H_{12}	465.4	1136.4	120.195	1.060	134.30
50	Methyl Alcohol	CH_4O	1174.2	923.0	32.042	1.237	473.0
51	Ethyl Alcohol	C_2H_6O	925.3	929.6	46.069	1.149	367.0
52	Carbon Monoxide	CO	507.0	240.0	28.010	1.403	92.7
53	Carbon Dioxide	CO_2	1071.0	547.9	44.010	1.293	238.2
54	Hydrogen Sulfide	H_2S	1306.0	672.7	34.076	1.323	235.6
55	Sulfur Dioxide	SO_2	1145.1	775.5	64.059	1.272	166.7
56	Ammonia	NH_3	1636.1	730.3	17.031	1.304	587.2
57	Air	N_2O_2	547.0	238.7	28.964	1.395	92.0
58	Hydrogen	H_2	188.1	60.2	2.016	1.408	193.9
59	Oxygen	O_2	736.9	278.9	31.999	1.401	91.6
60	Nitrogen	N_2	493.0	227.4	28.013	1.402	87.8
61	Chloride	Cl_2	1118.4	751.0	70.906	1.330	123.8
62	Water	H_2O	3208.0	1165.6	18.015	1.335	970.3
63	Helium	He	—	—	4.003	1.660	—
64	Hydrogen Chloride	HCl	1198.0	584.5	36.461	1.410	185.5

Note: C_p/C_v calculated by the formula $k = C_p/(C_p - 1.1987)/M$.

CHAPTER SEVEN

Pitot Tubes

Pitot tubes measure flow by generating a differential pressure proportional to the square of flow. They have the same characteristics as orifice plates and have only started becoming popular in recent years as performance data have become more available.

Their big advantages are low pressure loss and low installed cost, and they are thus finding many applications on large lines and for measuring flow in centrifugal compressor discharge lines. Their biggest disadvantage is that they produce a fixed and unalterable differential range as low as a few inches of water for some applications. This problem is disappearing as more sensitive differential pressure instruments become available. There also has been some fear of excessive vibration, resulting in the tube entering rotating equipment and causing catastrophic damage. Vibration analysis techniques and new designs appear to have solved this problem.

The formulas and techniques used in sizing are from the *Annubar Flow Handbook,* published by the Dieterich Standard Corporation, and this is recommended for reference data.

Program 17
Liquid Flow

Program 17: User Instructions

a) Initiate program, press A.
b) Enter:
   1. Annubar type number (see page 225), dimensionless — Press R/S
   2. Flowrate, pounds per hour — Press R/S

3. Flow temperature, °F	Press R/S
4. Specific gravity at flow temperature, dimensionless	Press R/S
5. Absolute viscosity, centipoises	Press R/S
6. Pipe inside diameter, inches	Press R/S
7. Flow coefficient K from page 225, dimensionless	Press R/S
c) Program calculates Reynolds number R_D.	Press R/S
d) Enter:	
8. Reynolds number correction factor F_{RA} (see pages 226–228), dimensionless	Press R/S
e) Program calculates differential range in inches of water.	

Note: The E subroutine is available to re-enter data and recalculate.

Program 17: TI 59 Data Sheet

```
*****************   ***

     PITOT-LIQUID

*********************

ENTR  TYPE   N°
           75.
ENTR  FLOW  PPH
    2475000.
ENTR  TEMP   °F
          100.
ENTR  FLOW   SG
         0.825

ENTR  VISC   CP
            4.
ENTR  PIPE   ID   IN
         19.25
ENTR COEFFCNT K
        0.7092
CALC     RD
   203014.2857
ENTR   FRA
        0.9739
CALC DIFF RANGE IN/W
   14.090432

*********************
```

Program 17: TI 59 Register Loading

PARTITIONING
479.59

0.	00	0.	10
0.	01	0.	11
0.	02	0.	12
0.	03	0.	13
0.	04	0.	14
0.	05	0.	15
0.	06	0.	16
0.	07	0.	17
0.	08	0.	18
0.	09	0.	19
		0.	20
		2830.823696	21
		0.	22

0.	23	56.272625	42
.0000190813	24	33243317.	43
24316343.	25	42243615.	44
3513312217.	26	37173033.	45
1624212100.	27	21273243.	46
1531370026.	28	0.	47
1532172121.	29	0.	48
54.535251	30	3173.	49
0.5049	31	37453317.	50
2416.4637	32	1600000000.	51
1533.4536	33	2724344124.	52
3622.4634	34	2437323720.	53
213513.4433	35	33.	54
7321.433241	36	5151515151.	55
333323.2928	37	1513271500.	56
3516.	38	1731373500.	57
56.38	39	0.	58
27.35	40	0.	59
2431.	41		

Program 17: TI 59 Listing

SUBROUTINES

PRINT & STORE VARIABLES

```
000  76  LBL
001  10  E'
002  29  CP
003  01   1
004  44  SUM
005  58   58
006  73  RC*
007  58   58
008  22  INV
009  59  INT
010  52  EE
011  22  INV
012  52  EE
013  67   EQ
014  19  D'
015  85   +
016  05   5
017  07   7
018  95   =
019  17  B'
020  69  OP
021  21   21
022  73  RC*
023  01   01
024  87  IFF
025  00   00
026  00   00
027  31   31
028  91  R/S
029  72  ST*
030  01   01
031  73  RC*
032  01   01
033  99  PRT
034  61  GTO
035  10  E'
```

PRINT LINES

```
036  76  LBL
037  19  D'
038  01   1
039  44  SUM
040  58   58
041  73  RC*
042  58   58
043  76  LBL
044  17  B'
045  42  STO
046  59   59
047  73  RC*
048  59   59
049  69  OP
050  01   01
051  18  C'
052  69  OP
053  02   02
054  18  C'
055  69  OP
056  03   03
057  18  C'
058  69  OP
059  04   04
060  69  OP
061  05   05
062  92  RTN
```

DECODE LINES

```
063  76  LBL
064  18  C'
065  01   1
066  00   0
067  00   0
068  48  EXC
069  59   59
070  22  INV
071  59  INT
072  49  PRD
073  59   59
074  73  RC*
075  59   59
076  92  RTN
```

PRINT LINE OF STARS

```
077  76  LBL
```

```
078  16  A'
079  93  .
080  00  0
081  01  1
082  08  8
083  35  1/X
084  98  ADV
085  17  B'
086  98  ADV
087  92  RTN
```

RE-ENTER VARIABLES

```
088  76  LBL
089  15  E
090  99  PRT
091  85  +
092  01  1
093  95  =
094  42  STO
095  01  01
096  73  RC*
097  01  01
098  91  R/S
099  72  ST*
100  01  01
101  99  PRT
102  98  ADV
103  86  STF
104  00  00
105  86  STF
106  01  01
107  91  R/S
108  61  GTO
109  22  INV
```

MAIN PROGRAM
ENTER DATA

```
110  76  LBL
111  11  A
112  22  INV
113  86  STF
114  01  01
115  01  1
116  42  STO
117  01  01
118  02  2
119  09  9
120  42  STO
121  58  58
122  16  A'
123  19  D'
124  16  A'
125  10  E'
```

```
126  76  LBL
127  22  INV
128  06  6
129  93  .
130  03  3
131  01  1
132  06  6
133  65  ×
134  43  RCL
135  03  03
136  55  ÷
137  43  RCL
138  07  07
139  55  ÷
140  43  RCL
141  06  06
142  95  =
143  99  PRT
```

ENTER F_{RA}

```
144  03  3
145  09  9
146  42  STO
147  58  58
148  08  8
149  42  STO
150  01  01
151  10  E'
152  87  IFF
153  01  01
154  24  CE
155  22  INV
156  86  STF
157  00  00
```

CALC dP

```
158  76  LBL
159  24  CE
160  43  RCL
161  03  03
162  55  ÷
163  53  (
164  43  RCL
165  21  21
166  65  ×
167  43  RCL
168  08  08
169  65  ×
170  43  RCL
171  07  07
172  33  X²
173  65  ×
174  43  RCL
175  09  09
176  65  ×
177  53  (
178  43  RCL
179  24  24
180  65  ×
181  43  RCL
182  04  04
183  54  )
184  22  INV
185  23  LNX
186  65  ×
187  43  RCL
188  05  05
189  34  √X
190  54  )
191  95  =
192  33  X²
193  99  PRT
194  42  STO
195  22  22
196  16  A'
197  98  ADV
198  98  ADV
199  43  RCL
200  22  22
201  91  R/S
```

(Program 17: HP 41 CV Data Sheet on next page)

Program 17: HP 41CV Data Sheet

```
************

PITOT LIQUID

************

ENTER TYPE NUMBER
        75.0000     ***
ENTER FLOW  PPH
   2,475,000.000    ***
ENTER TEMP DEG F
          100.0000  ***
ENTER FLOW  SG
            0.8250  ***
ENTER VISCOSITY cP
            4.0000  ***
ENTER PIPE ID INS
           19.2500  ***
ENTER COEF K
            0.7092  ***
CALC   RD
     203,014.2857   ***
ENTER COEF FRA
           0.9739   ***
CALC   DIFF
RANGE  IN  H2O
          14.0904   ***

************
```

Program 17: HP 41CV Register Loading

SIZE 080

```
R00=  0.000000
R01=  0.000000
R02=  0.000000
R03=  0.000000
R04=  0.000000
R05=  0.000000
R06=  0.000000
R07=  0.000000
R08=  0.000000
R09=  0.000000
R10=  0.000000
R11=  0.000000
R12=  0.000000
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  0.000000
R17=  0.000000
R18=  0.000000
R19=  0.000000
R20=  0.000000
R21=  2,830.823696
R22=  0.000000
R23=  0.000000
R24=  0.000019
R25= "PITOT "
R26= "LIQUID"
R27=  0.000000
R28=  0.000000
R29=  0.000000
R30=  25.260000
R31=  57.505100
R32=  57.525300
R33=  57.546000
R34=  57.526100
R35=  57.626300
R36=  57.646500
R37=  57.660000
R38=  0.000000
R39=  56.680000
R40=  57.677000
R41=  0.000000
R42=  56.717273
R43=  0.000000
R44=  0.000000
R45=  0.000000
R46=  0.000000
R47=  0.000000
R48=  0.000000
R49=  0.000000
R50= "TYPE N"
R51= "UMBER "
R52= "FLOW  "
R53= "PPH   "
R54= "TEMP D"
R55= "******"
R56= "CALC  "
R57= "ENTER "
R58=  42.000000
R59=  0.000000
R60= "EG F  "
R61= "SG    "
R62= "VISCOS"
R63= "ITY cP"
R64= "PIPE I"
R65= "D INS "
R66= "COEF K"
R67= "COEF  "
R68= "RD    "
R69=  0.000000
R70= "FRA   "
R71= "DIFF  "
R72= "RANGE "
R73= "IN H2O"
R74=  0.000000
R75=  0.000000
R76=  0.000000
R77=  0.000000
R78=  0.000000
R79=  0.000000
```

Program 17: HP 41CV Listing

SUBROUTINES

```
01♦LBL "PI LIQ"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
```

```
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 GTO d
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53♦LBL 01
54 XEQ J
55 GTO e
```

RE-ENTER VARIABLES

```
56♦LBL "REENTER"
57 ADV
58 1
59 +
60 STO 01
61 RCL IND 01
62 XEQ J
63 STOP
64 XEQ J
65 STO IND 01
66 ADV
67 SF 00
68 SF 02
69 STOP
70 GTO 02
```

BYPASS PRINTER

```
71♦LBL J
72 FC? 55
73 GTO 01
74 PRX
75 RTN
76♦LBL 01
77 VIEW X
78 RTN
```

ENTER DATA

```
79♦LBL A
80 1
81 STO 01
82 29
83 STO 58
84 CF 02
85 XEQ a
86 XEQ d
87 XEQ a
88 XEQ e
```

CALC R_D

```
89♦LBL 02
90 6.316
91 RCL 03
92 *
93 RCL 07
94 /
95 RCL 06
96 /
97 STO 10
98 XEQ J
```

ENTER F_{RA}

```
99 8
100 STO 01
101 39
102 STO 58
103 XEQ e
```

CALC DIFF RANGE

```
104 RCL 03
105 RCL 21
106 /
107 RCL 08
108 /
109 RCL 07
110 X↑2
111 /
112 RCL 09
113 /
114 RCL 24
115 RCL 04
116 *
117 E↑X
118 /
119 RCL 05
120 SQRT
121 /
122 X↑2
123 STO 11
124 XEQ J
```

```
125 FS? 02
126 STOP
127 XEQ a
128 CF 00
129 RCL 11
130 VIEW X
131 BEEP
132 ADV
133 STOP
134 .END.
```

Program 17: Sequence of Calculations

1. Calculate Reynolds number.

$$R_D = \frac{6.316\, W_m}{D\, \mu_{cp}}$$

2. Calculate differential range.

$$h_m = \left(\frac{W_m}{2830.824\, K\, D^2\, F_{RA}\, \epsilon^{.00001908 T_f} \sqrt{G_f}} \right)^2 \text{ inches of water}$$

Program 17: Nomenclature

- D Inside diameter of pipe, inches
- F_{RA} Reynolds number factor, dimensionless
- G_f Specific gravity of liquid at flowing temperature, dimensionless
- h_m Differential range, inches of water
- K Flow coefficient, dimensionless
- R_D Reynolds number, dimensionless
- T_f Flowing temperature, °F
- W_m Maximum rate of flow, pounds per hour
- ϵ Base of natural logarithms
- μ_{cp} Absolute viscosity, centipoises

References

Formulas extracted from *Annubar Flow Handbook,* Dieterich Standard Corporation.

Program 18
Gas or Vapor Flow

Program 18: User Instructions

a) Initiate program, press A.
b) Enter:
   1. Annubar type number (see page 225), dimensionless — Press R/S
   2. Flowrate, pounds per hour — Press R/S
   3. Flow temperature, °F — Press R/S
   4. Flow pressure, PSIG — Press R/S
   5. Gas or vapor density (specific weight), pounds per cubic foot — Press R/S
   6. Ratio of specific heats C_p/C_v, dimensionless — Press R/S
   7. Absolute viscosity, centipoises — Press R/S
   8. Pipe inside diameter, inches — Press R/S
   9. Flow coefficient K from page 225, dimensionless — Press R/S
c) Program calculates Reynolds number R_D. — Press R/S

d) Enter:
   10. Reynolds number correction factor F_{RA} (see pages 226 –228), dimensionless — Press R/S

e) Program calculates the differential range, inches of water.

Note: The E subroutine is available to re-enter data and recalculate.

Program 18: TI 59 Data Sheet

```
*******************

     PITOT GAS

*******************

ENTR  TYPE    N°
         76.
ENTR  FLOW   PPH
     529900.
ENTR  TEMP    °F
        620.
ENTR  PRSS PSIG
       485.3
ENTR DENSITY    PPCF
      0.8413
```

```
ENTR CP/CV
          1.3
ENTR  VISC   CP
        0.022
ENTR  PIPE    ID  INS
          24.
ENTR COEFFCNT K
        0.7101
CALC      RD
    6338728.03
ENTR    FRA
        1.0084
CALC DIFF RANGE IN/W
   14.92092355

*******************
```

Program 18: HP 41CV Register Loading

PARTITIONING
479.59

0.	00	0.	17
0.	01	0.	18
0.	02	358.4449888	19
0.	03	1533631542.	20
0.	04	.8912914674	21
0.	05	.0049422857	22
0.	06	33243317.	23
0.	07	.0000190813	24
0.	08	24316343.	25
0.	09	3513312217.	26
0.	10	1624212100.	27
0.	11	1531370026.	28
0.	12	1532172121.	29
0.	13	0.5352	30
0.	14	243136.515	31
0.	15	2416.4637	32
0.	16	1533.4538	33
		213513.434	34
		3622.494847	35
		221336.2	36

333323.4233	37	1617313624.	49
7321.233231	38	3173.	50
3516.2928	39	37453317.	51
33362422.	40	22133600.	52
56.39	41	3324373237.	53
42243615.34	42	0.	54
33353636.	43	5151515151.	55
56.272625	44	1513271500.	56
37173033.	45	1731373500.	57
21273243.	46	0.	58
33331521.	47	0.	59
3745000000.	48		

Program 18: TI 59 Listing

SUBROUTINES

PRINT & STORE VARIABLES

```
000  76 LBL
001  10 E'
002  29 CP
003  01  1
004  44 SUM
005  58  58
006  73 RC*
007  58  58
008  22 INV
009  59 INT
010  52 EE
011  22 INV
012  52 EE
013  67  EQ
014  19 D'
015  85  +
016  05  5
017  07  7
018  95  =
019  17 B'
020  69 OP
021  21  21
022  73 RC*
023  01  01
024  87 IFF
025  00  00
026  00  00
027  31  31
028  91 R/S
029  72 ST*
030  01  01
031  73 RC*
032  01  01
033  99 PRT
034  61 GTO
035  10 E'
```

PRINT LINES

```
036  76 LBL
037  19 D'
038  01  1
039  44 SUM
040  58  58
041  73 RC*
042  58  58
043  76 LBL
044  17 B'
045  42 STO
046  59  59
047  73 RC*
048  59  59
049  69 OP
050  01  01
051  18 C'
052  69 OP
053  02  02
054  18 C'
055  69 OP
056  03  03
057  18 C'
058  69 OP
059  04  04
060  69 OP
061  05  05
062  92 RTN
```

DECODE LINES

```
063  76 LBL
064  18 C'
065  01  1
066  00  0
067  00  0
068  48 EXC
069  59  59
070  22 INV
071  59 INT
072  49 PRD
073  59  59
074  73 RC*
075  59  59
076  92 RTN
```

PRINT LINE OF STARS

```
077  76 LBL
078  16 A'
079  93  .
080  00  0
081  01  1
082  08  8
083  35 1/X
084  98 ADV
085  17 B'
086  98 ADV
087  92 RTN
```

RE-ENTER VARIABLES

```
088  76 LBL
089  15  E
090  99 PRT
091  85  +
092  01  1
093  95  =
094  42 STO
095  01  01
096  73 RC*
097  01  01
098  91 R/S
099  72 ST*
100  01  01
101  99 PRT
102  98 ADV
103  86 STF
104  00  00
```

```
105   86  STF
106   01   01
107   91  R/S
108   12   B
```

CALC hw

```
109   76  LBL
110   22  INV
111   53   (
112   43  RCL
113   03   03
114   55   ÷
115   53   (
116   43  RCL
117   19   19
118   65   ×
119   43  RCL
120   10   10
121   65   ×
122   43  RCL
123   09   09
124   33  X²
125   65   ×
126   43  RCL
127   11   11
128   65   ×
129   53   (
130   43  RCL
131   24   24
132   65   ×
133   43  RCL
134   04   04
135   54   )
136   22  INV
137   23  LNX
138   65   ×
139   43  RCL
140   12   12
141   65   ×
142   43  RCL
143   06   06
144   34  √X
145   54   )
146   54   )
147   33  X²
148   42  STO
149   13   13
150   92  RTN
```

CALC YA

```
151   76  LBL
152   23  LNX
153   53   (
154   01   1
155   75   -
156   53   (
157   43  RCL
158   21   21
159   65   ×
160   43  RCL
161   14   14
162   54   )
163   22  INV
164   23  LNX
165   65   ×
166   43  RCL
167   22   22
168   65   ×
169   71  SBR
170   22  INV
171   55   ÷
172   43  RCL
173   07   07
174   55   ÷
175   53   (
176   43  RCL
177   05   05
178   85   +
179   01   1
180   04   4
181   93   .
182   07   7
183   54   )
184   54   )
185   42  STO
186   12   12
187   92  RTN
```

MAIN PROGRAM

ENTER DATA

```
188   76  LBL
189   11   A
190   22  INV
191   86  STF
192   01   01
193   01   1
194   42  STO
195   01   01
196   02   2
197   09   9
198   42  STO
199   58   58
200   16  A'
201   19  D'
202   16  A'
203   10  E'
```

DECODE FOR α

```
204   76  LBL
205   12   B
206   43  RCL
207   02   02
208   32  X⇌T
209   06   6
210   01   1
211   67   EQ
212   25  CLR
213   07   7
214   03   3
215   67   EQ
216   24   CE
217   07   7
218   05   5
219   67   EQ
220   32  X⇌T
221   07   7
222   06   6
223   67   EQ
224   32  X⇌T
225   08   8
226   05   5
227   67   EQ
228   33  X²
229   08   8
230   06   6
231   67   EQ
232   33  X²
```

CALC α TYPE 61

```
233   76  LBL
234   25  CLR
235   01   1
236   75   -
237   93   .
238   02   2
239   03   3
240   08   8
241   07   7
242   55   ÷
243   43  RCL
244   09   09
245   61  GTO
246   44  SUM
```

CALC α TYPE 73

```
247   76  LBL
248   24   CE
249   01   1
250   75   -
251   53   (
252   93   .
253   01   1
254   02   2
255   05   5
256   85   +
```

257	93	.
258	03	3
259	01	1
260	02	2
261	05	5
262	65	×
263	43	RCL
264	09	09
265	54	)
266	55	÷
267	93	.
268	07	7
269	08	8
270	05	5
271	04	4
272	55	÷
273	43	RCL
274	09	09
275	33	X²
276	61	GTO
277	44	SUM

CALC α TYPE 75 & 76

278	76	LBL
279	32	X⇌T
280	01	1
281	75	-
282	04	4
283	55	÷
284	89	π
285	55	÷
286	43	RCL
287	09	09
288	61	GTO
289	44	SUM

CALC α TYPE 85 & 86

290	76	LBL
291	33	X²
292	01	1
293	75	-
294	09	9
295	93	.
296	05	5
297	55	÷
298	89	π
299	55	÷
300	43	RCL
301	09	09

CALC R_D

302	76	LBL
303	44	SUM
304	95	=
305	42	STO
306	14	14
307	06	6
308	93	.
309	03	3
310	01	1
311	06	6
312	65	×
313	43	RCL
314	03	03
315	55	÷
316	43	RCL
317	09	09
318	55	÷
319	43	RCL
320	08	08
321	95	=
322	99	PRT

ENTER F_{RA}

323	01	1
324	00	0
325	42	STO
326	01	01
327	04	4
328	01	1
329	42	STO
330	58	58
331	10	E'
332	87	IFF
333	01	01
334	42	STO
335	22	INV
336	86	STF
337	00	00
338	76	LBL
339	42	STO

CALC dP

340	01	1
341	42	STO
342	12	12
343	71	SBR
344	22	INV
345	71	SBR
346	23	LNX
347	71	SBR
348	22	INV
349	71	SBR
350	23	LNX
351	71	SBR
352	22	INV
353	99	PRT
354	16	A'
355	98	ADV
356	98	ADV
357	43	RCL
358	13	13
359	91	R/S

Program 18: HP 41CV Data Sheet

```
************

*PITOT   GAS*

*************
ENTER TYPE NUMBER
        76.0000    ***
ENTER FLOW  PPH
   529,900.0000    ***
ENTER TEMP DEG F
       620.0000    ***
ENTER PRSS PSIG
       485.3000    ***
ENTER DENSITY PPCF
         0.8413    ***
ENTER CP/CV
         1.3000    ***
ENTER VISCOSITY cP
         0.0220    ***
ENTER PIPE ID INS
        24.0000    ***
ENTER COEF K
         0.7101    ***
CALC   RD
  6,338,728.032    ***
ENTER COEF FRA
         1.0084    ***
CALC   DIFF
RANGE  IN  H2O
        14.9209    ***

*************
```

Program 18: TI 59 Register Loading

SIZE 080

```
R00=  0.000000
R01=  0.000000
R02=  0.000000
R03=  0.000000
R04=  0.000000
R05=  0.000000
R06=  0.000000
R07=  0.000000
R08=  0.000000
R09=  0.000000
R10=  0.000000
R11=  0.000000
R12=  0.000000
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  0.000000
R17=  0.000000
R18=  0.000000
R19=  0.000000
R20=  0.000000
R21=  0.000000
R22=  0.000000
R23=  0.000000
R24=  0.000000
R25= "*PITOT"
R26= "  GAS*"
R27=  0.000000
R28=  0.000000
R29=  0.000000
R30=  25.260000
R31=  57.505100
R32=  57.525300
R33=  57.546000
R34=  57.484900
R35=  57.617400
R36=  57.750000
R37=  57.626300
R38=  57.646500
R39=  57.660000
R40=  0.000000
R41=  56.680000
R42=  57.697000
R43=  0.000000
R44=  56.717273
R45=  0.000000
R46=  0.000000
R47=  0.000000
R48= "PRSS P"
R49= "SIG   "
R50= "TYPE N"
R51= "UMBER "
R52= "FLOW  "
R53= "PPH   "
R54= "TEMP D"
R55= "******"
R56= "CALC  "
R57= "ENTER "
R58=  44.000000
R59=  0.000000
R60= "EG F "
R61= "DENSIT"
R62= "VISCOS"
R63= "ITY cP"
R64= "PIPE I"
R65= "D INS "
R66= "COEF K"
R67=  0.000000
R68= "RD    "
R69= "COEF  "
R70= "FRA   "
R71= "DIFF  "
R72= "RANGE "
R73= "IN H2O"
R74= "Y PPCF"
R75= "CP/CV"
R76=  0.000000
R77=  0.000000
R78=  0.000000
R79=  0.000000
```

Program 18: HP 41CV Listing

SUBROUTINES

```
01♦LBL "PI GAS"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 GTO d
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53♦LBL 01
54 XEQ J
55 GTO e
```

RE-ENTER VARIABLES

```
56♦LBL "REENTER"
57 ADV
58 1
59 +
60 STO 01
61 RCL IND 01
62 XEQ J
63 STOP
64 XEQ J
65 STO IND 01
66 ADV
67 SF 00
```

```
68 SF 02
69 STOP
70 GTO I
```

BYPASS PRINTER

```
71♦LBL J
72 FC? 55
73 GTO 01
74 PRX
75 RTN
76♦LBL 01
77 VIEW X
78 RTN
```

CALC h_m

```
79♦LBL G
80 RCL 03
81 358.4449888
82 /
83 RCL 10
84 /
85 RCL 09
86 X↑2
87 /
88 RCL 11
89 /
90 .000019081
91 RCL 04
92 *
93 E↑X
94 /
95 RCL 12
96 /
97 RCL 06
98 SQRT
99 /
100 X↑2
101 STO 13
102 RTN
```

CALC Y_A

```
103♦LBL H
104 .8912914674
105 RCL 14
106 *
107 E↑X
108 .0049422857
109 *
110 XEQ G
111 *
112 RCL 07
113 /
114 RCL 05
115 14.7
116 +
117 /
118 CHS
119 1
120 +
121 STO 12
122 RTN
```

MAIN PROGRAM

ENTER DATA

```
123♦LBL A
124 1
125 STO 01
126 29
127 STO 58
128 CF 02
129 XEQ a
130 XEQ d
131 XEQ a
132 XEQ e
```

DECODE FOR α

```
133♦LBL I
134 RCL 02
135 61
136 -
137 X=0?
138 GTO 01
139 12
140 -
141 X=0?
142 GTO 02
143 2
144 -
145 X=0?
146 GTO 03
147 1
148 -
149 X=0?
150 GTO 03
151 9
152 -
153 X=0?
154 GTO 04
155 1
156 -
157 X=0?
158 GTO 04
159 0
160 1/X
```

CALC α TYPE 61

```
161♦LBL 01
162 1
163 ENTER↑
164 .2387
165 RCL 09
166 /
167 -
168 GTO 05
```

CALC α Type 73

```
169♦LBL 02
170 .125
171 RCL 09
172 .3125
173 *
174 +
175 .7854
176 /
177 RCL 09
178 X↑2
179 /
180 CHS
181 1
182 +
183 GTO 05
```

CALC α TYPE 75 & 76

```
184♦LBL 03
185 1
186 ENTER↑
187 4
188 RCL 09
189 /
190 PI
191 /
192 -
193 GTO 05
```

CALC α TYPE 85 & 86

```
194♦LBL 04
195 1
196 ENTER↑
197 9.5
198 RCL 09
199 /
200 PI
201 /
202 -
```

CALC R_D

```
203♦LBL 05
204 STO 14
205 6.316
206 RCL 03
207 *
208 RCL 09
209 /
210 RCL 08
211 /
212 STO 15
213 XEQ J
```

ENTER F_{RA}

```
214 10
```

```
215 STO 01
216 41
217 STO 58
218 XEQ e
219 1
220 STO 12
221 XEQ G
222 XEQ H
223 XEQ G
224 XEQ H
225 XEQ G
226 XEQ J
227 FS? 02
228 STOP
229 CF 00
230 XEQ a
231 RCL 13
232 VIEW X
233 BEEP
234 ADV
235 STOP
236 .END.
```

Program 18: Sequence of Calculations

1. Calculate Reynolds number.

$$R_D = \frac{6.316\, W_m}{D\, \mu_{cp}}$$

2. Calculate the uncorrected differential range.

$$h_m = \left(\frac{W_m}{358.445\, K D^2 F_{RA}\, \epsilon^{.0000190813 T_f} \sqrt{\gamma_f}}\right)^2 \text{ inches of water}$$

3. Calculate expansion factor.

$$Y_A = 1 - (.004943\, \epsilon^{.8913\alpha})\, \frac{h_m}{P_f K}$$

where for type 61 Annubar (see pages 223-224)

$$\alpha = 1 - \frac{.2387}{D}$$

For type 73

$$\alpha = 1 - \frac{[.125 + .3125D]}{.7854D^2}$$

For types 75 and 76

$$\alpha = 1 - \frac{4}{\pi D}$$

For type 86

$$\alpha = 1 - \frac{9.5}{\pi D}$$

4. Divide step 2 by $(Y_A)^2$.
5. Repeat step 3 to find corrected expansion factor.
6. Divide step 2 by corrected $(Y_A)^2$.

Program 18: Nomenclature

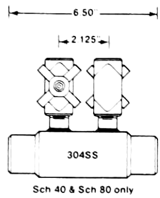
D Inside diameter of pipe, inches
F_{RA} Reynolds number factor, dimensionless
h_m Differential range, inches of water
K Flow coefficient, dimensionless
P_f Flowing pressure, PSIA
R_D Reynolds number, dimensionless
T_f Flowing temperature, °F
W_m Maximum rate of flow, pounds per hour
Y_A Expansion factor, dimensionless
α Ratio of areas, dimensionless
ϵ Base of natural logarithms
γ_f Specific weight at flowing conditions, pounds per cubic foot
μ_{cp} Absolute viscosity, centipoises

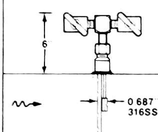
References

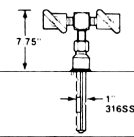
Annubar Flow Handbook, Dieterich Standard Corporation.

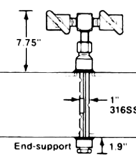
Typical Data

Annubar Regular Models*







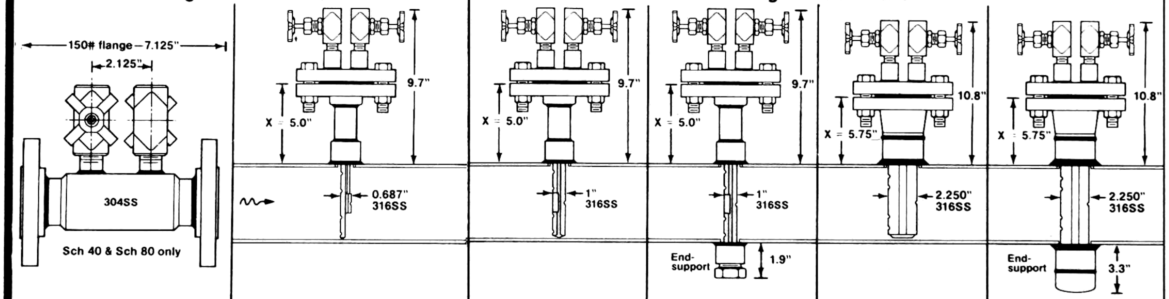


	ANR				ANR			
	Small line sizes		General purpose installations		General purpose installations			
	61		73		75		76	
	3000	2310	2000		2000		2000	
	100	600	up to 750°F max.		up to 750°F max.		up to 750°F max.	
Nom. Pipe Size	Max DP: inches of water, *GPM water*; DP shown is for up to 200°F. Above 200°F, reduce value by 3% per 100°F				Max DP: inches of water, *GPM water*; DP shown is for up to 200°F. Above 200°F, reduce value by 3% per 100°F			
1"	1,121	*129*						
1¼"	648	*176*						
1½"	476	*215*						
2"			468	*360*				
2½"			328	*446*				
3"			212	*567*				
3½"			159	*665*				
4"			123	*760*				
5"			78	*957*				
6"					515	*3,132*		
8"					297	*4,247*		
10"					189	*5,444*		
12"					133	*6,556*	506	*12,790*
14"					110	*7,236*	419	*14,120*
16"					84	*8,271*	321	*16,170*
18"					66	*9,289*	253	*18,190*
20"					53	*10,350*	204	*20,310*
24"					37	*12,530*	141	*24,450*
30"					22	*16,160*	84	*31,580*
36"					15	*19,400*	58	*38,140*
42"					11	*22,760*	42	*44,470*
48"							31	*51,750*
60"							20	*64,990*
72"							14	*78,320*

Courtesy Dieterich Standard Corporation, a subsidiary of Dover Corp.

Annubar Flanged Models*

ANF — Flanged installations



Nom. Pipe Size	61		73		75		76		85		86	
	235	150	235	150	235	150	235	150	235	150	235	150
	100	600	100	600	100	600	100	600	100	600	100	600
	Max DP: inches of water, *GPM* water. DP shown is for up to 200°F. Above 200°F, reduce value by 3% per 100°F.				Max DP: inches of water, *GPM water*. DP shown is for up to 200°F. Above 200°F, reduce value by 3% per 100°F.							
1"	1,121	*129*										
1¼"	648	*176*										
1½"	476	*215*										
2"			468	*360*								
2½"			328	*446*								
3"			212	*567*								
3½"			159	*665*								
4"			123	*760*								
5"			78	*957*								
6"					515	*3,132*						
8"					297	*4,247*						
10"					189	*5,444*						
12"					133	*6,556*	506	*12,790*	—	—		
14"					110	*7,236*	419	*14,120*	589	*14,390*		
16"					84	*8,271*	321	*16,170*	451	*16,730*		
18"					66	*9,289*	253	*18,190*	356	*19,060*	—	—
20"					53	*10,350*	204	*20,310*	287	*21,490*	—	—
24"					37	*12,530*	141	*24,450*	198	*26,200*	1,102	*61,810*
30"					22	*16,160*	84	*31,580*	119	*34,470*	659	*81,110*
36"					15	*19,400*	58	*38,140*	82	*41,620*	454	*97,940*
42"					11	*22,760*	42	*44,470*	60	*48,820*	332	*114,800*
48"							31	*51,750*	44	*56,660*	245	*133,700*
60"							20	*64,990*	28	*70,710*	157	*167,400*
72"							14	*78,320*	20	*86,120*	109	*201,000*

Courtesy Dieterich Standard Corporation, a subsidiary of Dover Corp.

Annubar Flow Coefficient *K**

TYPE 61

Nom. Pipe Size	Schedule	Pipe ID	K
1"	80	0.957	.9506
	40	1.049	.9561
1¼"	80	1.278	.9696
	40	1.380	.9754
1½"	80	1.500	.9779
	40	1.610	.9802

TYPE 73

Nom. Pipe Size	Schedule	Pipe ID	K
2"	XX-STG	1.503	.5718
	160	1.689	.6197
	80	1.939	.6677
	----	2.000	.6773
	40	2.067	.6871
2½"	XX-STG	1.771	.6372
	160	2.125	.6950
	80	2.323	.7062
	40	2.469	.7122
	----	2.500	.7134
3"	XX-STG	2.300	.7052
	160	2.624	.7177
	80	2.900	.7257
	----	3.000	.7282
	40	3.068	.7298
3½"	XX-STG	2.728	.7209
	80	3.364	.7359
	----	3.500	.7383
	40	3.548	.7391
4"	XX-STG	3.152	.7317
	160	3.438	.7372
	80	3.826	.7432
	----	4.000	.7455
	40	4.026	.7459
5"	XX-STG	4.063	.7463
	160	4.313	.7491
	80	4.813	.7503
	----	5.000	.7506
	40	5.047	.7506

TYPE 75/76

Nom. Pipe Size	Schedule	Pipe ID	K
4"	XX-STG	3.152	.4570
	X-STG	3.826	.5348
	40	4.026	.5528
6"	XX-STG	4.987	.6194
	160	5.189	.6303
	80	5.761	.6569
	----	6.000	.6612
	40	6.065	.6622
8"	160	6.813	.6718
	XX-STG	6.875	.6725
	80	7.625	.6800
	40	7.981	.6830
	----	8.000	.6831
10"	160	8.500	.6869
	80	9.564	.6936
	X-STG	9.750	.6947
	----	10.000	.6960
	40	10.020	.6961
12"	160	10.126	.6966
	80	11.376	.7021
	X-STG	11.750	.7035
	40	11.938	.7042
	STD	12.000	.7044
14"	80	12.500	.7060
	X-STG	13.000	.7069
	40	13.124	.7070
	STD	13.250	.7071
	----	14.000	.7074
16"	80	14.314	.7076
	40	15.000	.7079
	STD	15.250	.7080
	----	16.000	.7082
18"	80	16.126	.7083
	X-STG	17.000	.7086
	STD	17.250	.7087
	----	18.000	.7089
20"	80	17.938	.7089
	X-STG	19.000	.7091
	STD	19.250	.7092
	----	20.000	.7094
24"	80	21.564	.7097
	X-STG	23.000	.7100
	STD	23.250	.7100
	----	24.000	.7101
30"	X-STG	29.000	.7108
	STD	29.250	.7108
	----	30.000	.7109
36"	X-STG	35.000	.7113
	STD	35.250	.7113
	----	36.000	.7114
42"	X-STG	41.000	.7117
	STD	41.250	.7117
	----	42.000	.7117
48" and larger		48.000	.7120

TYPE 85/86

Nom. Pipe Size	Schedule	Pipe ID	K
12"	160	10.126	.5208
	80	11.376	.5567
	X-STG	11.750	.5659
	40	11.938	.5703
	STD	12.000	.5718
14"	80	12.500	.5828
	X-STG	13.000	.5930
	40	13.124	.5954
	STD	13.250	.5978
	----	14.000	.6083
16"	80	14.314	.6101
	40	15.000	.6139
	STD	15.250	.6151
	----	16.000	.6187
18"	80	16.126	.6192
	X-STG	17.000	.6229
	STD	17.250	.6239
	----	18.000	.6266
20"	80	17.938	.6264
	X-STG	19.000	.6300
	STD	19.250	.6307
	----	20.000	.6329
24"	80	21.564	.6370
	X-STG	23.000	.6402
	STD	23.250	.6408
	----	24.000	.6423
30"	X-STG	29.000	.6502
	STD	29.250	.6505
	----	30.000	.6515
36"	X-STG	35.000	.6526
	STD	35.250	.6526
	----	36.000	.6527
42"	X-STG	41.000	.6534
	STD	41.250	.6534
	----	42.000	.6535
48"	----	48.000	.6541
60"	----	60.000	.6549
72"	----	72.000	.6555
84"	----	84.000	.6559
96"	----	96.000	.6562
108" & larger		108.000	.6564

*This table shows the flow coefficients for various Annubars with varying internal line or pipe diameter. Linear interpolation may be used for pipe sizes not listed.

Reynolds Number Factor F_{RA}

ANNUBAR SENSOR TYPE 61															
NOMINAL LINE SIZE	PIPE REYNOLDS NUMBER R_D														
	1.0 E4	1.5 E4	2.0 E4	3.0 E4	5.0 E4	7.0 E4	1.0 E5	1.5 E5	2.0 E5	3.0 E5	5.0 E5	7.0 E5	1.0 E6	1.5 E6	2.0 E6
1"	0.9551	0.9682	0.9761	0.9854	0.9947	0.9997	1.0041	1.0083	1.0107	1.0137	1.0166	1.0182	1.0196	1.0209	----
1.25"	----	----	0.9424	0.9619	0.9815	0.9919	1.0012	1.0100	1.0152	1.0213	1.0275	1.0308	1.0338	1.0365	----
1.50"	----	----	0.9477	0.9644	0.9811	0.9900	0.9980	1.0054	1.0099	1.0151	1.0204	1.0232	1.0257	1.0281	1.0295

ANNUBAR SENSOR 73															
NOMINAL LINE SIZE	PIPE REYNOLDS NUMBER R_D														
	2.0 E4	2.5 E4	3.0 E4	5.0 E4	7.0 E4	1.0 E5	2.0 E5	3.0 E5	5.0 E5	7.0 E5	1.0 E6	2.0 E6	3.0 E6	5.0 E6	7.0 E6
2"	0.9515	0.9597	0.9657	0.9800	0.9876	0.9944	1.0044	1.0090	1.0136	1.0160	1.0181	1.0213	1.0227	----	----
2.5"	----	0.9569	0.9630	0.9774	0.9850	0.9918	1.0021	1.0066	1.0112	1.0136	1.0158	1.0190	1.0204	1.0219	----
3"	----	0.9632	0.9681	0.9796	0.9858	0.9912	0.9995	1.0031	1.0068	1.0087	1.0104	1.0130	1.0142	1.0153	----
3.5"	----	----	0.9679	0.9790	0.9850	0.9902	0.9982	1.0017	1.0052	1.0071	1.0088	1.0113	1.0124	1.0135	----
4"	----	----	----	0.9737	0.9808	0.9871	0.9966	1.0007	1.0050	1.0072	1.0092	1.0122	1.0135	1.0148	1.0155
5"	----	----	----	0.9722	0.9791	0.9853	0.9946	0.9987	1.0028	1.0050	1.0070	1.0099	1.0112	1.0125	1.0132

Note: Pipe Reynolds Numbers are expressed in computer notation.
Example: $R = 5.0\ E5 = 5.0 \times 10^5 = 500{,}000$

Liquid

$$R_D = \frac{3160 \times GPM \times G_f}{D \times \mu_{cp}}$$

Gas

$$R_D = \frac{0.4831 \times SCFH \times G}{D \times \mu_{cp}}$$

Liquid-Gas-Steam

$$R_D = \frac{6.316 \times lbm/hr}{D \times \mu_{cp}}$$

$$R_D = \frac{6.316 \times ACFH \times \rho_f}{D \times \mu_{cp}}$$

Note: Values below and to the left of the heavy black line are outside the range of sufficient calibration data and may be subject to larger tolerances.

ANNUBAR SENSOR TYPE 75/76

NOMINAL LINE SIZE	PIPE REYNOLDS NUMBER R_D														
	5.0 E4	7.0 E4	1.0 E5	1.5 E5	2.0 E5	3.0 E5	5.0 E5	7.0 E5	1.0 E6	2.0 E6	3.0 E6	5.0 E6	7.0 E6	1.0 E7	2.0 E7
4"	0.9779	0.9839	0.9892	0.9941	0.9971	1.0006	1.0042	1.0060	1.0077	1.0102	1.0113	1.0125	----	----	----
6"	0.9692	0.9765	0.9830	0.9891	0.9928	0.9971	1.0014	1.0037	1.0058	1.0088	1.0102	1.0116	1.0123	----	----
8"	----	0.9751	0.9814	0.9874	0.9909	0.9951	0.9993	1.0016	1.0036	1.0066	1.0079	1.0092	1.0099	1.0106	----
10"	----	----	0.9735	0.9814	0.9860	0.9916	0.9972	1.0001	1.0028	1.0067	1.0085	1.0102	1.0112	1.0120	----
12"	----	----	0.9637	0.9739	0.9800	0.9872	0.9945	0.9983	1.0018	1.0070	1.0093	1.0115	1.0128	1.0139	1.0155
14"	----	----	----	0.9719	0.9783	0.9858	0.9933	0.9973	1.0009	1.0062	1.0086	1.0110	1.0122	1.0134	1.0150

NOMINAL LINE SIZE	PIPE REYNOLDS NUMBER R_D														
	1.5 E5	2.0 E5	3.0 E5	4.0 E5	5.0 E5	6.0 E5	8.0 E5	1.0 E6	1.5 E6	2.0 E6	3.0 E6	5.0 E6	7.0 E6	1.0 E7	2.0 E7
16"	0.9697	0.9763	0.9840	0.9886	0.9917	0.9941	0.9973	0.9995	1.0030	1.0051	1.0075	1.0100	1.0113	1.0124	1.0142
18"	0.9675	0.9743	0.9823	0.9870	0.9903	0.9927	0.9961	0.9984	1.0020	1.0041	1.0066	1.0092	1.0105	1.0117	1.0135
20"	----	0.9737	0.9816	0.9863	0.9895	0.9919	0.9952	0.9975	1.0010	1.0031	1.0056	1.0081	1.0094	1.0106	1.0124
24"	----	0.9688	0.9776	0.9829	0.9865	0.9892	0.9929	0.9955	0.9994	1.0018	1.0046	1.0074	1.0089	1.0102	1.0122
30"	----	----	0.9746	0.9801	0.9839	0.9867	0.9906	0.9933	0.9975	0.9999	1.0029	1.0058	1.0074	1.0088	1.0109
36"	----	----	----	0.9750	0.9795	0.9828	0.9873	0.9905	0.9954	0.9983	1.0017	1.0052	1.0070	1.0087	1.0111
42"	----	----	----	0.9672	0.9728	0.9769	0.9826	0.9865	0.9926	0.9962	1.0005	1.0048	1.0071	1.0092	1.0123
48" or Larger	----	----	----	0.9599	0.9664	0.9712	0.9779	0.9825	0.9896	0.9939	0.9989	1.0040	1.0067	1.0091	1.0127

Note: Pipe Reynolds Numbers are expressed in computer notation.

Example: R = 5.0 E5 = 5.0×10^5 = 500,000

Liquid

$$R_D = \frac{3160 \times GPM \times G_f}{D \times \mu_{cp}}$$

Gas

$$R_D = \frac{0.4831 \times SCFH \times G}{D \times \mu_{cp}}$$

Liquid-Gas-Steam

$$R_D = \frac{6.316 \times lbm/hr}{D \times \mu_{cp}}$$

$$R_D = \frac{6.316 \times ACFH \times \rho_f}{D \times \mu_{cp}}$$

Note: Values below and to the left of the heavy black line are outside the range of sufficient calibration data and may be subject to larger tolerances.

Reynolds Number Factor F_{RA} continued

ANNUBAR SENSOR TYPE 85/86															
NOMINAL LINE SIZE	PIPE REYNOLDS NUMBER R_D														
	1.5 E5	2.0 E5	3.0 E5	4.0 E5	5.0 E5	6.0 E5	8.0 E5	1.0 E6	2.0 E6	3.0 E6	5.0 E6	7.0 E6	1.0 E7	2.0 E7	3.0 E7
12"	0.9851	0.9886	0.9927	0.9952	0.9969	0.9981	0.9998	1.0010	1.0040	1.0053	1.0066	1.0073	1.0079	----	----
14"	0.9845	0.9880	0.9921	0.9946	0.9963	0.9975	0.9993	1.0005	1.0034	1.0047	1.0060	1.0067	1.0074	----	----
16"	0.9801	0.9844	0.9895	0.9925	0.9946	0.9961	0.9982	0.9997	1.0033	1.0049	1.0066	1.0074	1.0082	1.0093	----
18"	----	0.9836	0.9887	0.9918	0.9938	0.9954	0.9975	0.9990	1.0026	1.0042	1.0058	1.0067	1.0075	1.0086	----
20"	----	0.9821	0.9874	0.9907	0.9928	0.9945	0.9967	0.9983	1.0021	1.0038	1.0055	1.0064	1.0072	1.0085	----
24"	----	0.9811	0.9864	0.9896	0.9918	0.9934	0.9957	0.9973	1.0011	1.0028	1.0045	1.0054	1.0062	1.0074	1.0080
30"	----	----	0.9801	0.9845	0.9874	0.9896	0.9927	0.9948	1.0000	1.0023	1.0046	1.0058	1.0069	1.0085	1.0093
NOMINAL LINE SIZE	PIPE REYNOLDS NUMBER R_D														
	3.0 E5	4.0 E5	5.0 E5	6.0 E5	7.0 E5	8.0 E5	9.0 E5	1.0 E6	1.5 E6	2.0 E6	3.0 E6	5.0 E6	7.0 E6	1.0 E7	3.0 E7
36"	0.9790	0.9834	0.9863	0.9885	0.9902	0.9916	0.9927	0.9937	0.9969	0.9988	1.0011	1.0034	1.0047	1.0058	1.0081
42"	----	0.9761	0.9801	0.9831	0.9854	0.9873	0.9888	0.9901	0.9946	0.9972	1.0004	1.0035	1.0052	1.0067	1.0100
48"	----	----	0.9730	0.9769	0.9799	0.9823	0.9843	0.9860	0.9917	0.9951	0.9991	1.0032	1.0054	1.0073	1.0115
60"	----	----	----	0.9751	0.9781	0.9805	0.9825	0.9842	0.9893	0.9933	0.9973	1.0014	1.0036	1.0055	1.0096
72"	----	----	----	----	0.9768	0.9792	0.9812	0.9829	0.9886	0.9920	0.9960	1.0001	1.0022	1.0041	1.0083

Note: Pipe Reynolds Numbers are expressed in computer notation.

Example: R = 5.0 E5 = 5.0×10^5 = 500,000

Liquid

$$R_D = \frac{3160 \times GPM \times G_f}{D \times \mu_{cp}}$$

Gas

$$R_D = \frac{0.4831 \times SCFH \times G}{D \times \mu_{cp}}$$

Liquid-Gas-Steam

$$R_D = \frac{6.316 \times lbm/hr}{D \times \mu_{cp}}$$

$$R_D = \frac{6.316 \times ACFH \times \rho_f}{D \times \mu_{cp}}$$

Note: Values below and to the left of the heavy black line are outside the range of sufficient calibration data and may be subject to larger tolerances.

CHAPTER EIGHT

Rotameters

Program 19A Liquid Flow
Program 19B Gas or Vapor Flow
Typical Data

For many years, glass-tube and metal-tube rotameters have been used by industry to measure flow. They are usually used where great accuracy is not required, and are inexpensive to purchase and install. Safety precludes the glass tube from most hydrocarbon and pressure services, but the metal-tube models perform well in these services.

Rotameters are sized on the basis of water equivalent rates for liquids, and air equivalent rates for gas and vapor. The liquid capacity is limited by a maximum permissible viscosity. This is calculated from the viscosity immunity ceiling published by the manufacturer for each device. The program does all unit conversions.

Specifications and sizing data Bulletin 20-4000, published by Ametek, Schutte and Koerting Company, will describe the sizing technique in greater detail.

Program 19
Rotameters

Program 19: User Instructions

Liquid calculation, press A.

a) Enter:
   1. Flowrate, pounds per hour — Press R/S
   2. Liquid specific gravity at flow temperature, dimensionless — Press R/S
   3. Float density, grams per cubic centimeter (see typical data on p. 237) — Press R/S

4. Absolute viscosity, centipoises — Press R/S

b) Program calculates equivalent water flow, USGPM, and sizing viscosity, centistokes.

c) Enter:

5. Viscosity immunity ceiling from manufacturers data, centistokes (see typical data on page 237) — Press R/S

d) Program calculates maximum allowable viscosity for the process conditions, centipoises.

Gas or vapor calculation, press B.

a) Enter:

1. Flowrate, pounds per hour — Press R/S
2. Gas or vapor specific weight, pounds per cubic foot — Press R/S
3. Float density, grams per cubic centimeter (see page 237 — Press R/S

b) Program calculates equivalent air flow, SCFM.

Note: See Program 16 for specific weight calculation.

Program 19: TI 59 Data Sheet

```
*******************

 ROTAMETER GAS

*******************

ENTR  FLOW  PPH
       3000.
ENTR  GAS SP WT PPCF
       0.364
ENTR FLOAT DENSITY
        8.02
CALC  AIR EQUIV SCFM
 302.5886733

*******************
```

```
*******************

 ROTAMETER  LIQUID

*******************

ENTR  FLOW  PPH
       10000.
ENTR   LIQ FLOW   SG
         0.528
ENTR FLOAT DENSITY
          8.02
ENTR  VISC   CP
          0.16
CALC GPM WATER EQUIV
 26.64771801
CALC SIZNG VISC   CS
 .2131817441
ENTR VISC CEILING CS
           8.
CALC   MAX VISC   CP
  5.81308868

*******************
```

Program 19: TI 59 Register Loading

PARTITIONING
479.59

0.	00	1734412442.	29
0.	01	54.533152	30
0.	02	272434.5134	31
0.	03	0.315144	32
0.	04	1536.474521	33
0.	05	333323.2543	34
0.	06	13243500.	35
0.	07	56.282729	36
0.	08	56.262533	37
0.	09	57.242322	38
0.	10	36152130.	39
0.	11	56.422543	40
0.	12	54.535	41
0.	13	301344.5134	42
0.	14	1533.504948	43
0.	15	3622.474521	44
0.	16	16173136.	45
0.	17	56.352939	46
0.	18	2127321337.	47
0.	19	3331521.	48
0.	20	3633004337.	49
2437450000.	21	22133600.	50
3122001536.	22	21273243.	51
1517242724.	23	4124160000.	52
4224361500.	24	3017371735.	53
42243615.	25	35323713.	54
3624463122.	26	5151515151.	55
1337173500.	27	1513271500.	56
2233300043.	28	1731373500.	57
		0.	58
		0.	59

Program 19: TI 59 Listing

SUBROUTINES

PRINT & STORE VARIABLES

```
000  76 LBL
001  10 E'
002  29 CP
003  01  1
004  44 SUM
005  58  58
006  73 RC*
007  58  58
008  22 INV
009  59 INT
010  52 EE
011  22 INV
012  52 EE
013  67  EQ
014  19 D'
015  85  +
016  05  5
017  07  7
018  95  =
019  17 B'
020  69 OP
021  21  21
022  73 RC*
023  01  01
024  87 IFF
025  00  00
026  00  00
027  30  30
028  91 R/S
029  72 ST*
030  01  01
031  73 RC*
032  01  01
033  99 PRT
034  61 GTO
035  10 E'
```

PRINT LINES

```
036  76 LBL
037  19 D'
038  01  1
039  44 SUM
040  58  58
041  73 RC*
042  58  58
043  76 LBL
044  17 B'
045  42 STO
046  59  59
```

```
049   69  OP
050   01   01
051   18  C'
052   69  OP
053   02   02
054   18  C'
055   69  OP
056   03   03
057   18  C'
058   69  OP
059   04   04
060   69  OP
061   05   05
062   92  RTN
```

DECODE LINES

```
063   76  LBL
064   18  C'
065   01   1
066   00   0
067   00   0
068   48  EXC
069   59   59
070   22  INV
071   59  INT
072   49  PRD
073   59   59
074   73  RC*
075   59   59
076   92  RTN
```

PRINT LINE OF STARS

```
077   76  LBL
078   16  A'
079   93   .
080   00   0
081   01   1
082   08   8
083   35  1/X
084   98  ADV
085   17  B'
086   98  ADV
087   92  RTN
```

RE-ENTER VARIABLES

```
088   76  LBL
089   15   E
090   99  PRT
091   85   +
092   01   1
093   95   =
094   42  STO
095   01   01
096   73  RC*
097   01   01
098   91  R/S
099   72  ST*
100   01   01
101   99  PRT
102   98  ADV
103   86  STF
104   00   00
105   86  STF
106   01   01
107   91  R/S
108   61  GTO
109   13   C
```

MAIN PROGRAM LIQUID CALC ENTER DATA

```
110   76  LBL
111   11   A
112   22  INV
113   86  STF
114   01   01
115   87  IFF
116   00   00
117   39  COS
118   22  INV
119   86  STF
120   03   03
121   76  LBL
122   39  COS
123   87  IFF
124   03   03
125   12   B
126   86  STF
127   02   02
128   01   1
129   42  STO
130   01   01
131   02   2
132   09   9
133   42  STO
134   58   58
135   16  A'
136   19  D'
137   16  A'
138   10  E'
```

CALC GPM WATER

```
139   76  LBL
140   42  STO
141   43  RCL
142   02   02
143   55   ÷
144   06   6
145   00   0
146   65   ×
147   93   .
148   03   3
149   01   1
150   08   8
151   55   ÷
152   53   (
153   53   (
154   43  RCL
155   04   04
156   75   -
157   43  RCL
158   03   03
159   54   )
160   65   ×
161   43  RCL
162   03   03
163   54   )
164   34  √X
165   42  STO
166   10   10
167   95   =
168   99  PRT
169   42  STO
170   07   07
```

CALC SIZING VISCOSITY

```
171   43  RCL
172   37   37
173   17  B'
174   43  RCL
175   05   05
176   65   ×
177   02   2
178   93   .
179   06   6
180   05   5
181   55   ÷
182   43  RCL
183   10   10
184   95   =
185   99  PRT
```

ENTER VISCOSITY CEILING

```
186   43  RCL
187   38   38
188   17  B'
189   43  RCL
190   06   06
```

```
191   87  IFF
192   01   01
193   32  X:T
194   87  IFF
195   00   00
196   33  X²
197   76  LBL
198   32  X:T
199   91  R/S
200   76  LBL
201   33  X²
202   42  STO
203   06   06
204   99  PRT
```

CALC MAX VISC

```
205   43  RCL
206   40   40
207   17  B'
208   43  RCL
209   06   06
210   65   ×
211   43  RCL
212   03   03
213   34  √X
214   95   =
215   99  PRT
216   16  A'
217   43  RCL
218   07   07
219   98  ADV
220   98  ADV
221   87  IFF
222   01   01
223   34  √X
224   22  INV
225   86  STF
226   00   00
227   76  LBL
228   34  √X
229   43  RCL
230   07   07
231   91  R/S
```

GAS CALC
ENTER DATA

```
232   76  LBL
233   12   B
234   22  INV
235   86  STF
236   01   01
237   87  IFF
238   00   00
239   38  SIN
240   22  INV
241   86  STF
242   02   02
243   76  LBL
244   38  SIN
245   87  IFF
246   02   02
247   11   A
248   86  STF
249   03   03
250   01   1
251   42  STO
252   01   01
253   04   4
254   00   0
255   42  STO
256   58   58
257   16  A'
258   19  D'
259   16  A'
260   10  E'
261   22  INV
262   86  STF
263   00   00
```

CALC SCFM

```
264   76  LBL
265   43  RCL
266   43  RCL
267   02   02
268   55   ÷
269   06   6
270   00   0
271   65   ×
272   01   1
273   00   0
274   93   .
275   03   3
276   04   4
277   55   ÷
278   53   (
279   43  RCL
280   04   04
281   65   ×
282   43  RCL
283   03   03
284   54   )
285   34  √X
286   95   =
287   99  PRT
288   42  STO
289   07   07
290   16  A'
291   43  RCL
292   07   07
293   98  ADV
294   98  ADV
295   91  R/S
296   76  LBL
297   13   C
298   87  IFF
299   02   02
300   42  STO
301   61  GTO
302   43  RCL
```

Program 19: HP 41CV Data Sheet

```
************

*ROTAMETER*
  *LIQUID*

************

ENTER FLOW PPH
     10,000.000    ***

ENTER LIQUID FLOWING SG
           0.528   ***
ENTER FLOAT DENSITY G/CC
           8.020   ***
ENTER VISCOSITY cP
           0.160   ***
CALC   GPM
WATER  EQUIV
          26.648   ***

CALC  SIZING
VISCOSITY  cS
           0.213   ***
ENTER VISC IMMUN CLNG cS
           8.000   ***
CALC   MAX  VI
SCOSITY  cP
           5.813   ***
************
```

```
*************          ENTER FLOW PPH              CALC   SCFM
                             3,000.000    ***      AIR EQUIV
*ROTAMETER*            ENTER GAS DENSITY PPCF             302.589    ***
   *GAS*                     0.364    ***
                       ENTER FLOAT DENSITY G/CC    *************
*************                8.020    ***
```

Program 19: HP 41CV Register Loading

```
SIZE 080
R00=  0.000000      R26= "ETER* "       R53= "NSITY"
R01=  0.000000      R27= "   *GA"       R54= " PPCF"
R02=  0.000000      R28= "S*    "       R55= "******"
R03=  0.000000      R29= "  *LIQ"       R56= "CALC  "
R04=  0.000000      R30= "UID*"         R57= "ENTER "
R05=  0.000000      R31=  25.262930     R58=  41.000000
R06=  0.000000      R32=  57.505100     R59=  0.000000
R07=  0.000000      R33=  57.666768     R60= "FLOAT "
R08=  0.000000      R34=  57.606162     R61= "DENSIT"
R09=  0.000000      R35=  57.697000     R62= "Y G/CC"
R10=  0.000000      R36=  0.000000      R63= "SCFM  "
R11=  0.000000      R37=  56.717265     R64= "AIR "
R12=  0.000000      R38=  24.486949     R65= "EQUIV"
R13=  0.000000      R39=  57.737475     R66= "LIQUID"
R14=  0.000000      R40=  0.000000      R67= " FLOWI"
R15=  0.000000      R41=  56.767778     R68= "NG SG "
R16=  0.000000      R42=  25.262728     R69= "VISCOS"
R17=  0.000000      R43=  57.505100     R70= "ITY cP"
R18=  0.000000      R44=  57.525354     R71= "GPM   "
R19=  0.000000      R45=  57.606162     R72= "WATER "
R20=  0.000000      R46=  0.000000      R73= "VISC I"
R21=  0.000000      R47=  56.636465     R74= "MMUN C"
R22=  0.000000      R48= "IZING "       R75= "LNG cS"
R23=  0.000000      R49= "ITY cS"       R76= "MAX VI"
R24= "CALC S"       R50= "FLOW "        R77= "SCOSIT"
R25= "*ROTAM"       R51= "PPH"          R78= "Y cP  "
                    R52= "GAS DE"       R79=  0.000000
```

Program 19: HP 41CV Listing

SUBROUTINES

```
01♦LBL "ROTAMR"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
```

```
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 GTO d
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53♦LBL 01
54 XEQ J
55 GTO e
```

RE-ENTER VARIABLES

```
56♦LBL "REENTER"
57 ADV
58 FS? 03
59 GTO 01
60 6
61 GTO 02
62♦LBL 01
63 1
64♦LBL 02
65 +
66 STO 01
67 RCL IND 01
68 XEQ J
69 STOP
70 XEQ J
71 STO IND 01
72 ADV
73 SF 00
74 SF 02
75 STOP
76 FS? 03
77 GTO G
78 GTO H
```

BYPASS PRINTER

```
79♦LBL J
80 FC? 55
81 GTO 01
82 PRX
83 RTN
84♦LBL 01
85 VIEW X
86 RTN
```

MAIN PROGRAM LIQUID ENTER DATA

```
87♦LBL A
88 FC? 00
89 CF 04
90 FS? 04
91 GTO "GAS"
92 1
93 STO 01
94 30
95 STO 58
96 CF 02
97 XEQ a
98 XEQ d
99 XEQ a
100 XEQ e
101 SF 03
102 CF 04
```

CALC GPM

```
103♦LBL G
104 5
105 STO 01
106 1
107 37
108 STO 58
109 RCL 02
110 60
111 /
112 .318
113 *
114 RCL 04
115 RCL 03
116 -
117 RCL 03
118 *
119 SQRT
120 STO 10
121 /
122 STO 11
123 XEQ J
```

CALC SIZING VISC

```
124 XEQ d
125 RCL 05
126 2.65
127 *
128 RCL 10
129 /
130 XEQ J
```

ENTER VISC CEILING

```
131 XEQ e
```

CALC MAX VISC

```
132 RCL 06
133 RCL 03
134 SQRT
135 *
136 XEQ J
137 GTO I
```

GAS ENTER DATA

```
138♦LBL "GAS"
139 FC? 00
140 CF 03
141 FS? 03
142 GTO A
143 6
144 STO 01
145 41
146 STO 58
147 CF 02
148 SF 04
149 CF 03
150 XEQ a
151 XEQ d
152 XEQ a
153 XEQ e
```

CALC MAX VISC

```
154♦LBL H
155 6
156 STO 01
157 RCL 07
158 60
159 /
160 10.34
161 *
162 RCL 09
163 RCL 08
164 *
165 SQRT
166 /
167 STO 11
168 XEQ J
169♦LBL I
170 FS? 02
171 STOP
172 CF 00
173 XEQ a
174 RCL 11
175 VIEW X
176 BEEP
177 ADV
178 STOP
179 .END.
```

Program 19: Sequence of Calculations

Liquid

1. US gallons per minute water equivalent.

$$Q_W = \frac{W_m}{60} \frac{.318}{\sqrt{\gamma_f(\gamma_F - \gamma_f)}}$$

2. Sizing viscosity.

$$= \frac{\mu_{cp}\, 2.65}{\sqrt{\gamma_f(\gamma_F - \gamma_f)}} \text{ centistokes.}$$

3. Maximum allowable viscosity.

$$= \mu_{cs} \sqrt{G_f} \text{ centipoises}$$

Gas or Vapor

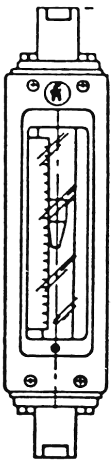
1. Standard cubic feet per minute air equivalent.

$$Q_A = \frac{W_m}{60} \frac{10.34}{\sqrt{\gamma_F \gamma_f}}$$

Program 19: Nomenclature

G_f Specific gravity of liquid at flowing conditions, dimensionless
Q_A Calculated equivalent air flow, standard cubic feet per minute
Q_W Calculated equivalent water flow, US gallons per minute
W_m Maximum rate of flow, pounds per hour
γ_F Density of float, grams per cubic centimeter
γ_f Specific weight of gas, pounds per cubic foot
μ_{cs} Rotameter viscosity immunity ceiling, centistokes
μ_{cp} Liquid absolute viscosity, centipoises

Typical Data



Float Density

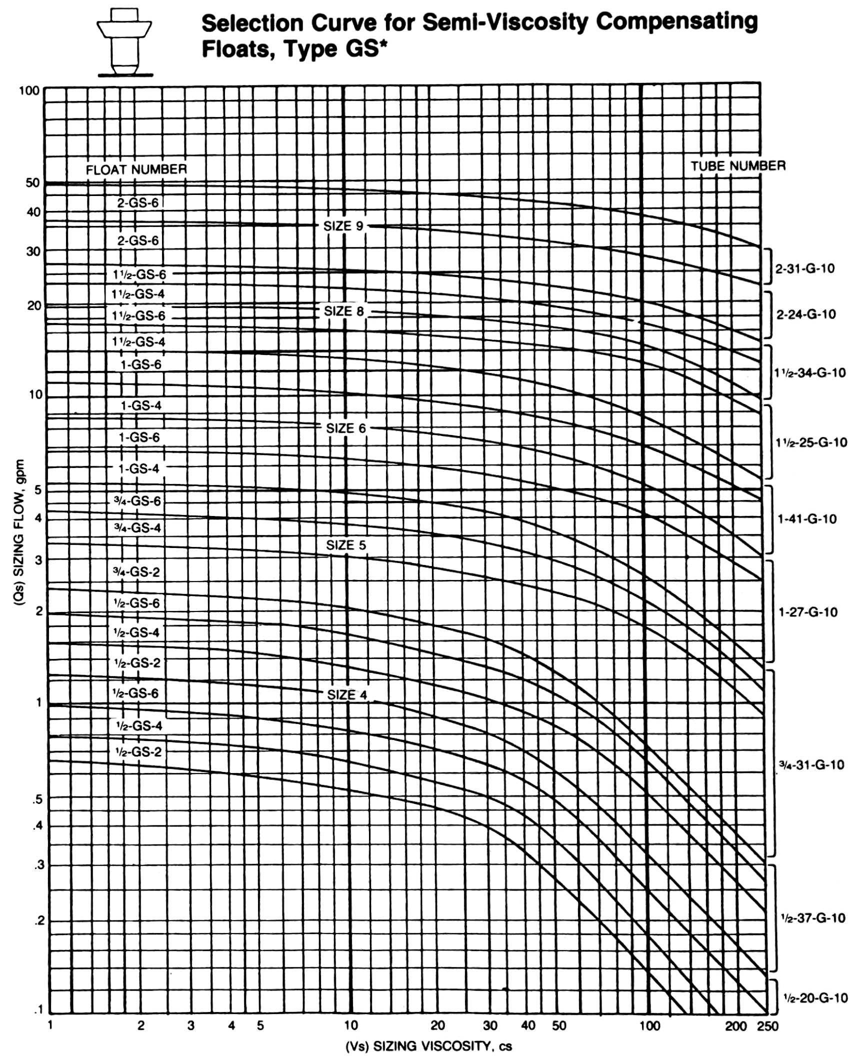
Material	Density
Alloy 20*	8.02
Aluminum	2.7
Brass	8.47
Hastelloy C	8.94
Monel	8.84
Nickel	8.91
Hastelloy B	9.24
Titanium	4.5

*TM Carpenter Steel Company

Capacities for Series 20-4000 "SAFEGUARD" Rotameters with 10" Scales and GS Semi-Viscosity Compensating Floats

gpm Water @ 70°F	cfm Air @ 70°F and 14.7 psia	Group* and Conn. Size	Meter Size	Tube No.	Float No.	Visc. Ceiling cs. **	Max. Press. Drop in. W.C.	Max. Recommended Pressure, psig @ 200°F
.79	3.28	B ½"	4	½-20-G-10	½-GS-2	.7	3.7	300
1.00	4.11				½-GS-4	.8	6.0	
1.25	5.16				½-GS-6	.9	9.6	
1.59	6.55			½-37-G-10	½-GS-2	.8	7.1	300
1.99	8.20				½-GS-4	.9	11.2	
2.45	10.10				½-GS-6	1.0	17.2	
3.40	14.0	C 1"	5	¾-31-G-10	¾-GS-2	2.0	5.2	300
4.28	17.6				¾-GS-4	2.3	8.2	
5.26	21.7				¾-GS-6	2.5	12.9	
6.85	28.2		6	1-27-G-10	1-GS-4	3.0	11.0	250
8.73	35.9				• 1-GS-6	4.0	20.8	
11.0	45.3			1-41-G-10	1-GS-4	2.5	18.7	250
14.0	57.6				• 1-GS-6	3.0	30.5	
17.3	71.2	D 1½"	8	1½-25-G-10	1½-GS-4	6.0	12.9	135
19.8	81.5				1½-GS-6	7.0	16.5	
23.4	96.4			1½-34-G-10	1½-GS-4	5.0	14.9	135
26.9	111.0				• 1½-GS-6	8.0	19.9	
36.3	150		9	2-24-G-10	2-GS-6	10.0	24.2	90
47.8	197			2-31-G-10	2-GS-6	10.0	32.8	90

Courtesy Ametek, Schutte and Koerting Co., Cornwells Heights, PA.



Courtesy Ametek, Schutte and Koerting Co., Cornwells Heights, PA.

CHAPTER NINE

Flow Conversions

Program 20A	SCFH to PPH
Program 20A′	PPH to SCFH
Program 20B	USGPM to PPH
Program 20B′	PPH to USGPM
Program 20C	SCFH to CFH
Program 20C′	CFH to SCFH

All of the programs in this book require the flowrate to be in pounds per hour for liquid, gas, or vapor. Weight was chosen because it is independent of pressure and temperature, whereas volume is dependent. Volume must always be accompanied with a temperature and pressure statement because conditions vary with custom and industry. Barrels are invariably at 60°F, gallons can be at any temperature, cubic feet can be at any pressure or temperature, and standard cubic feet is usually (but not necessarily) at 14.7 PSIA and 60°F. Gallons also come in two sizes; the Imperial gallon is approximately 20% larger than the US gallon.

When flow is calculated in pounds per hour, the specific gravities, specific weights, compressibility factors, ratios of specific heats, and viscosities are at flowing conditions. When converting from and to USGPM, the specific gravity must be the value at the temperature for which the USGPM is to be measured.

Program 20
Flow Conversions

Program 20: User Instructions

Standard cubic feet per hour to pounds per hour, press A.

a) Enter:
   1. Flowrate, SCFH (60°F, 14.7 PSIA) — Press R/S
   2. Molecular weight, dimensionless — Press R/S

b) Program calculates flowrate, pounds per hour.

Pounds per hour to standard cubic feet per hour, press A'.

a) Enter:
   1. Flowrate, pounds per hour — Press R/S
   2. Molecular weight, dimensionless — Press R/S

b) Program calculates flowrate in SCFH (60°F, 14.7 PSIA).

US gallons per minute to pounds per hour, press B.

a) Enter:
   1. Flowrate, US gallons per minute — Press R/S
   2. Specific gravity at the same temperature, dimensionless — Press R/S

b) Program calculates flowrate, pounds per hour.

Pounds per hour to US gallons per minute, press B'.

a) Enter:
   1. Flowrate, pounds per hour — Press R/S
   2. Specific gravity at the required temperature, dimensionless — Press R/S

b) Program calculates flowrate in US gallons per minute.

Standard cubic feet per hour to actual cubic feet per hour, press C.

a) Enter:
   1. Flowrate, SCFH — Press R/S
   2. Flow pressure, PSIG — Press R/S
   3. Flow temperature, °F — Press R/S

b) Program calculates flowrate, ACFH.

Actual cubic feet per hour to standard cubic feet per hour, press C'.

a) Enter:
   1. Flowrate, ACFH — Press R/S
   2. Flow pressure, PSIG — Press R/S
   3. Flow temperature, °F — Press R/S

b) Program calculates flowrate, SCFH.

Program 20: TI 59 Data Sheet

A

```
********************

 FLOW CONVERSIONS
 SCFH  TO   PPH

ENTER FLOW RATE SCFH
      47375.
ENTER  MOL WGHT
        24.
 CONV FLOW   =
       3000.      PPH

********************
```

A¹

```
********************

 FLOW CONVERSIONS
  PPH  TO  SCFH

ENTER FLOW RATE  PPH
       3000.
ENTER  MOL WGHT
        24.
 CONV FLOW   =
      47375.    SCFH

********************
```

B

```
********************

 FLOW CONVERSIONS
USGPM  TO   PPH

ENTER FLOW RATEUSGPM
        10.
ENTER SAME COND  SG
        0.6
 CONV FLOW   =
       3000.      PPH

********************
```

B¹

```
********************

 FLOW CONVERSIONS
  PPH  TO USGPM

ENTER FLOW RATE  PPH
       3000.
ENTER SAME COND  SG
        0.6
 CONV FLOW   =
               USGPM
        10.

********************
```

C

```
********************

 FLOW CONVERSIONS
 SCFH  TO  ACFH

ENTER FLOW RATE SCFH
       2000.
ENTER FLOW PRSS PSIG
       14.7
ENTER FLOW TEMP   °F
       580.
 CONV FLOW   =
       2000.     ACFH

********************
```

C¹

```
********************

 FLOW CONVERSIONS
 ACFH  TO  SCFH

ENTER FLOW RATE ACFH
       2000.
ENTER FLOW PRSS PSIG
       14.7
ENTER FLOW TEMP   °F
       580.
 CONV FLOW   =
       2000.     SCFH

********************
```

Program 20: TI 59 Register Loading

PARTITIONING
479.59

0.	00
0.	01
0.	02
0.	03
0.	04
0.	05
0.	06
0.	07
0.	08
0.	09
0.	10
0.	11
0.	12
0.	13
0.	14
0.	15
0.	16
0.	17
0.	18
0.	19
0.	20
15323116.	21
0.	22
0.	23
29.292929	24
36133017.	25
56.5345	26
53.414	27
53.4342	28
5151515151.	29
25.2144	30
47.46	31
53.5158	32
53.5148	33
53.515	34
53.5149	35
49.5258	36
50.5248	37
50.5249	38
49.525	39
7321.	40
37173033.	41
33362422.	42
33353636.	43
362200.	44
640000.	45
43222337.	46
303227.	47
4136223330.	48
36152123.	49
333323.	50
35133717.	51
373200.	52
21273243.	53
3136000000.	54
1735362432.	55
15323142.	56
1731371735.	57
13152123.	58
53.565554	59

Program 20: TI 59 Listing

SUBROUTINES
PRINT & STORE VARIABLES

```
000  76 LBL
001  42 STO
002  42 STO
003  23  23
004  43 RCL
005  57  57
006  69 OP
007  01  01
008  73 RC*
009  23  23
010  69 OP
011  02  02
012  71 SBR
013  43 RCL
014  69 OP
015  03  03
016  71 SBR
017  43 RCL
018  69 OP
019  04  04
020  69 OP
021  05  05
022  69 OP
023  21  21
024  73 RC*
025  01  01
026  91 R/S
027  99 PRT
028  72 ST*
029  01  01
030  92 RTN
```

DECODE LINES

```
031  76 LBL
032  43 RCL
033  43 RCL
034  23  23
035  22 INV
036  59 INT
037  65  ×
038  01  1
039  00  0
040  00  0
041  95  =
042  42 STO
043  23  23
044  73 RC*
045  23  23
046  92 RTN
```

PRINT LINES

```
047   76 LBL
048   61 GTO
049   42 STO
050   23  23
051   73 RC*
052   23  23
053   69 OP
054   01  01
055   71 SBR
056   43 RCL
057   69 OP
058   02  02
059   71 SBR
060   43 RCL
061   69 OP
062   03  03
063   71 SBR
064   43 RCL
065   69 OP
066   04  04
067   69 OP
068   05  05
069   92 RTN
```

PRINT COMMON HEADINGS

```
070   76 LBL
071   90 LST
072   01   1
073   42 STO
074   01  01
075   43 RCL
076   24  24
077   71 SBR
078   61 GTO
079   98 ADV
080   43 RCL
081   59  59
082   71 SBR
083   61 GTO
084   92 RTN
```

PRINT COMMON END

```
085   76 LBL
086   97 DSZ
087   42 STO
088   05  05
089   98 ADV
090   43 RCL
091   24  24
092   71 SBR
093   61 GTO
094   98 ADV
095   98 ADV
096   98 ADV
097   98 ADV
098   43 RCL
099   05  05
100   91 R/S
```

MAIN PROGRAM SCFH TO PPH

```
101   76 LBL
102   11   A
103   71 SBR
104   90 LST
105   43 RCL
106   39  39
107   71 SBR
108   61 GTO
109   98 ADV
110   43 RCL
111   35  35
112   71 SBR
113   42 STO
114   43 RCL
115   31  31
116   71 SBR
117   42 STO
118   43 RCL
119   26  26
120   71 SBR
121   61 GTO
122   43 RCL
123   50  50
124   69 OP
125   04  04
126   43 RCL
127   02  02
128   65   ×
129   43 RCL
130   03  03
131   55   ÷
132   03   3
133   07   7
134   09   9
135   95   =
136   69 OP
137   06  06
138   61 GTO
139   97 DSZ
```

PPH TO SCFH

```
140   76 LBL
141   16 A'
142   71 SBR
143   90 LST
144   43 RCL
145   38  38
146   71 SBR
147   61 GTO
148   98 ADV
149   43 RCL
150   34  34
151   71 SBR
152   42 STO
153   43 RCL
154   31  31
155   71 SBR
156   42 STO
157   43 RCL
158   26  26
159   71 SBR
160   61 GTO
161   43 RCL
162   49  49
163   69 OP
164   04  04
165   43 RCL
166   02  02
167   65   ×
168   03   3
169   07   7
170   09   9
171   55   ÷
172   43 RCL
173   03  03
174   95   =
175   69 OP
176   06  06
177   61 GTO
178   97 DSZ
```

USGPM TO PPH

```
179   76 LBL
180   12   B
181   71 SBR
182   90 LST
183   43 RCL
184   39  39
185   75   -
186   01   1
187   95   =
188   71 SBR
189   61 GTO
190   98 ADV
191   43 RCL
192   33  33
193   71 SBR
194   42 STO
195   43 RCL
196   30  30
```

```
197  71  SBR
198  42  STO
199  43  RCL
200  26   26
201  71  SBR
202  61  GTO
203  43  RCL
204  50   50
205  69  OP
206  04   04
207  43  RCL
208  02   02
209  65   ×
210  43  RCL
211  03   03
212  65   ×
213  05   5
214  00   0
215  00   0
216  95   =
217  69  OP
218  06   06
219  61  GTO
220  97  DSZ
```

PPH TO SCFH

```
221  76  LBL
222  17  B'
223  71  SBR
224  90  LST
225  43  RCL
226  37   37
227  71  SBR
228  61  GTO
229  98  ADV
230  43  RCL
231  34   34
232  71  SBR
233  42  STO
234  43  RCL
235  30   30
236  71  SBR
237  42  STO
238  43  RCL
239  26   26
240  71  SBR
241  61  GTO
242  69  OP
243  00   00
244  43  RCL
245  48   48
246  69  OP
247  04   04
248  69  OP
249  05   05
250  43  RCL
251  02   02
252  55   ÷
253  43  RCL
254  03   03
255  55   ÷
256  05   5
257  00   0
258  00   0
259  95   =
260  99  PRT
261  61  GTO
262  97  DSZ
```

SUBROUTINE FOR SCFH CALCS

```
263  76  LBL
264  70  RAD
265  43  RCL
266  28   28
267  71  SBR
268  42  STO
269  43  RCL
270  27   27
271  71  SBR
272  42  STO
273  43  RCL
274  26   26
275  71  SBR
276  61  GTO
277  01   1
278  04   4
279  93   .
280  07   7
281  44  SUM
282  03   03
283  04   4
284  06   6
285  00   0
286  44  SUM
287  04   04
288  43  RCL
289  03   03
290  55   ÷
291  01   1
292  04   4
293  93   .
294  07   7
295  65   ×
296  05   5
297  02   2
298  00   0
299  55   ÷
300  43  RCL
301  04   04
302  95   =
303  42  STO
304  05   05
305  92  RTN
```

SCFH TO PPH

```
306  76  LBL
307  13   C
308  71  SBR
309  90  LST
310  43  RCL
311  36   36
312  71  SBR
313  61  GTO
314  98  ADV
315  43  RCL
316  35   35
317  71  SBR
318  42  STO
319  71  SBR
320  70  RAD
321  43  RCL
322  58   58
323  69  OP
324  04   04
325  43  RCL
326  02   02
327  55   ÷
328  43  RCL
329  05   05
330  95   =
331  69  OP
332  06   06
333  61  GTO
334  97  DSZ
```

ACFH TO SCFH

```
335  76  LBL
336  18  C'
337  71  SBR
338  90  LST
339  43  RCL
340  38   38
341  85   +
342  08   8
343  95   =
344  71  SBR
345  61  GTO
346  98  ADV
```

347	43	RCL	354	49	49	361	05	05
348	32	32	355	69	OP	362	95	=
349	71	SBR	356	04	04	363	69	OP
350	42	STO	357	43	RCL	364	06	06
351	71	SBR	358	02	02	365	61	GTO
352	70	RAD	359	65	×	366	97	DSZ
353	43	RCL	360	43	RCL			

Program 20: HP 41CV Data Sheet

```
************

CONVERSIONS
 SCFH TO PPH

************

ENTER  FLOW  RATE  SCFH
      47,375.00     ***
ENTER  MW
          24.00     ***
CONVERTED
 FLOW PPH
       3,000.00     ***

************

               3,000.00
```

```
************

CONVERSIONS
USGPM TO PPH

************

ENTER  FLOW  RATE USGPM
          10.00     ***
ENTER SAME COND SG
           0.60     ***
CONVERTED
 FLOW PPH
       3,000.00     ***

************

               3,000.00
```

```
************

CONVERSIONS
SCFH TO ACFH

************

ENTER  FLOW  FLOW  SCFH
      47,375.00     ***
ENTER PRSS PSIG
          14.70     ***
ENTER TEMP DEG F
         580.00     ***
CONVERTED
 FLOW  ACFH
      47,375.00     ***

************

              47,375.00
```

```
************

CONVERSIONS
PPH TO SCFH

************

ENTER  FLOW  RATE PPH
       3,000.00     ***
ENTER  MW
          24.00     ***
CONVERTED
 FLOW  SCFH
      47,375.00     ***

************

              47,375.00
```

```
************

CONVERSIONS
PPH TO USGPM

************

ENTER  FLOW  RATE PPH
       3,000.00     ***
ENTER SAME COND SG
           0.60     ***
CONVERTED
 FLOW USGPM
          10.00     ***

************

                  10.00
```

```
************

CONVERSIONS
ACFH TO SCFH

************

ENTER  FLOW  RATE  ACFH
      47,375.00     ***
ENTER PRSS PSIG
          14.70     ***
ENTER TEMP DEG F
         580.00     ***
CONVERTED
 FLOW  SCFH
      47,375.00     ***

************

              47,375.00
```

Program 20: HP 41CV Register Loading

SIZE 080

```
R00=  0.000000
R01=  0.000000
R02=  0.000000
R03=  0.000000
R04=  0.000000
R05=  0.000000
R06=  0.000000
R07=  0.000000
R08=  0.000000
R09=  0.000000
R10=  0.000000
R11=  0.000000
R12=  0.000000
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  0.000000
R17=  0.000000
R18= " FLOW "
R19= " RATE "
R20= "PPH   "
R21= " MW   "
R22= "CONVER"
R23= "TED   "
R24= "SAME C"
R25= "OND SG"
R26= "PRSS P"
R27= "SIG   "
R28= "TEMP D"
R29= "EG F  "
R30= " ACFH "
R31=  0.000000
R32=  72.737475
R33=  57.181974
R34=  57.210000
R35=  0.000000
R36=  22.231820
R37=  72.737674
R38=  57.181920
R39=  57.210000
R40=  0.000000
R41=  22.231874
R42=  72.737775
R43=  57.181977
R44=  57.242500
R45=  0.000000
R46=  22.231820
R47=  72.737678
R48=  57.181920
R49=  57.242500
R50=  0.000000
R51=  22.231877
R52= "0 ACFH"
R53= "ACFH T"
R54= "0 SCFH"
R55= "******"
R56=  0.000000
R57= "ENTER "
R58=  71.000000
R59=  0.000000
R60=  72.737952
R61=  57.181874
R62=  57.262700
R63=  57.282900
R64=  0.000000
R65=  22.231830
R66=  72.735354
R67=  57.181930
R68=  57.262700
R69=  57.282900
R70=  0.000000
R71=  22.231874
R72= "CONVER"
R73= "SIONS "
R74= " SCFH "
R75= "TO PPH"
R76= "PPH TO"
R77= "USGPM "
R78= " USGPM"
R79= "SCFH T"
```

Program 20: HP 41CV Listing

SUBROUTINES

```
01♦LBL "CONVSN"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 GTO d
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53♦LBL 01
54 XEQ J
55 GTO e
```

RE-ENTER VARIABLES

```
56♦LBL "REENTER"
57 ADV
58 FC? 14
59 GTO 01
60 1
61 GTO 02
```

```
62♦LBL 01
63 FC? 15
64 GTO 01
65 3
66 GTO 02
67♦LBL 01
68 FC? 16
69 GTO 01
70 5
71 GTO 02
72♦LBL 01
73 FC? 17
74 GTO 01
75 7
76 GTO 02
77♦LBL 01
78 FC? 18
79 GTO 01
80 9
81 GTO 02
82♦LBL 01
83 FC? 19
84 GTO F
85 12
86♦LBL 02
87 +
88 STO 01
89 RCL IND 01
90 XEQ J
91 STOP
92 XEQ J
93 STO IND 01
94 ADV
95 SF 00
96 SF 02
97 STOP
98 FS? 14
99 GTO 07
100 FS? 15
101 GTO 08
102 FS? 16
103 GTO 09
104 FS? 17
105 GTO 10
106 FS? 18
107 GTO 11
108 FS? 19
109 GTO 12
```

BYPASS PRINTER

```
110♦LBL J
111 FC? 55
112 GTO 01
113 PRX
114 RTN
115♦LBL 01
116 VIEW X
117 RTN
```

SELECT PROGRAM FOR REPRINT

```
118♦LBL B
119 FS? 14
120 GTO 01
121 FS? 15
122 GTO 02
123 FS? 16
124 GTO 03
125 FS? 17
126 GTO 04
127 FS? 18
128 GTO 05
129 FS? 19
130 GTO 06
```

CLEAR FLAGS NEW ENTRY

```
131♦LBL C
132 CF 14
133 CF 15
134 CF 16
135 CF 17
136 CF 18
137 CF 19
138 RTN
139♦LBL D
140 XEQ a
141 XEQ d
142 XEQ a
143 XEQ e
144 CF 02
145 RTN
```

MAIN PROGRAM

SCFH TO PPH

```
146♦LBL A
147 FS? 00
148 GTO B
149 XEQ C
150 SF 14
151♦LBL 01
152 1
153 STO 01
154 31
155 STO 58
156 XEQ D
157♦LBL 07
158 RCL 02
159 STO 10
160 RCL 03
161 STO 05
162 *
163 379
164 /
165 STO 04
166 STO 08
167 GTO I
```

PPH TO SCFH

```
168♦LBL "P TO F"
169 FS? 00
170 GTO B
171 XEQ C
172 SF 15
173♦LBL 02
174 3
175 STO 01
176 36
177 STO 58
178 XEQ D
179♦LBL 08
180 RCL 04
181 STO 08
182 379
183 *
184 RCL 05
185 STO 03
186 /
187 STO 02
188 STO 10
189 GTO I
```

USGPM TO PPH

```
190♦LBL "G TO P"
191 FS? 00
192 GTO B
193 XEQ C
194 SF 16
195♦LBL 03
196 5
197 STO 01
198 41
199 STO 58
200 XEQ D
201♦LBL 09
202 RCL 06
203 500
204 *
205 RCL 07
206 STO 09
207 *
208 STO 04
209 STO 08
210 GTO I
```

PPH TO USGPM

```
211♦LBL "P TO G"
212 FS? 00
213 GTO B
```

```
214 XEQ C
215 SF 17
216♦LBL 04
217 7
218 STO 01
219 46
220 STO 58
221 XEQ D
222♦LBL 10
223 RCL 08
224 STO 04
225 500
226 /
227 RCL 09
228 STO 07
229 /
230 STO 16
231 GTO I
```

```
245 STO 15
246 460
247 +
248 520
249 /
250 14.7
251 ENTER↑
252 ENTER↑
253 RCL 11
254 STO 14
255 +
256 /
257 *
258 RCL 10
259 STO 02
260 *
261 STO 13
262 GTO I
```

```
276 RCL 15
277 STO 12
278 460
279 +
280 /
281 RCL 14
282 STO 11
283 14.7
284 +
285 14.7
286 /
287 *
288 RCL 13
289 *
290 STO 10
291 STO 02
```

SCFH TO ACFH

```
232♦LBL "S TO A"
233 FS? 00
234 GTO B
235 XEQ C
236 SF 18
237♦LBL 05
238 9
239 STO 01
240 59
241 STO 58
242 XEQ D
243♦LBL 11
244 RCL 12
```

ACFH TO SCFH

```
263♦LBL "A TO S"
264 FS? 00
265 GTO B
266 XEQ C
267 SF 19
268♦LBL 06
269 12
270 STO 01
271 65
272 STO 58
273 XEQ D
274♦LBL 12
275 520
```

COMMON ENDING

```
292♦LBL I
293 STO 16
294 XEQ J
295 FS? 02
296 STOP
297 CF 00
298 XEQ a
299 RCL 16
300 VIEW X
301 BEEP
302 ADV
303 STOP
304 .END.
```

Program 20: Sequence of Calculations

1. Standard cubic feet per hour to pounds per hour.

$$W_m = \frac{Q_m M}{379} \text{ pounds per hour}$$

2. Pounds per hour to standard cubic feet per hour.

$$Q_m = \frac{379\ W_m}{M} \text{ SCFH}$$

3. US gallons per minute to pounds per hour.

$$W_m = 500\ Q_m\ G \text{ pounds per hour}$$

4. Pounds per hour to US gallons per minute.

$$Q_m = \frac{W_m}{500\,G}\ \text{USGPM}$$

5. Standard cubic feet per hour to actual cubic feet per hour.

$$Q_S = \frac{Q_A}{\left(\dfrac{520}{T_f + 460}\right)\left(\dfrac{P_f + 14.7}{14.7}\right)}\ \text{ACFH}$$

6. Actual cubic feet per hour to standard cubic feet per hour.

$$Q_A = Q_S\left(\frac{520}{T_f + 460}\right)\left(\frac{P_f + 14.7}{14.7}\right)\ \text{SCFH}$$

Program 20: Nomenclature

G Specific gravity at the same conditions at which flow is measured, dimensionless
M Molecular weight, dimensionless
P_f Flow pressure, PSIG
Q_A Rate of flow, actual cubic feet per hour
Q_m Rate of flow, US gallons per minute
Q_S Rate of flow, standard cubic feet per hour
T_f Flow temperature, °F
W_m Rate of flow, pounds per hour

CHAPTER TEN

Pressure Relief Valves

Most instrument engineers do not consider pressure relief valves as instruments—they are the orphans of the petrochemical industry, and nobody wishes to own them. ISA publishes a specification sheet for them, yet very rarely does ISA mention them again. Engineering contractors generally delegate them to their Instrument Department, yet operating companies rarely do. They are, however, vital to the safe operation of the plant, and the person responsible for them must be familiar with API 520 parts 1 and 2 and the ASME and any other authoritative body. The manufacturers are also a valuable source of information.

Plant operations must be thoroughly understood, and an analysis of all possible contingencies must be made and the worst case selected (typical cases are shown in Table 10-1). It is not normal, however, to consider double contingencies such as an external fire and, at the same time, an operations error, unless there is a real possibility of it happening. Good engineering judgment is called for. The valves are inexpensive insurance for the plant, and underinsurance can be an unmitigated disaster.

Pressure relief valves are required on all equipment that can be blocked in, although it is permissible to have a block valve car sealed open. Rupture discs are sometimes installed under a relief valve where bubble-tight shutoff is required or where corrosive or dirty service conditions exist. In such cases a pressure gauge should be installed between the two so that rupture-disc failures can be detected. Dual valves with a special three-way valve that ensures that full relief area is always available can be installed where servicing may be required between unit shutdowns.

When sizing pressure relief valves, remember that they are basically a differential pressure device. They open when the inlet pressure minus the back pressure equals the set pressure. Most valves relieve into a relief header which is tied into the flare. If the relief header already has some valves discharging into it, a higher back pressure will be exerted on those valves not yet open, and a higher inlet pressure will be required to open them.

Since most valves are set at the maximum allowable working pressure of the vessel, and since the ASME codes have strict limitations as to how much this can be exceeded, special care must be taken to select the correct valve for the service.

There are essentially two types of valves—standard valves and bellows valves (some typical valves are shown in Figure 10-1). The latter have a bellows installed over the seat mechanism to keep the back pressure at atmospheric pressure.

Standard valves are usually selected for cases where the back pressure is likely to be nearly constant. (This is not necessarily atmospheric pressure.) The spring is adjusted to give the desired opening pressure. A variable back pressure of 10% of set pressure is usually allowed, for a valve is usually sized on the basis of critical flow. Therefore, a 10% overpressure would only delay the valve opening; it would not affect flowrate or accumulation (accumulation being defined as the allowable increase in pressure during discharge through the relief valve.

Where back pressure variations exceed 10% of the set pressure, a bellows valve is normally chosen. The bellows must be vented to atmosphere. These valves inherently require more maintenance than standard valves. Failure of the bellows by corrosion, rupture, or plugging of the vent converts them to standard valves. They have back-pressure and size limitations, and where the back pressure is sufficiently high to prevent sonic velocity through the valve, they usually have a smaller capacity than the standard valve.

The set pressure is the pressure at which a liquid valve starts to lift and a gas or vapor valve pops open. Maximum flow is achieved at a slightly higher pressure called accumulation. ASME has very definite limits as to the accumulation rise if the set pressure is also the maximum allowable working pressure. Accumulation is defined as

(set pressure PSIG $\times$ overpressure factor $+$ 14.7) PSIA

(text continued on page 255)

Table 10-1
Operational Difficulties and Required Capacities**

Item No.	Condition	Required Relief Capacity: Relief Valve for Liquid Relief	Required Relief Capacity: Safety-Relief Valve for Vapor Relief*
1	Closed outlets on vessels	Maximum liquid pump-in rate	Total incoming steam and vapor, plus that generated therein under normal operation.
2	Cooling water failure to condenser	—	Total incoming steam and vapor, plus that generated therein under normal operation, less vapor condensed by sidestream reflux.
3	Top-tower reflux failure	—	Total vapor to condenser at relieving conditions.
4	Sidestream reflux failure	—	Difference between vapor entering and leaving section.
5	Lean oil failure to absorber	—	None.
6	Accumulation of noncondensables	—	Same effect in towers as for items No. 2 and No. 8 in other vessels.
7	Entrance of highly volatile material:		
	a. Water into hot oil	—	For towers—usually not predictable.
	b. Light hydrocarbons into hot oil	—	For heat exchangers—assume an area twice the internal crosssectional area of one tube to provide for the vapor generated by the entrance of the volatile fluid.
8	Overfilling storage or surge vessel	Maximum liquid pump-in rate	—
9	Failure of automatic controls:		
	a. Tower pressure controller, to closed position	—	Total normally uncondensed vapor.
	b. All valves to closed position, except water and reflux valves	No operational requirement	No operational requirement.
10	Abnormal heat or vapor input:		
	a. Fired heaters or steam reboilers	—	Estimated maximum vapor generation including noncondensable from overheating.
	b. Split reboiler tube	—	Steam entering from twice the cross-sectional area of one tube

(table continued on next page)

Operational Difficulties and Required Capacities (continued)**

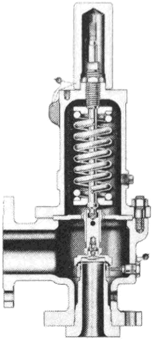
Item No.	Condition	Required Relief Capacity: Relief Valve for Liquid Relief	Required Relief Capacity: Safety-Relief Valve for Vapor Relief*
11	Internal explosions	—	Not controlled by conventional relief devices, but by avoidance of circumstances.
12	Chemical reaction	—	Estimated vapor generation from both normal and uncontrolled conditions
13	Hydraulic expansion:		
	a. Cold fluid shut in	Nominal size	—
	b. Lines outside process area shut in	Nominal size	—
14	Exterior fire	—	Estimate by the method given in Section 6.
15	Power failure (steam, electric, or other)	—	Study the installation to determine the effect of power failure. Size relief valve for the worst condition that can occur.
	a. Fractionators	—	All pumps could be down, with the result that reflux and cooling water would fail. Size valves as in item No. 2.
	b. Reactors	—	The agitation or stirring would stop and the quench or retarding stream would fail. Size valves for product generation from a runaway reaction.
	c. Air-cooled exchangers	—	Fans would fail. Size valves for the difference between normal and emergency duty.
	d. Surge vessels	Maximum liquid inlet rate	—

*Consideration may be given to the suppression of vapor production as the result of the valve's relieving pressure being above operating pressure, assuming constant heat input.

**Reprinted by Courtesy of the American Petroleum Institute, API RP520, Part 1, *Design,* Fourth Edition, December 1976.

PROCESS SAFETY RELIEF VALVES*

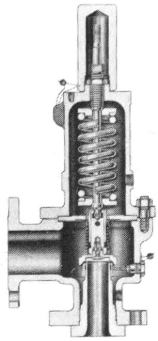
SERIES 2600



Conventional

ASME, NB Certified. Sizes 1" × 2" to 8" × 10". Effective orifice areas from .110 sq." to 26.0 sq.". Pressures –5 to 10,000 PSI. Temp. range, –450°F. to 1500°F. Stl. body—St. Stl. trim. Hardened St. Stl. disc to significantly reduce wear and prolong life. Optically ground for ultimate in tightness. No thermal distortion. Hastelloy, Monel and 316 SS materials available as well as NACE construction. Optional O-Ring elastomer seat seal for supreme tightness.

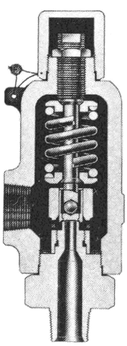
SERIES 2600



Balanseal

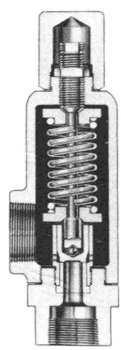
ASME, NB Certified. Sizes 1" × 2" to 8" × 10". Effective orifice areas from .110 sq." to 26.0 sq.". Pressures from –5 to 10,000 PSI. Temp. range, –450°F. to 1500°F. Stl. body—St. Stl. trim. Hardened St. Stl. disc to significantly reduce wear and prolong life. Optically ground for ultimate in tightness. No thermal distortion. Patented bellows isolate working parts and top-works from fouling or corrosive fluids. Nullifies back pressure. Optional O-Ring elastomer seat seal for supreme tightness.

SERIES 2740



ASME, NB Certified (2740U). Sizes 1/2" × 1" to 1" × 1". Effective orifice areas from .06 sq.". Pressures from 10 PSI to 2000 PSI. Temp. range of –450° F. to 750°F. Stl. body—Stl. bonnet—St. Stl. trim. Available with screwed, flanged, socket weld or welding nipple connection. Hastelloy, Monel and 316 SS materials available as well as NACE construction. Optional O-Ring elastomer seat seal for supreme tightness.

SERIES 2741



Sizes 3/4" × 1" to 2" × 2". Effective orifice areas from .110 sq." to .442 sq.". Pressures from 10 PSI to 5,000 PSI. Temperature range –450°F to 750°F. St. Stl. body—Stl. bonnet—St. Stl. trim. Available with screwed, flanged, socket weld or welding nipple connection. Hastelloy, Monel and 316 SS materials available as well as NACE construction. Optional O-Ring elastomer seat seal for supreme tightness.

Designation & Orifice Letter	Orifice Area Sq. In.	Designation & Orifice Letter	Orifice Area Sq. In.
D	0.110	L	2.853
E	0.196	M	3.60
F	0.307	N	4.34
G	0.503	P	6.38
H	0.785	Q	11.05
J	1.287	R	16.0
K	1.838	T	26.0

Figure 10-1. Typical pressure relief valves. (Courtesy Teledyne Farris Engineering, 400 Commercial Avenue, Palisades, Park, NJ 07650.)

For ASME-coded vessels protected by a single valve, Section VIII ASME Boiler and Pressure Vessel Code limits the overpressure factor to 1.2 for fire contingencies, and to 1.1 for all others. Section I ASME Power Boiler Code limits the overpressure factor to 1.03.

API 520 indicates that the overpressure factor for liquid relief on non-coded service is generally considered to be 1.25.

Material selection for the valves is usually based on worst conditions. For cold service this is very often the operating conditions, and for hot service it is the relief conditions.

The procedure for sizing a valve is to calculate the required orifice area, then pick the next largest available standard size. This means the valve has extra capacity, which is sometimes useful when designing relief header systems in terms of increased back pressure. The maximum back pressure that maintains flow at relief conditions is calculated and printed. If this figure is of any significance, it should be checked against the selected valve-manufacturers' data because there are limitations and variations between manufacturers, and the program will only provide typical data.

It is recommended that copies of API RP520, parts 1 and 2, and the Farris Bulletin FIC 117, "Safety and Relief Valves," be obtained for reference.

Program 21
Gas or Vapor Relief

Program 21: User Instructions

a) Initiate program, press A.
b) Enter:
   1. One (1) if the valve is to be sized for the fire case, any other number if not — Press R/S
   2. One (1) if the valve is to be a bellows type, any other number if not — Press R/S
   3. Maximum required flow through valve, pounds per hour — Press R/S
   4. Valve set pressure, PSIG — Press R/S
   5. Back pressure before the valve opens, PSIG — Press R/S
   6. Discharge temperature at flow conditions, °F — Press R/S
   7. Compressibility factor, dimensionless — Press R/S
   8. Ratio of specific heats C_p/C_v, dimensionless — Press R/S
   9. Gas or vapor molecular weight, dimensionless — Press R/S
c) Program calculates required relief area, square inches.

d) Enter:
   10. Selected valve area, square inches — Press R/S
e) Program calculates the maximum backpress that maintains flow at relief conditions, PSIG.

Note: The E subroutine is available to re-enter data and recalculate.

Program 21: TI 59 Data Sheet

```
*******************

  RELIEF  VALVE GAS

*******************

ENTR 1 FOR FIRE CASE
           0.
ENTR 1 FOR BLWS VALV
           0.
ENTR  FLOW  PPH
       12005.
ENTR   SET PRSS PSIG
          50.
ENTR  BACK PRSS PSIG
           2.
```

```
ENTR  DSCH TEMP   °F
          100.
ENTR      Z
        0.935
ENTR CP/CV
        1.024
ENTR     MW
          58.
CALC  AREA  IN²
 1.706696369
ENTR VALVE AREA  IN²
        1.838
CALC    MAX   BP PSIG
 38.01903663

*******************
```

Program 21: TI 59 Register Loading

PARTITIONING
479.59

0.	00	0.	18
0.	01	0.	19
0.	02	15133617.	20
0.	03	0.	21
0.	04	0.	22
0.	05	21243517.	23
0.	06	0.	24
0.	07	0.	25
0.	08	0.	26
0.	09	14131526.	27
0.	10	243170.	28
0.	11	13351713.	29
0.	12	54.535251	30
0.	13	0.50232	31
0.	14	0.504948	32
0.	15	333323.3733	33
0.	16	1433.383945	34
0.	17	46.273945	35
		7321.404336	36
		21273243.35	37
		361737.46	38

33353636.42	39	200213235.	50
16361523.	40	22133600.	51
56.2928	41	4213274217.	52
3043.522928	42	2417210000.	53
37173033.	43	351727.	54
56.473445	44	5151515151.	55
33362422.	45	1513271500.	56
1533631542.	46	1731373500.	57
301344.	47	0.	58
42132742.	48	0.	59
14274336.	49		

Program 21: TI 59 Listing

SUBROUTINES

ENTER & STORE VARIABLES

```
000  76 LBL
001  10 E'
002  29 CP
003  01  1
004  44 SUM
005  58  58
006  73 RC*
007  58  58
008  22 INV
009  59 INT
010  52 EE
011  22 INV
012  52 EE
013  67  EQ
014  19 D'
015  85  +
016  05  5
017  07  7
018  95  =
019  17 B'
020  69 OP
021  21  21
022  73 RC*
023  01  01
024  87 IFF
025  00  00
026  00  00
027  31  31
028  91 R/S
029  72 ST*
030  01  01
031  73 RC*
032  01  01
033  99 PRT
034  61 GTO
035  10 E'
```

PRINT LINES

```
036  76 LBL
037  19 D'
038  01  1
039  44 SUM
040  58  58
041  73 RC*
042  58  58
043  76 LBL
044  17 B'
045  42 STO
046  59  59
047  73 RC*
048  59  59
049  69 OP
050  01  01
051  18 C'
052  69 OP
053  02  02
054  18 C'
055  69 OP
056  03  03
057  18 C'
058  69 OP
059  04  04
060  69 OP
061  05  05
062  92 RTN
```

DECODE LINES

```
063  76 LBL
064  18 C'
065  01  1
066  00  0
067  00  0
068  48 EXC
069  59  59
070  22 INV
071  59 INT
072  49 PRD
073  59  59
074  73 RC*
075  59  59
076  92 RTN
```

PRINT LINE OF STARS

```
077  76 LBL
078  16 A'
079  93  .
080  00  0
081  01  1
082  08  8
083  35 1/X
084  98 ADV
085  17 B'
086  98 ADV
087  92 RTN
```

RE-ENTER VARIABLES

```
088  76 LBL
089  15  E
090  99 PRT
091  85  +
092  01  1
093  95  =
094  42 STO
095  01  01
096  73 RC*
097  01  01
098  91 R/S
099  72 ST*
100  01  01
101  99 PRT
102  98 ADV
103  86 STF
104  00  00
```

```
105   86  STF
106   01   01
107   91  R/S
108   61  GTO
109   52  EE
```

CALC P_1

```
110   76  LBL
111   22  INV
112   53   (
113   43  RCL
114   05   05
115   65   ×
116   43  RCL
117   16   16
118   85   +
119   01   1
120   04   4
121   93   .
122   07   7
123   54   )
124   92  RTN
```

CALC K_b

```
125   76  LBL
126   25  CLR
127   53   (
128   53   (
129   43  RCL
130   22   22
131   65   ×
132   53   (
133   43  RCL
134   12   12
135   45  Y×
136   43  RCL
137   24   24
138   75   -
139   43  RCL
140   12   12
141   45  Y×
142   43  RCL
143   25   25
144   54   )
145   54   )
146   34  ΓX
147   65   ×
148   07   7
149   03   3
150   05   5
151   55   ÷
152   43  RCL
153   26   26
154   54   )
155   92  RTN
```

CALC C

```
156   76  LBL
157   24  CE
158   53   (
159   05   5
160   02   2
161   00   0
162   65   ×
163   53   (
164   01   1
165   93   .
166   02   2
167   01   1
168   03   3
169   75   -
170   12   B
171   54   )
172   54   )
173   92  RTN
```

CALC $(2/(k+1))^k(k-1)$

```
174   76  LBL
175   12   B
176   53   (
177   53   (
178   02   2
179   55   ÷
180   53   (
181   43  RCL
182   09   09
183   85   +
184   01   1
185   54   )
186   54   )
187   45  Y×
188   43  RCL
189   22   22
190   54   )
191   92  RTN
```

MAIN PROGRAM
ENTER DATA

```
192   76  LBL
193   11   A
194   22  INV
195   86  STF
196   01   01
197   01   1
198   42  STO
199   01   01
200   02   2
201   09   9
202   42  STO
203   58   58
204   16  A'
205   19  D'
206   16  A'
207   10  E'
```

CALC $k/(k-1)$

```
208   76  LBL
209   52  EE
210   43  RCL
211   09   09
212   55   ÷
213   53   (
214   43  RCL
215   09   09
216   75   -
217   01   1
218   54   )
219   95   =
220   42  STO
221   22   22
```

CALC $(k+1)/k$

```
222   43  RCL
223   09   09
224   85   +
225   01   1
226   95   =
227   55   ÷
228   43  RCL
229   09   09
230   95   =
231   42  STO
232   25   25
```

CALC $2/k$

```
233   02   2
234   55   ÷
235   43  RCL
236   09   09
237   95   =
238   42  STO
239   24   24
```

CALC OVERPRESS FACTOR

```
240   71  SBR
241   24  CE
242   42  STO
243   26   26
244   01   1
```

```
245   32  X:T
246   43  RCL
247   02   02
248   22  INV
249   67   EQ
250   33  X²
251   93   .
252   01   1
253   85   +
254   76  LBL
255   33  X²
256   01   1
257   93   .
258   01   1
259   95   =
260   42  STO
261   16   16
```

CALC r

```
262   43  RCL
263   03   03
264   67   EQ
265   67   EQ
266   43  RCL
267   06   06
268   85   +
269   01   1
270   04   4
271   93   .
272   07   7
273   95   =
274   55   ÷
275   71  SBR
276   22  INV
277   95   =
278   32  X:T
279   12   B
280   42  STO
281   12   12
282   42  STO
283   21   21
284   77   GE
285   43  RCL
286   32  X:T
287   42  STO
288   12   12
```

CALC K_b

```
289   01   1
290   32  X:T
291   71  SBR
292   25  CLR
293   61  GTO
294   42  STO
295   76  LBL
296   67   EQ
297   43  RCL
298   05   05
299   65   ×
300   93   .
301   00   0
302   04   4
303   94  +/-
304   95   =
305   22  INV
306   23  LNX
307   65   ×
308   93   .
309   03   3
310   94  +/-
311   85   +
312   01   1
313   93   .
314   06   6
315   95   =
316   42  STO
317   17   17
318   75   -
319   43  RCL
320   06   06
321   55   ÷
322   43  RCL
323   05   05
324   65   ×
325   01   1
326   93   .
327   01   1
328   08   8
329   76  LBL
330   42  STO
331   95   =
332   22  INV
333   77   GE
334   32  X:T
335   76  LBL
336   43  RCL
337   01   1
338   76  LBL
339   32  X:T
340   42  STO
341   13   13
```

CALC A

```
342   43  RCL
343   07   07
344   85   +
345   04   4
346   06   6
347   00   0
348   95   =
349   65   ×
350   43  RCL
351   08   08
352   55   ÷
353   43  RCL
354   10   10
355   95   =
356   34  ΓX
357   65   ×
358   43  RCL
359   04   04
360   55   ÷
361   43  RCL
362   26   26
363   55   ÷
364   93   .
365   09   9
366   05   5
367   03   3
368   55   ÷
369   71  SBR
370   22  INV
371   55   ÷
372   43  RCL
373   13   13
374   95   =
375   99  PRT
376   42  STO
377   14   14
```

ENTER VALVE AREA

```
378   87  IFF
379   01   01
380   44  SUM
381   10  E'
382   22  INV
383   86  STF
384   00   00
385   76  LBL
386   44  SUM
387   43  RCL
388   21   21
389   42  STO
390   12   12
391   43  RCL
392   14   14
393   55   ÷
394   43  RCL
395   11   11
396   65   ×
397   43  RCL
398   13   13
399   95   =
```

```
400  42 STO
401  15  15
```

CALC MAX BACKPRES

```
402  01   1
403  32 X:T
404  43 RCL
405  03  03
406  22 INV
407  67  EQ
408  23 LNX
409  43 RCL
410  17  17
411  75   -
412  43 RCL
413  15  15
414  95   =
415  55   ÷
416  01   1
417  93   .
418  01   1
419  08   8
420  65   ×
421  43 RCL
422  05  05
423  95   =
424  61 GTO
425  61 GTO
426  76 LBL
427  23 LNX
428  01   1
429  32 X:T
430  43 RCL
431  21  21
432  85   +
433  01   1
434  95   =
435  34  ΓX
436  49 PRD
437  12  12
438  93   .
439  00   0
440  00   0
441  01   1
442  32 X:T
443  71 SBR
444  25 CLR
445  75   -
446  43 RCL
447  15  15
448  95   =
449  66 PAU
450  42 STO
451  21  21
452  50 I×I
453  77  GE
454  23 LNX
455  43 RCL
456  12  12
457  65   ×
458  71 SBR
459  22 INV
460  75   -
461  01   1
462  04   4
463  93   .
464  07   7
465  95   =
466  76 LBL
467  61 GTO
468  99 PRT
469  42 STO
470  18  18
471  16  A'
472  98 ADV
473  98 ADV
474  43 RCL
475  14  14
476  91 R/S
```

Program 21: HP 41CV Data Sheet

```
************

   *RV GAS*

************

ENTER 1 FOR FIRE CASE
        0.0000    ***
ENTER 1 FOR BELLWS VALVE
        0.0000    ***
ENTER FLOW PPH
   12,005.0000    ***
ENTER  SET PRSS PSIG
       50.0000    ***
ENTER BACK PRSS PSIG
        2.0000    ***
ENTER DISCH TEMP DEG F
      100.0000    ***
ENTER  Z
        0.9350    ***
ENTER CP/CV
        1.0240    ***
ENTER  MW
       58.0000    ***
CALC    AREA
SQ INS
        1.7067    ***
ENTER  VALVE AREA SQ INS
        1.8380    ***
CALC   MAX BA
CK PRSS PSIG
       38.0190    ***

************
```

Program 21: HP 41CV Register Loading

SIZE 080

```
R00=  0.000000
R01=  0.000000
R02=  0.000000
R03=  0.000000
R04=  0.000000
R05=  0.000000
R06=  0.000000
R07=  0.000000
R08=  0.000000
R09=  0.000000
R10=  0.000000
R11=  0.000000
R12=  0.000000
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  0.000000
R17=  0.000000
R18=  0.000000
R19=  0.000000
R20=  0.000000
R21=  0.000000
R22=  0.000000
R23=  0.000000
R24=  0.000000
```

```
R25=  0.000000
R26=  0.000000
R27= "1 FOR "
R28= "FIRE C"
R29= "ASE   "
R30=  46.470000
R31=  57.272829
R32=  57.275051
R33=  57.525300
R34=  57.546061
R35=  57.626061
R36=  57.636465
R37=  57.660000
R38=  57.730000
R39=  57.670000
R40=  0.000000
R41=  56.686900
R42=  57.516869
R43=  0.000000
```

```
R44=  56.707172
R45=  0.000000
R46= "  *RV "
R47= "GAS*  "
R48=  0.000000
R49=  0.000000
R50= "BELLWS"
R51= " VALVE"
R52= "FLOW P"
R53= "PH    "
R54= " SET P"
R55= "******"
R56= "CALC  "
R57= "ENTER "
R58=  44.000000
R59=  0.000000
R60= "RSS PS"
R61= "IG    "
R62= "BACK P"
```

```
R63= "DISCH "
R64= "TEMP D"
R65= "EG F  "
R66= " Z    "
R67= " MW   "
R68= " AREA "
R69= "SQ INS"
R70= "MAX BA"
R71= "CK PRS"
R72= "S PSIG"
R73= "CP/CV "
R74=  0.000000
R75=  0.000000
R76=  0.000000
R77=  0.000000
R78=  0.000000
R79=  0.000000
```

Program 21: HP 41CV Listing

SUBROUTINES

```
01♦LBL "RV GAS"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 GTO d
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53♦LBL 01
54 XEQ J
55 GTO e
```

RE-ENTER VARIABLES

```
56♦LBL "REENTER"
57 ADV
58 1
59 +
60 STO 01
61 RCL IND 01
62 XEQ J
63 STOP
64 XEQ J
65 STO IND 01
66 ADV
67 SF 00
68 SF 02
69 STOP
70 GTO 02
```

BYPASS PRINTER

```
71♦LBL J
72 FC? 55
73 GTO 01
74 PRX
75 RTN
76♦LBL 01
77 VIEW X
78 RTN
```

CALC P_1

```
79♦LBL F
80 RCL 05
81 RCL 16
82 *
83 14.7
84 +
85 RTN
```

CALC K_b

```
 86♦LBL G
 87 RCL 12
 88 RCL 24
 89 Y↑X
 90 RCL 12
 91 RCL 25
 92 Y↑X
 93 -
 94 RCL 22
 95 *
 96 SQRT
 97 735
 98 *
 99 RCL 26
100 /
101 RTN
```

CALC C

```
102♦LBL H
103 1.213
104 XEQ B
105 -
106 520
107 *
108 RTN
```

CALC C

```
109♦LBL B
110 2
111 ENTER↑
112 RCL 09
113 1
114 +
115 /
116 RCL 22
117 Y↑X
118 RTN
```

MAIN PROGRAM

ENTER DATA

```
119♦LBL A
120 1
121 STO 01
122 29
123 STO 58
124 XEQ a
125 XEQ d
126 XEQ a
127 XEQ e
128 CF 02
```

AIR CALC k/(k − 1) & CALC (k + 1)/k

```
129♦LBL 02
130 10
131 STO 01
132 41
133 STO 58
134 RCL 09
135 RCL 09
136 1
137 -
138 /
139 STO 22
140 RCL 09
141 1
142 +
143 RCL 09
144 /
145 STO 25
```

CALC 2/k

```
146 2
147 RCL 09
148 /
149 STO 24
```

CALC OVERPRES FACTOR

```
150 XEQ H
151 STO 26
152 1
153 RCL 02
154 X≠Y?
155 GTO 01
156 1.2
157 GTO 02
158♦LBL 01
159 1.1
160♦LBL 02
161 STO 16
```

CALC r

```
162 RCL 03
163 1
164 X=Y?
165 GTO 01
166 RCL 06
167 14.7
168 +
169 XEQ F
170 /
171 STO 23
172 XEQ B
173 STO 12
174 STO 21
175 RCL 23
176 X<>Y
177 X>Y?
178 GTO 03
179 RCL 23
180 STO 12
```

CALC K_b

```
181 XEQ G
182 GTO 02
183♦LBL 01
184 RCL 05
185 -.04
186 *
187 E↑X
188 -.3
189 *
190 1.6
191 +
192 STO 17
193 RCL 06
194 RCL 05
195 /
196 1.18
197 *
198 -
199♦LBL 02
200 1
201 X<>Y
202 X<=Y?
203 GTO 01
204♦LBL 03
205 1
206♦LBL 01
207 STO 13
```

CALC A

```
208 RCL 07
209 460
210 +
211 RCL 08
212 *
213 RCL 10
214 /
215 SQRT
216 RCL 04
217 *
218 RCL 26
219 /
220 .953
221 /
222 XEQ F
223 /
224 RCL 13
225 /
226 STO 14
227 XEQ J
```

ENTER VALVE AREA

```
228 XEQ e
```

CALC BACKPRES BELLOWS VALVE

```
229 RCL 21
```

```
230 STO 12
231 RCL 14
232 RCL 11
233 /
234 RCL 13
235 *
236 STO 15
237 1
238 RCL 03
239 X≠Y?
240 GTO C
241 RCL 17
242 RCL 15
243 -
244 1.18
245 /
246 RCL 05
247 *
248 GTO I
```

CONV VALVES

```
249♦LBL C
250 RCL 21
251 1
252 +
253 SQRT
254 ST* 12
255 XEQ G
256 RCL 15
257 -
258 PSE
259 STO 21
260 ABS
261 .001
262 X<>Y
263 X>Y?
264 GTO C
265 RCL 12
266 XEQ F
267 *
268 14.7
269 -
270♦LBL I
271 STO 18
272 XEQ J
273 FS? 02
274 STOP
275 CF 00
276 XEQ a
277 RCL 14
278 VIEW X
279 BEEP
280 ADV
281 STOP
282 .END.
```

Program 21: Sequence of Calculations

1. Calculate pressure ratio.[1]

$$r = \frac{P_2}{P_1} \text{ limited to a minimum of } \left(\frac{2}{k+1}\right)^{k/k-1}$$

2. Calculate the specific heat ratio coefficient.[1]

$$C = 520\sqrt{k\left(\frac{2}{k+1}\right)^{(k+1)/(k-1)}} = 520(1.213 - r)$$

3. Calculate back pressure correction factor.

Conventional valves:[1]

$$K_b = \frac{735\,F_2}{C}\sqrt{1-r}$$

where

$$F_2 = \sqrt{\left(\frac{k}{k-1}\right)(r^{2/k})\left(\frac{1-(r^{(k-1)/k})}{1-r}\right)}$$

Bellows valves:

$$K_b = 1.6 - .3e^{-.04}\,P_{IN} - 1.18\,r$$

4. Calculate required relief area.[1]

$$A = \frac{W_m}{.953\, C\, P_1\, K_b} \sqrt{\frac{T_f Z}{M}} \text{ square inches}$$

5. Calculate maximum allowable back pressure for selected valve area.

$$\text{maximum } K_b = \frac{A}{\text{selected } A} \times K_b$$

Conventional valves: Iterate 3A to find r, then

$$\text{maximum back pressure} = (r \times P_1) - 14.7 \text{ PSIG}$$

Bellows valves:

$$\text{maximum back pressure} = \frac{P_{IN}(1.6 - .3e^{-.04\, P_{IN}}) - \max K_b}{1.18} \text{ PSIG}$$

Program 21: Nomenclature

A Relief area, square inches
C Specific heat ratio coefficient, dimensionless
K_b Back pressure correction factor, dimensionless
k Ratio of specific heats C_p/C_v, dimensionless
M Molecular weight, dimensionless
P_{IN} Set pressure, PSIG
P_1 Relieving pressure (P_{IN} × overpressure factor + 14.7), PSIA
P_2 Back pressure, PSIA
r Pressure ratio, dimensionless
T_f Relief temperature, °K
W_m Flow through valve, pounds per hour
Z Compressibility factor, dimensionless

The overpressure factor is 1.2 for fire conditions, and 1.1 for all other.

Literature Cited

1. API RP520 Part 1, *Design,* American Petroleum Institute, Fourth Edition, 1976.

Physical Properties of Hydrocarbon Vapor

	k* (C_p/C_v)	M
Acetaldehyde	1.14	44.05
Acetic acid	1.15	60.05
Acetylene	1.26	26.04
Air	1.40	28.97
Ammonia	1.33	17.03
Argon	1.67	39.94
Benzene	1.12	78.11
Butadiene 1.3	1.12	54.09
n-Butane	1.094	58.12
iso-Butane	1.094	58.12
Carbon dioxide	1.30	44.01
Carbon disulfide	1.21	76.13
Carbon monoxide	1.40	28.00
Chlorine	1.36	70.90
Cyclohexane	1.09	84.16
n-Decane	1.03	142.28
Dowtherm A	1.046	165.00
Ethane	1.22	30.07
Ethyl alcohol	1.13	46.07
Ethyl chloride	1.19	64.52
Ethylene (ethene)	1.26	28.05
Freon 11	1.14	137.37
Freon 12	1.14	120.92
Freon 22	1.18	86.48
Freon 114	1.09	170.93
Helium	1.66	4.00
n-Hexane	1.06	86.17
Hydrogen chloride	1.41	36.50
Hydrogen	1.41	2.016
Hydrogen sulfide	1.32	34.07
Methane	1.31	16.04
Methyl alcohol	1.20	32.04
Methyl butane	1.08	72.15
Methyl chloride	1.20	50.49
Natural gas	1.27	19.00
Nitric oxide	1.40	30.00
Nitrogen	1.40	28.00
Nitrous oxide	1.30	44.00
Nonane	1.04	128.25
n-Octane	1.05	114.22
Oxygen	1.40	32.00
n-Pentane	1.07	72.15
Propane	1.13	44.09
Propylene	1.15	42.08
Steam	1.324	18.02
Styrene	1.07	104.14
Sulfur dioxide	1.29	64.06
Toluene	1.09	92.13

*k-values at 14.7 PSIG and 600°F.

Program 22
Steam Relief—Boilers and Unfired Pressure Vessels, Known Flow

Program 22: User Instructions

a) Initiate program, press A.
b) Enter:
   1. Applicable ASME section—8 for unfired pressure vessels, 1 for power boilers — Press R/S
   2. One (1) if the valve is to be sized for the fire case, any other number if not — Press R/S
   3. One (1) if the valve is to be a bellows type, any other number if not — Press R/S
   4. Maximum required flow through valve, pounds per hour — Press R/S
   5. Valve set pressure, PSIG — Press R/S
   6. Back pressure before the valve opens, PSIG — Press R/S
   7. Superheat degrees, °F — Press R/S
c) Program calculates required relief area, square inches.
d) Enter:
   8. Selected valve area, square inches — Press R/S
e) Program calculates the maximum back pressure which maintains flow at relief conditions, PSIG.

Note: The E subroutine is available to re-enter data and recalculate.

Program 22: TI 59 Data Sheet

```
*********************

 RELIEF VALVE STEAM

*********************
ENTR  ASME SECTION
          8.
ENTR 1 FOR FIRE CASE
          0.
ENTR 1 FOR BLWS VALV
          0.
ENTR  FLOW  PPH
      20000.
ENTR   SET PRSS PSIG
         200.
ENTR  BACK PRSS PSIG
           2.
ENTR  SUPERHEAT   °F
         140.
CALC  AREA  IN²
 1.902926207
ENTR  VALV AREA  IN²
       2.853
CALC MX BP PSIG
 192.5486334

*********************
```

Program 22: TI 59 Register Loading

PARTITIONING
479.59

0.	00	54.535251	29
0.	01	0.504948	30
0.	02	0.472019	31
0.	03	0.474645	32
0.	04	333323.4433	33
0.	05	0.43424	34
0.	06	0.37424	35
0.	07	0.162839	36
0.	08	14131526.	37
0.	09	56.2726	38
0.	10	7321.452726	39
0.	11	33362422.	40
0.	12	56.254	41
0.	13	33353636.	42
0.	14	361737.	43
0.	15	21273243.	44
36413317.	16	42132742.	45
0.	17	14274336.	46
0.	18	200213235.	47
15133617.	19	2432310000.	48
21243517.	20	36171537.	49
0.	21	13363017.	50
0.00004	22	3717133000.	51
0.00012	23	2742170036.	52
.5394811532	24	1721004213.	53
3044001433.	25	35172724.	54
243170.	26	5151515151.	55
13351713.	27	1513271500.	56
3523171337.	28	1731373500.	57
		0.	58
		0.	59

Program 22: TI 59 Listing

SUBROUTINES

PRINT & STORE VARIABLES

```
000  76  LBL
001  10  E'
002  01   1
003  44  SUM
004  58   58
005  03   3
006  01   1
007  32  X:T
008  43  RCL
009  58   58
010  22  INV
011  67   EQ
012  24  CE
013  01   1
014  32  X:T
015  43  RCL
016  02   02
017  22  INV
018  67   EQ
019  24  CE
020  01   1
021  44  SUM
022  58   58
023  44  SUM
024  01   01
025  76  LBL
026  24  CE
027  29  CP
028  73  RC*
029  58   58
030  22  INV
031  59  INT
032  52  EE
033  22  INV
034  52  EE
035  67   EQ
036  19  D'
037  85   +
038  05   5
039  07   7
040  95   =
041  17  B'
042  69  OP
043  21   21
044  73  RC*
045  01   01
046  87  IFF
```

```
047  00  00
048  45  YX
049  91  R/S
050  72  ST*
051  01  01
052  76  LBL
053  45  YX
054  99  PRT
055  61  GTO
056  10  E'
```

PRINT LINES

```
057  76  LBL
058  19  D'
059  01  1
060  44  SUM
061  58  58
062  73  RC*
063  58  58
064  76  LBL
065  17  B'
066  42  STO
067  59  59
068  73  RC*
069  59  59
070  69  OP
071  01  01
072  18  C'
073  69  OP
074  02  02
075  18  C'
076  69  OP
077  03  03
078  18  C'
079  69  OP
080  04  04
081  69  OP
082  05  05
```

DECODE LINES

```
083  92  RTN
084  76  LBL
085  18  C'
086  01  1
087  00  0
088  00  0
089  48  EXC
090  59  59
091  22  INV
092  59  INT
093  49  PRD
094  59  59
095  73  RC*
096  59  59
097  92  RTN
```

PRINT LINE OF STARS

```
098  76  LBL
099  16  A'
100  93  .
101  00  0
102  01  1
103  08  8
104  35  1/X
105  98  ADV
106  17  B'
107  98  ADV
108  92  RTN
```

RE-ENTER VARIABLES

```
109  76  LBL
110  15  E
111  99  PRT
112  85  +
113  01  1
114  95  =
115  42  STO
116  01  01
117  32  X:T
118  02  2
119  67  EQ
120  90  LST
121  01  1
122  32  X:T
123  43  RCL
124  02  02
125  22  INV
126  67  EQ
127  90  LST
128  01  1
129  44  SUM
130  01  01
131  76  LBL
132  90  LST
133  73  RC*
134  01  01
135  91  R/S
136  72  ST*
137  01  01
138  99  PRT
139  98  ADV
140  86  STF
141  00  00
142  86  STF
143  01  01
144  91  R/S
145  61  GTO
146  52  EE
```

CALC P_1

```
147  76  LBL
148  22  INV
149  53  (
150  43  RCL
151  06  06
152  65  ×
153  43  RCL
154  10  10
155  85  +
156  01  1
157  04  4
158  93  .
159  07  7
160  54  )
161  92  RTN
```

CALC K_b

```
162  76  LBL
163  25  CLR
164  53  (
165  04  4
166  93  .
167  01  1
168  09  9
169  65  ×
170  53  (
171  43  RCL
172  12  12
173  45  YX
174  01  1
175  93  .
176  05  5
177  75  -
178  43  RCL
179  12  12
180  45  YX
181  01  1
182  93  .
183  07  7
184  05  5
185  54  )
186  34  √X
187  54  )
188  92  RTN
```

MAIN PROGRAM ENTER DATA

```
189  76  LBL
190  11  A
191  87  IFF
192  00  00
193  99  PRT
```

```
194   00    0
195   42  STO
196   03   03
197   76  LBL
198   99  PRT
199   22  INV
200   86  STF
201   01   01
202   01    1
203   42  STO
204   01   01
205   02    2
206   08    8
207   42  STO
208   58   58
209   16  A'
210   19  D'
211   16  A'
212   10  E'
```

CALC OVERPRES FACTOR

```
213   76  LBL
214   52  EE
215   01    1
216   32  X:T
217   43  RCL
218   02   02
219   67   EQ
220   53    (
221   43  RCL
222   03   03
223   22  INV
224   67   EQ
225   33  X²
226   93    .
227   01    1
228   85    +
229   76  LBL
230   33  X²
231   01    1
232   93    .
233   01    1
234   95    =
235   42  STO
236   10   10
237   61  GTO
238   54    )
239   76  LBL
240   53    (
241   01    1
242   93    .
243   00    0
244   03    3
245   42  STO
246   10   10
```

CALC K_{SH}

```
247   76  LBL
248   54    )
249   71  SBR
250   22  INV
251   23  LNX
252   65    ×
253   43  RCL
254   08   08
255   65    ×
256   43  RCL
257   23   23
258   94  +/-
259   85    +
260   43  RCL
261   22   22
262   65    ×
263   43  RCL
264   08   08
265   85    +
266   01    1
267   95    =
268   42  STO
269   11   11
```

CALC K_b

```
270   01    1
271   32  X:T
272   43  RCL
273   04   04
274   67   EQ
275   67   EQ
276   43  RCL
277   07   07
278   85    +
279   01    1
280   04    4
281   93    .
282   07    7
283   95    =
284   55    ÷
285   71  SBR
286   22  INV
287   95    =
288   32  X:T
289   43  RCL
290   24   24
291   42  STO
292   12   12
293   77   GE
294   43  RCL
295   32  X:T
296   42  STO
297   12   12
298   01    1
299   32  X:T
300   71  SBR
301   25  CLR
302   61  GTO
303   42  STO
304   76  LBL
305   67   EQ
306   43  RCL
307   06   06
308   65    ×
309   93    .
310   00    0
311   04    4
312   94  +/-
313   95    =
314   22  INV
315   23  LNX
316   65    ×
317   93    .
318   03    3
319   94  +/-
320   85    +
321   01    1
322   93    .
323   06    6
324   95    =
325   42  STO
326   17   17
327   75    -
328   43  RCL
329   07   07
330   55    ÷
331   43  RCL
332   06   06
333   65    ×
334   01    1
335   93    .
336   01    1
337   08    8
338   76  LBL
339   42  STO
340   95    =
341   22  INV
342   77   GE
343   32  X:T
344   76  LBL
345   43  RCL
346   01    1
347   76  LBL
348   32  X:T
349   42  STO
350   13   13
```

CALC A

```
351   43  RCL
```

```
352  05  05
353  55  ÷
354  04  4
355  09  9
356  55  ÷
357  71  SBR
358  22  INV
359  55  ÷
360  43  RCL
361  11  11
362  55  ÷
363  43  RCL
364  13  13
365  95  =
366  99  PRT
367  42  STO
368  14  14
```

ENTER VALVE AREA

```
369  87  IFF
370  01  01
371  44  SUM
372  10  E'
373  22  INV
374  86  STF
375  00  00
376  76  LBL
377  44  SUM
378  43  RCL
379  14  14
380  65  ×
381  43  RCL
382  13  13
383  55  ÷
384  43  RCL
385  09  09
386  95  =
387  42  STO
388  15  15
389  43  RCL
390  24  24
391  42  STO
392  12  12
393  42  STO
394  21  21
```

CALC MAX BACKPRES

```
395  01  1
396  32  X:T
397  43  RCL
398  04  04
399  22  INV
400  67  EQ
401  23  LNX
402  43  RCL
403  17  17
404  75  -
405  43  RCL
406  15  15
407  95  =
408  55  ÷
409  01  1
410  93  .
411  01  1
412  08  8
413  65  ×
414  43  RCL
415  06  06
416  95  =
417  61  GTO
418  61  GTO
419  76  LBL
420  23  LNX
421  93  .
422  00  0
423  00  0
424  01  1
425  32  X:T
426  43  RCL
427  21  21
428  85  +
429  01  1
430  95  =
431  34  √X
432  34  √X
433  49  PRD
434  12  12
435  71  SBR
436  25  CLR
437  75  -
438  43  RCL
439  15  15
440  95  =
441  66  PAU
442  42  STO
443  21  21
444  50  I×I
445  77  GE
446  23  LNX
447  43  RCL
448  12  12
449  65  ×
450  71  SBR
451  22  INV
452  75  -
453  01  1
454  04  4
455  93  .
456  07  7
457  95  =
458  76  LBL
459  61  GTO
460  99  PRT
461  42  STO
462  18  18
463  16  A'
464  98  ADV
465  98  ADV
466  43  RCL
467  14  14
468  91  R/S
```

Program 22: HP 41CV Data Sheet

```
************

 *RV STEAM*

************

ENTER ASME SECTION NO
        8.0000    ***
ENTER 1 FOR FIRE CASE
        0.0000    ***
ENTER 1 FOR BELLWS VALVE
        0.0000    ***
ENTER FLOW PPH
        20,000.0000    ***
ENTER  SET PRSS PSIG
        200.0000    ***
ENTER BACK PRSS PSIG
        2.0000    ***
ENTER  SUPERHEAT DEG F
        140.0000    ***
CALC    AREA
SQ INS
        1.9029    ***
ENTER  VALVE AREA SQ INS
        2.8530    ***
CALC   MAX BA
CK PRSS PSIG
        192.5486    ***

************
```

Program 22: HP 41CV Register Loading

SIZE 080

```
R00=  0.000000
R01=  0.000000
R02=  0.000000
R03=  0.000000
R04=  0.000000
R05=  0.000000
R06=  0.000000
R07=  0.000000
R08=  0.000000
R09=  0.000000
R10=  0.000000
R11=  0.000000
R12=  0.000000
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  0.000000
R17=  0.000000
R18=  0.000000
R19=  0.000000
R20=  0.000000
R21=  0.000000
R22=  0.000000
R23=  0.000000
R24=  0.000000
R25=  0.000000
R26=  0.000000
R27= "1 FOR "
R28= "FIRE C"
R29= "ASE   "
R30=  46.470000
R31=  57.666773
R32=  57.272829
R33=  57.275051
R34=  57.525300
R35=  57.546061
R36=  57.626061
R37=  57.636465
R38=  0.000000
R39=  56.686900
R40=  57.516869
R41=  0.000000
R42=  56.707172
R43=  0.000000
R44=  56.707172
R45=  0.000000
R46= " *RV S"
R47= "TEAM* "
R48=  0.000000
R49=  0.000000
R50= "BELLWS"
R51= " VALVE"
R52= "FLOW P"
R53= "PH    "
R54= " SET P"
R55= "******"
R56= "CALC  "
R57= "ENTER "
R58=  0.000000
R59=  0.000000
R60= "RSS PS"
R61= "IG    "
R62= "BACK P"
R63= " SUPER"
R64= "HEAT D"
R65= "EG F  "
R66= "ASME S"
R67= "ECTION"
R68= " AREA "
R69= "SQ INS"
R70= "MAX BA"
R71= "CK PRS"
R72= "S PSIG"
R73= " NO   "
R74=  0.000000
R75=  0.000000
R76=  0.000000
R77=  0.000000
R78=  0.000000
R79=  0.000000
```

Program 22: HP 41CV Listing

SUBROUTINES

```
01♦LBL "RV STM"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 GTO d
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53♦LBL 01
54 XEQ J
55 GTO e
```

RE-ENTER VARIABLES

```
56♦LBL "REENTER"
57 ADV
58 1
59 +
60 STO 01
61 RCL IND 01
```

```
62 XEQ J
63 STOP
64 XEQ J
65 STO IND 01
66 ADV
67 SF 00
68 SF 02
69 STOP
70 GTO 02
```

BYPASS PRINTER

```
71♦LBL J
72 FC? 55
73 GTO 01
74 PRX
75 RTN
76♦LBL 01
77 VIEW X
78 RTN
```

CALC P_1

```
79♦LBL F
80 RCL 06
81 RCL 16
82 *
83 14.7
84 +
85 RTN
```

CALC K_b

```
86♦LBL G
87 RCL 12
88 1.5
89 Y↑X
90 RCL 12
91 1.75
92 Y↑X
93 -
94 SQRT
95 4.19
96 *
97 RTN
```

MAIN PROGRAM ENTER DATA

```
98♦LBL A
99 1
100 STO 01
101 29
102 STO 58
103 XEQ a
104 XEQ d
105 XEQ a
106 XEQ e
107 CF 02
```

CALC OVERPRES FACTOR

```
108♦LBL 02
109 8
110 STO 01
111 39
112 STO 58
113 1
114 RCL 02
115 X=Y?
116 GTO 03
117 1
118 RCL 03
119 X≠Y?
120 GTO 01
121 1.2
122 GTO 02
123♦LBL 03
124 1.03
125 GTO 02
126♦LBL 01
127 1.1
128♦LBL 02
129 STO 16
```

CALC K_{SH}

```
130 RCL 08
131 .00004
132 *
133 XEQ F
134 LN
135 RCL 08
136 *
137 .00012
138 *
139 -
140 1
141 +
142 STO 11
```

CALC r

```
143 RCL 04
144 1
145 X=Y?
146 GTO 01
147 RCL 07
148 14.7
149 +
150 XEQ F
151 /
152 STO 23
153 .53948
154 STO 12
155 STO 21
156 X>Y?
157 GTO 03
158 RCL 23
159 STO 12
160 XEQ G
161 GTO 02
```

CALC K_b BELLOWS VALVE

```
162♦LBL 01
163 RCL 06
164 -.04
165 *
166 E↑X
167 -.3
168 *
169 1.6
170 +
171 STO 17
172 RCL 07
173 RCL 06
174 /
175 1.18
176 *
177 -
178♦LBL 02
179 1
180 X<>Y
181 X<=Y?
182 GTO 01
183♦LBL 03
184 1
185♦LBL 01
186 STO 13
```

CALC A

```
187 RCL 05
188 49
189 /
190 XEQ F
191 /
192 RCL 13
193 /
194 RCL 11
195 /
196 STO 14
197 XEQ J
```

CALC BACKPRES BELLOWS

```
198 XEQ e
199 RCL 21
200 STO 12
201 RCL 14
202 RCL 09
203 /
204 RCL 13
205 *
206 STO 15
207 1
```

```
208 RCL 04
209 X≠Y?
210 GTO C
211 RCL 17
212 RCL 15
213 -
214 1.18
215 /
216 RCL 06
217 *
218 GTO I
```

CALC MAX BACKPRES STANDARD VALVE

```
219♦LBL C
220 RCL 21
221 1
222 +
223 SQRT
224 SQRT
225 ST* 12
226 XEQ G
227 RCL 15
228 -
229 PSE
230 STO 21
231 ABS
232 .001
233 X<>Y
234 X>Y?
235 GTO C
236 RCL 12
237 XEQ F
238 *
239 14.7
240 -
```

COMMON ENDING

```
241♦LBL I
242 STO 18
243 XEQ J
244 FS? 02
245 STOP
246 CF 00
247 XEQ a
248 RCL 14
249 VIEW X
250 BEEP
251 ADV
252 STOP
253 END
```

Program 22: Sequence of Calculations

1. Calculate pressure ratio.[1]

$$r = \frac{P_2}{P_1} \text{ limited to a minimum of } \left(\frac{2}{k+1}\right)^{k/(k-1)}$$
$$= .5395$$

2. Calculate back-pressure factor.
   Conventional valves:[1]

$$K_b = 4.19\sqrt{r^{1.5} - r^{1.75}}$$

   Bellows valves:

$$K_b = 1.6 - 3e^{-.04}\, P_{IN} - 1.18r$$

3. Calculate superheat correction factor.

$$K_{SH} = 1 + .00004T_{SH} - .00012\, T_{SH} \log P_1$$

4. Calculate required relief area.[1]

$$A = \frac{W_m}{49\, P_1\, K_{SH}\, K_b} \text{ square inches}$$

5. Calculate maximum allowable back pressure for selected valve area.

$$\text{maximum } K_b = \frac{A}{\text{selected } A} \times K_b$$

Conventional valves: Iterate 2A to find r, then

$$\text{maximum back pressure} = (r \times P_1) - 14.7 \text{ PSIG}$$

Bellows valves:

$$\text{maximum back pressure} = \frac{P_{IN}\,(1.6 - .3e^{-.04\,P_{IN}}) - \max K_b}{1.8} \text{ PSIG}$$

Program 22: Nomenclature

A	Relief area, square inches
k	Ratio of specific heats C_p/C_v, dimensionless
K_b	Back-pressure correction factor, dimensionless
K_{SH}	Superheat correction factor, dimensionless
P_{IN}	Set pressure, PSIG
P_1	Relieving pressure (P_{IN} × overpressure factor + 14.7), PSIA
P_2	Back pressure, PSIA
r	Pressure ratio, dimensionless
T_{SH}	Superheat, °F
W_m	Flow through valve, pounds per hour

The overpressure factor for ASME Section I, Power Boilers, is 1.03. For ASME Section VIII, Boiler and Pressure Vessel Code, it is 1.2 for fire conditions and 1.1 for all others.

Literature Cited

1. API RP520, Part 1, *Design,* American Petroleum Institute, Fourth Edition, 1976.

Program 23
Liquid Relief—Known Flow

Program 23: User Instructions

a) Initiate program, press A.

b) Enter:

1. Eight (8), if ASME-coded vessel, any other number if not — Press R/S
2. One (1) if the valve is a bellows type, any other number if not — Press R/S
3. Maximum required flow through valve, pounds per hour — Press R/S
4. Specific gravity at flow temperature, dimensionless — Press R/S
5. Absolute viscosity, centipoises
6. Valve set pressure, PSIG
7. Back pressure before valve opens, PSIG

c) Program calculates required relief area, square inches.

d) Enter:

8. Selected valve area, square inches — Press R/S

e) Program calculates the maximum back pressure which maintains flow at relief conditions, PSIG.

Notes:

1. The E subroutine is available to re-enter data and recalculate.
2. After entering the valve size, a viscosity check is made. If the selected valve is too small it will ask for another size. If there is a viscosity correction but the size is acceptable, it will print out the viscous size.

Program 23: TI 59 Data Sheet

```
********************

RELIEF VALVE LIQUID

********************

ENTR 8 IF ASME CODE
            1.
ENTR 1 FOR BLWS VALV
            0.
ENTR  FLOW  PPH
     125000.
ENTR    SG
            2.
ENTR  VISC   CP
            1.
ENTR   SET PRSS PSIG
           20.
ENTR  BACK PRSS PSIG
           14.
CALC  AREA  IN^2
 2.191619206
ENTR  VALV AREA  IN^2
       2.853
CALC MX BP PSIG
  18.5088845

********************

********************

RELIEF VALVE LIQUID

********************

ENTR 8 IF ASME CODE
            1.
ENTR 1 FOR BLWS VALV
            0.
```

```
ENTR  FLOW  PPH
     125000.
ENTR    SG
          2.
ENTR  VISC   CP
        250.
ENTR   SET PRSS PSIG
         20.
ENTR  BACK PRSS PSIG
         14.

CALC  AREA  IN²
 2.191619206
ENTR  VALV AREA  IN²
       2.853
CALC  VISC AREA  IN²
 2.383640044
CALC MX BF PSIG
 17.32160433

********************
```

Program 23: TI 59 Register Loading

PARTITIONING
479.59

0.	00	14131526.	29
0.	01	54.535251	30
0.	02	0.504948	31
0.	03	0.474645	32
0.	04	361737.4435	33
0.	05	42243615.4	34
0.	06	333323.3437	35
0.	07	0.334138	36
0.	08	1533.294138	37
0.	09	33362422.	38
0.	10	56.2726	39
0.	11	3622.452726	40
0.	12	33353636.	41
0.	13	56.342726	42
0.	14	56.2538	43
0.	15	21273243.	44
0.	16	42132742.	45
0.	17	14274336.	46
0.	18	200213235.	47
0.	19	1532161700.	48
0.	20	1336301700.	49
0.	21	1100242100.	50
0.	22	3441241600.	51
0.	23	4217002724.	52
1.891822816	24	2100421327.	53
3044001433.	25	3517272417.	54
243170.	26	5151515151.	55
13351713.	27	1513271500.	56
3335172730.	28	1731373500.	57
		0.	58
		0.	59

Program 23: TI 59 Listing

SUBROUTINES
PRINT & STORE
VARIABLES

```
000   76 LBL
001   10 E'
002   29 CP
003   01  1
004   44 SUM
005   58  58
006   73 RC*
007   58  58
008   22 INV
009   59 INT
010   52 EE
011   22 INV
012   52 EE
013   67  EQ
```

```
014  19  D'
015  85   +
016  05   5
017  07   7
018  95   =
019  17  B'
020  69  OP
021  21   21
022  73  RC*
023  01   01
024  87  IFF
025  00   00
026  00   00
027  31   31
028  91  R/S
029  72  ST*
030  01   01
031  73  RC*
032  01   01
033  99  PRT
034  61  GTO
035  10  E'
```

PRINT LINES

```
036  76  LBL
037  19  D'
038  01   1
039  44  SUM
040  58   58
041  73  RC*
042  58   58
043  76  LBL
044  17  B'
045  42  STO
046  59   59
047  73  RC*
048  59   59
049  69  OP
050  01   01
051  18  C'
052  69  OP
053  02   02
054  18  C'
055  69  OP
056  03   03
057  18  C'
058  69  OP
059  04   04
060  69  OP
061  05   05
062  92  RTN
```

DECODE LINES

```
063  76  LBL
064  18  C'
065  01   1
066  00   0
067  00   0
068  48  EXC
069  59   59
070  22  INV
071  59  INT
072  49  PRD
073  59   59
074  73  RC*
075  59   59
076  92  RTN
```

PRINT LINE OF STARS

```
077  76  LBL
078  16  A'
079  93   .
080  00   0
081  01   1
082  08   8
083  35  1/X
084  98  ADV
085  17  B'
086  98  ADV
087  92  RTN
```

RE-ENTER VARIABLES

```
088  76  LBL
089  15   E
090  99  PRT
091  85   +
092  01   1
093  95   =
094  42  STO
095  01   01
096  73  RC*
097  01   01
098  91  R/S
099  72  ST*
100  01   01
101  99  PRT
102  98  ADV
103  86  STF
104  00   00
105  86  STF
106  01   01
107  91  R/S
108  12   B
```

MAIN PROGRAM ENTER DATA

```
109  76  LBL
110  11   A
111  22  INV
112  86  STF
113  01   01
114  01   1
115  42  STO
116  01   01
117  02   2
118  09   9
119  42  STO
120  58   58
121  16  A'
122  19  D'
123  16  A'
124  10  E'
```

CALC K_p

```
125  76  LBL
126  12   B
127  03   3
128  09   9
129  42  STO
130  58   58
131  08   8
132  42  STO
133  01   01
134  08   8
135  32  X:T
136  43  RCL
137  02   02
138  22  INV
139  67   EQ
140  22  INV
141  93   .
142  06   6
143  65   X
144  76  LBL
145  22  INV
146  01   1
147  95   =
148  42  STO
149  23   23
```

CALC K_w

```
150  43  RCL
151  03   03
152  32  X:T
153  01   1
154  22  INV
155  67   EQ
156  23  LNX
157  01   1
158  93   .
159  03   3
160  06   6
161  75   -
162  01   1
```

```
163  93  .
164  02  2
165  65  ×
166  43  RCL
167  08   08
168  55  ÷
169  43  RCL
170  07   07
171  95  =
172  22  INV
173  77   GE
174  23  LNX
175  01   1
176  76  LBL
177  23  LNX
178  42  STO
179  22   22
```

CALC A

```
180  43  RCL
181  04   04
182  55  ÷
183  01   1
184  02   2
185  01   1
186  06   6
187  00   0
188  55  ÷
189  43  RCL
190  23   23
191  55  ÷
192  43  RCL
193  22   22
194  95  =
195  42  STO
196  16   16
197  55  ÷
198  53  (
199  43  RCL
200  05   05
201  65  ×
202  53  (
203  01   1
204  93  .
205  02   2
206  05   5
207  65  ×
208  43  RCL
209  07   07
210  75  -
211  43  RCL
212  08   08
213  54  )
214  54  )
215  34  ΓX
216  95  =
217  42  STO
218  20   20
219  42  STO
220  19   19
221  61  GTO
222  32  X:T
```

SUBROUTINE TO CALC K_v

```
223  76  LBL
224  13   C
225  05   5
226  93  .
227  06   6
228  65  ×
229  43  RCL
230  04   04
231  55  ÷
232  43  RCL
233  06   06
234  55  ÷
235  43  RCL
236  19   19
237  34  ΓX
238  95  =
239  42  STO
240  18   18
241  32  X:T
242  05   5
243  00   0
244  00   0
245  00   0
246  00   0
247  22  INV
248  77   GE
249  24  CE
250  43  RCL
251  18   18
252  32  X:T
253  02   2
254  00   0
255  77   GE
256  37  P/R
257  01   1
258  32  X:T
259  43  RCL
260  18   18
261  23  LNX
262  23  LNX
263  23  LNX
264  65  ×
265  43  RCL
266  24   24
267  75  -
268  43  RCL
269  18   18
275  55  ÷
276  43  RCL
277  18   18
278  45  YX
279  93  .
280  00   0
281  04   4
282  07   7
283  95  =
284  22  INV
285  77   GE
286  25  CLR
287  76  LBL
288  24  CE
289  01   1
290  76  LBL
291  25  CLR
292  42  STO
293  21   21
294  35  1/X
295  65  ×
296  43  RCL
297  20   20
298  95  =
299  92  RTN
```

PRINT A

```
300  76  LBL
301  34  ΓX
302  13   C
303  76  LBL
304  32  X:T
305  99  PRT
```

ENTER VALVE SIZE

```
306  43  RCL
307  40   40
308  22  INV
309  59  INT
310  85  +
311  05   5
312  07   7
313  95  =
314  17  B'
315  43  RCL
316  09   09
317  87  IFF
318  01   01
319  30  TAN
320  87  IFF
```

```
321  00  00
322  39  COS
323  76  LBL
324  30  TAN
325  91  R/S
326  76  LBL
327  39  COS
328  99  PRT
329  42  STO
330  09  09
331  42  STO
332  19  19
```

CALC A_{visc}

```
333  13  C
334  42  STO
335  17  17
336  32  X↕T
337  43  RCL
338  19  19
339  77  GE
340  33  X²
341  43  RCL
342  42  42
343  17  B'
344  61  GTO
345  34  √X
346  76  LBL
347  33  X²
348  43  RCL
349  20  20
350  77  GE
351  44  SUM
352  43  RCL
353  42  42
354  17  B'
355  43  RCL
356  17  17
357  99  PRT
```

CALC MAX BACKPRES

```
358  76  LBL
359  44  SUM
360  43  RCL
361  43  43
362  17  B'
363  01  1
364  93  .
365  02  2
366  05  5
367  65  ×
368  43  RCL
369  07  07
370  75  -
371  53  (
372  43  RCL
373  16  16
374  55  ÷
375  43  RCL
376  09  09
377  55  ÷
378  43  RCL
379  21  21
380  54  )
381  33  X²
382  55  ÷
383  43  RCL
384  05  05
385  95  =
386  42  STO
387  15  15
388  01  1
389  32  X↕T
390  43  RCL
391  03  03
392  22  INV
393  67  EQ
394  42  STO
395  01  1
396  93  .
397  03  3
398  06  6
399  75  -
400  43  RCL
401  22  22
402  65  ×
403  43  RCL
404  17  17
405  55  ÷
406  43  RCL
407  09  09
408  95  =
409  65  ×
410  43  RCL
411  07  07
412  55  ÷
413  01  1
414  93  .
415  02  2
416  95  =
417  32  X↕T
418  43  RCL
419  15  15
420  32  X↕T
421  22  INV
422  77  GE
423  43  RCL
424  32  X↕T
425  76  LBL
426  43  RCL
427  42  STO
428  15  15
429  76  LBL
430  42  STO
431  43  RCL
432  15  15
433  99  PRT
434  87  IFF
435  01  01
436  38  SIN
437  22  INV
438  86  STF
439  00  00
440  76  LBL
441  38  SIN
442  16  A'
443  98  ADV
444  98  ADV
445  43  RCL
446  17  17
447  91  R/S
```

Program 23: HP 41CV Data Sheet

```
************

*RV   LIQUID*

************

ENTER 0 IF ASME CODE
          1.000    ***

ENTER 1 FOR BELLWS VALVE
          0.000    ***
ENTER FLOW PPH
    125,000.000    ***
ENTER  SG
          2.000    ***
ENTER VISCOSITY cP
          1.000    ***

ENTER  SET PRSS PSIG
         20.000    ***
ENTER BACK PRSS PSIG
         14.000    ***

CALC    AREA
SQ  INS
          2.192    ***
```

```
ENTER  VALVE AREA SQ INS
          2.853    ***
CALC  MAX BACK PRSS PSIG
          18.509   ***

************

************

*RV   LIQUID*

************

ENTER 0 IF ASME CODE
          1.000    ***
```

```
ENTER 1 FOR BELLWS VALVE
          0.000    ***
ENTER FLOW PPH
     125,000.000   ***
ENTER  SG
          2.000    ***
ENTER VISCOSITY cP
        250.000    ***
ENTER  SET PRSS PSIG
         20.000    ***
ENTER BACK PRSS PSIG
         14.000    ***
CALC    AREA
SQ  INS
          2.192    ***
```

```
ENTER  VALVE AREA SQ INS
          2.853    ***
CALC  VISCOS AREA SQ INS
          2.384    ***
CALC  MAX BACK PRSS PSIG
         17.322    ***

************
```

Program 23: HP 41CV Register Loading

SIZE 080

```
R00=  0.000000
R01=  0.000000
R02=  0.000000
R03=  0.000000
R04=  0.000000
R05=  0.000000
R06=  0.000000
R07=  0.000000
R08=  0.000000
R09=  0.000000
R10=  0.000000
R11=  0.000000
R12=  0.000000
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  0.000000
R17=  0.000000
R18=  0.000000
R19=  0.000000
R20=  0.000000
R21=  0.000000
R22=  0.000000
R23=  0.000000
R24=  0.000000
R25= "*RV  L"
R26= "IQUID*"
R27= "1 FOR "
R28= "8 IF A"
R29= "SME CO"
R30=  25.260000
R31=  57.282973
R32=  57.275051
R33=  57.525300
R34=  57.630000
R35=  57.646500
R36=  57.546061
R37=  57.626061
R38=  0.000000
R39=  56.686900
R40=  57.516869
R41=  0.000000
R42=  56.646869
R43=  56.707172
R44=  0.000000
R45=  0.000000
R46=  0.000000
R47=  0.000000
R48=  0.000000
R49=  0.000000
R50= "BELLWS"
R51= " VALVE"
R52= "FLOW P"
R53= "PH    "
R54= " SET P"
R55= "******"
R56= "CALC  "
R57= "ENTER "
R58=  0.000000
R59=  0.000000
R60= "RSS PS"
R61= "IG    "
R62= "BACK P"
R63= " SG   "
R64= "VISCOS"
R65= "ITY cP"
R66=  0.000000
R67=  0.000000
R68= " AREA "
R69= "SQ INS"
R70= "MAX BA"
R71= "CK PRS"
R72= "S PSIG"
R73= "DE    "
R74=  0.000000
R75=  0.000000
R76=  0.000000
R77=  0.000000
R78=  0.000000
R79=  0.000000
```

Program 23: HP 41CV Listing

SUBROUTINES

```
01♦LBL "RV LIQ"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
```

```
CLA
♦LBL c
ARCL IND 59
RCL 59
FRC
100
*
STO 59
X≠0?
GTO c
FC? 55
GTO 01
PRA
CF 12
RTN
♦LBL 01
CF 12
AVIEW
RTN
```

PRINT & STORE VARIABLES

```
♦LBL e
1
ST+ 58
RCL IND 58
X=0?
RTN
XEQ b
1
ST+ 01
RCL IND 01
TONE 9
FS? 00
GTO 01
STOP
STO IND 01
♦LBL 01
XEQ J
GTO e
```

RE-ENTER VARIABLES

```
♦LBL "REENTER"
ADV
1
+
STO 01
RCL IND 01
XEQ J
STOP
XEQ J
STO IND 01
ADV
SF 02
STOP
GTO B
```

BYPASS PRINTER

```
♦LBL J
FC? 55
GTO 01
PRX
RTN
♦LBL 01
VIEW X
RTN
```

CALC K_v

```
♦LBL C
5.6
RCL 04
*
RCL 06
/
RCL 19
SQRT
/
STO 18
50000
X<=Y?
GTO 01
RCL 18
20
X>Y?
GTO 02
RCL 18
LN
LN
LN
1.891822816
*
RCL 18
-.6
Y↑X
-
RCL 18
.047
Y↑X
/
1
X<>Y
X<=Y?
GTO 02
♦LBL 01
1
♦LBL 02
STO 21
1/X
RCL 20
*
RTN
```

MAIN PROGRAM ENTER DATA

```
♦LBL A
1
STO 01
29
STO 58
FS? 02
SF 00
CF 02
XEQ a
XEQ d
XEQ a
XEQ e
XEQ d
```

CALC K_p

```
♦LBL B
39
STO 58
8
STO 01
RCL 02
X≠Y?
GTO 01
.6
GTO 02
♦LBL 01
1
♦LBL 02
STO 23
```

CALC K_w

```
RCL 03
1
X≠Y?
GTO 01
1.36
RCL 08
1.2
*
RCL 07
/
-
RCL 03
X<>Y
X<=Y?
GTO 01
1
♦LBL 01
STO 22
```

CALC A

```
RCL 04
12160
/
RCL 23
/
RCL 22
/
STO 16
```

```
174 1.25
175 RCL 07
176 *
177 RCL 08
178 -
179 RCL 05
180 *
181 SQRT
182 /
183 STO 20
184 STO 19
185 GTO E
```

PRINT A

```
186♦LBL D
187 XEQ C
188♦LBL E
189 XEQ J
```

ENTER VALVE SIZE

```
190 39
191 STO 58
192 8
193 STO 01
194 XEQ e
195 RCL 09
196 STO 19
```

CALC VISC SIZE

```
197 XEQ C
198 STO 17
199 RCL 19
200 X>Y?
201 GTO 01
202 RCL 42
203 XEQ b
204 GTO D
205♦LBL 01
206 RCL 17
207 RCL 20
208 X=Y?
209 GTO 01
210 X>Y?
211 GTO 01
212 RCL 42
213 XEQ b
214 RCL 17
215 XEQ J
```

CALC MAX BACKPRES CONV VALVE

```
216♦LBL 01
217 RCL 43
218 XEQ b
219 1.25
220 RCL 07
221 *
222 RCL 16
223 RCL 09
224 /
225 RCL 21
226 /
227 X↑2
228 RCL 05
229 /
230 -
231 STO 15
```

CALC BACKPRES BELLOWS VALVE

```
232 1
233 RCL 03
234 X≠Y?
235 GTO 01
236 1.36
237 RCL 22
238 RCL 17
239 *
240 RCL 09
241 /
242 -
243 RCL 07
244 *
245 1.2
246 /
247 RCL 15
248 X<=Y?
249 GTO 02
250 RDN
251♦LBL 02
252 STO 15
```

COMMON ENDING

```
253♦LBL 01
254 RCL 15
255 XEQ J
256 FS? 02
257 STOP
258 CF 00
259 XEQ a
260 RCL 17
261 VIEW X
262 BEEP
263 ADV
264 STOP
265 .END.
```

Program 23: Sequence of Calculations

1. Calculate back-pressure factor.
   Conventional valves:

$$K_w = 1$$

   Bellows valves:

$$K_w = 1.36 - 1.2\left(\frac{P_{OUT}}{P_{IN}}\right)$$

2. Calculate required relief area.[1]

$$A = \frac{W_m}{12{,}160\, K_p K_w \sqrt{G_f (1.25\, P_{IN} - P_{OUT})}} \text{ square inches}$$

3. Calculate viscosity correction factor.

$$R_D = \frac{5.6\, W_m}{\mu_{cp} \sqrt{A}}$$

$$K_v = \frac{1.892 \ln \ln \ln R_D - R_D^{-.6}}{R_D^{0.047}}$$

When $R_D > 50{,}000$, $K_v = 1$
When $R_D < 20$, an error exists

4. Divide A by K_v for viscosity correction.
5. Calculate maximum allowable back pressure for selected valve area.
Conventional valves:

$$P_{B_{max}} = 1.25\, P_{IN} - \left(\frac{\left(\dfrac{W_m}{12{,}160\, K_p K_w A K_v} \right)^2}{G_f} \right) \text{ PSIG}$$

Bellows valves: Same as for conventional valves, or

$$P_{B_{max}} = \frac{P_{IN} \left(1.36 - \left(\dfrac{A_{visc}}{A_{valve}} \right) K_w \right)}{1.2} \text{ PSIG}$$

whichever is the smallest.

Program 23: Nomenclature

A	Relief area, square inches
G_f	Specific gravity of the liquid at flowing temperature, dimensionless
K_p	Overpressure correction factor—.6 if ASME Section 8, 1.0 for others, dimensionless
K_w	Back-pressure correction factor, dimensionless

K_v Viscosity correction factor, dimensionless
$P_{B_{max}}$ Maximum allowable back pressure, PSIG
P_{IN} Set pressure, PSIG
P_{OUT} Back pressure, PSIG
R_D Reynolds number, dimensionless
W_m Flow through valve, pounds per hour
μ_{cp} Absolute viscosity, centipoises

Literature Cited

1. API RP520, Part 1, *Design,* American Petroleum Institute, Fourth Edition, 1976.

Program 24
Liquid Relief—Entrapped in Heat Exchanger

This program calculates the size relief valve required when heat is applied to a liquid-filled heat exchanger before the valves on the inlet and outlet are opened.

Program 24: User Instructions

a) Initiate program, press A.
b) Enter:
   1. Eight (8) if it is an ASME-coded vessel, any other number if not — Press R/S
   2. One (1) if the valve is to be a bellows type, any other number if not — Press R/S
   3. Coefficient of cubical expansion for the entrapped liquid per °F, dimensionless — Press R/S
   4. Heat input to the vessel, Btu per hour (usually the duty of the exchanger) — Press R/S
   5. Specific heat of the entrapped liquid, Btu per pound per °F — Press R/S
c) Program calculates required flow, pounds per hour.
d) Enter:
   6. Specific gravity at relief temperature, dimensionless — Press R/S
   7. Absolute viscosity, centipoises — Press R/S
   8. Valve set pressure, PSIG — Press R/S
   9. Back pressure before the valve opens, PSIG — Press R/S

e) Program calculates required relief area, square inches.
f) Enter:
   10. Selected valve area, square inches — Press R/S
g) Program calculates the maximum back pressure that maintains flow at relief conditions, PSIG.

Notes:
1. The E subroutine is available to re-enter data and recalculate.
2. After entering the valve size, a viscosity check is made. If the selected valve size is too small it will ask for another size. If there is a viscosity correction but the size is acceptable, it will print out the viscous size.

Program 24: TI 59 Data Sheet

```
********************

RV LIQD THERMAL EXPN

********************

ENTR 8  IF ASME CODE
          8.
ENTR 1 FOR BLWS VALV
          1.
ENTR CUBICAL EXP/°F
      0.0008
ENTR HT NPT BTU  /HR
    1000000.
ENTR SPC HT BTU/P/°F
         0.5
CALC  FLOW  PPH
        1600.

ENTR     SG
         0.9
ENTR  VISC   CP
        250.
ENTR     SP PSIG
        100.
ENTR     BP PSIG
         20.
CALC  AREA  IN²
 .0225589693
ENTR  VALV AREA  IN²
        0.06
CALC  VISC AREA  IN²
 .0336780259
CALC    MX   BP PSIG
 66.55829734

********************
```

Program 24: TI 59 Register Loading

PARTITIONING
479.59

0.	00	0.	09
0.	01	0.	10
0.	02	0.	11
0.	03	0.	12
0.	04	0.	13
0.	05	0.	14
0.	06	0.	15
0.	07	0.	16
0.	08	0.	17
		0.	18
		1.891822816	19

13351713.	20	632335.3321	40
33362422.	21	333323.3221	41
42243615.	22	14274336.	42
3633150023.	23	56.2039	43
6333637321.	24	57.362039	44
3700143741.	25	56.222039	45
2337003133.	26	56.313221	46
3363732100.	27	200213235.	47
1327001744.	28	15321617.	48
1541142415.	29	13363017.	49
54.535251	30	1100002421.	50
3044.504948	31	17443331.	51
1433.474236	32	1735301327.	52
3633.292827	33	3416003723.	53
1533.26254	34	3542002724.	54
3622.232524	35	5151515151.	55
42132742.	36	1513271500.	56
56.3841	37	1731373500.	57
21273243.35	38	0.	58
243170.2234	39	0.	59

Program 24: TI 59 Listing

SUBROUTINES PRINT & STORE VARIABLES

```
000  76 LBL
001  10 E'
002  29 CP
003  01  1
004  44 SUM
005  58  58
006  73 RC*
007  58  58
008  22 INV
009  59 INT
010  52 EE
011  22 INV
012  52 EE
013  67  EQ
014  19 D'
015  85  +
016  05  5
017  07  7
018  95  =
019  17 B'
020  69 OP
021  21  21
022  73 RC*
023  01  01
024  87 IFF
025  00  00
026  00  00
027  31  31
028  91 R/S
029  72 ST*
030  01  01
031  99 PRT
032  61 GTO
033  10 E'
```

PRINT LINES

```
034  76 LBL
035  19 D'
036  01  1
037  44 SUM
038  58  58
039  73 RC*
040  58  58
041  76 LBL
042  17 B'
043  42 STO
044  59  59
045  73 RC*
046  59  59
047  69 OP
048  01  01
049  18 C'
050  69 OP
051  02  02
052  18 C'
053  69 OP
054  03  03
055  18 C'
056  69 OP
057  04  04
058  69 OP
059  05  05
060  92 RTN
```

DECODE LINES

```
061  76 LBL
062  18 C'
063  01  1
064  00  0
065  00  0
066  48 EXC
067  59  59
068  22 INV
069  59 INT
070  49 PRD
071  59  59
072  73 RC*
073  59  59
074  92 RTN
```

PRINT LINE OF STARS

```
075  76 LBL
076  16 A'
077  93  .
078  00  0
```

```
079  01  1
080  08  8
081  35  1/X
082  98  ADV
083  17  B'
084  98  ADV
085  92  RTN
```

RE-ENTER VARIABLES

```
086  76  LBL
087  15  E
088  99  PRT
089  85  +
090  01  1
091  95  =
092  42  STO
093  01  01
094  73  RC*
095  01  01
096  91  R/S
097  72  ST*
098  01  01
099  99  PRT
100  98  ADV
101  86  STF
102  00  00
103  86  STF
104  01  01
105  91  R/S
106  12  B
```

MAIN PROGRAM ENTER DATA

```
107  76  LBL
108  11  A
109  22  INV
110  86  STF
111  01  01
112  01  1
113  42  STO
114  01  01
115  02  2
116  09  9
117  42  STO
118  58  58
119  16  A'
120  19  D'
121  16  A'
122  10  E'
```

CALC FLOW

```
123  76  LBL
124  12  B
125  43  RCL
126  04  04
127  65  ×
128  43  RCL
129  05  05
130  55  ÷
131  43  RCL
132  06  06
133  95  =
134  42  STO
135  18  18
136  99  PRT
```

CALC K_p

```
137  87  IFF
138  01  01
139  35  1/X
140  10  E'
141  76  LBL
142  35  1/X
143  08  8
144  32  X:T
145  43  RCL
146  02  02
147  22  INV
148  67  EQ
149  22  INV
150  93  .
151  06  6
152  65  ×
153  76  LBL
154  22  INV
155  01  1
156  95  =
157  42  STO
158  13  13
```

CALC K_w

```
159  43  RCL
160  03  03
161  32  X:T
162  01  1
163  22  INV
164  67  EQ
165  23  LNX
166  01  1
167  93  .
168  03  3
169  06  6
170  75  -
171  01  1
172  93  .
173  02  2
174  65  ×
175  43  RCL
176  10  10
177  55  ÷
178  43  RCL
179  09  09
180  95  =
181  22  INV
182  77  GE
183  23  LNX
184  01  1
185  76  LBL
186  23  LNX
187  42  STO
188  14  14
```

CALC A

```
189  43  RCL
190  18  18
191  55  ÷
192  01  1
193  02  2
194  01  1
195  06  6
196  00  0
197  55  ÷
198  43  RCL
199  13  13
200  55  ÷
201  43  RCL
202  14  14
203  55  ÷
204  53  (
205  43  RCL
206  07  07
207  65  ×
208  53  (
209  01  1
210  93  .
211  02  2
212  05  5
213  65  ×
214  43  RCL
215  09  09
216  75  -
217  43  RCL
218  10  10
219  54  )
220  54  )
221  34  √X
222  95  =
223  42  STO
224  12  12
```

```
225  61 GTO
226  32 X:T
```

SUBROUTINE TO CALC K_v

```
227  76 LBL
228  13  C
229  05  5
230  93  .
231  06  6
232  65  ×
233  43 RCL
234  18  18
235  55  ÷
236  43 RCL
237  08  08
238  55  ÷
239  43 RCL
240  11  11
241  34 ΓX
242  95  =
243  42 STO
244  16  16
245  32 X:T
246  05  5
247  00  0
248  00  0
249  00  0
250  00  0
251  22 INV
252  77  GE
253  24 CE
254  43 RCL
255  16  16
256  32 X:T
257  02  2
258  00  0
259  77  GE
260  37 P/R
261  01  1
262  32 X:T
263  43 RCL
264  16  16
265  23 LNX
266  23 LNX
267  23 LNX
268  65  ×
269  43 RCL
270  19  19
271  75  -
272  43 RCL
273  16  16
274  45 YX
275  93  .
276  06  6
279  55  ÷
280  43 RCL
281  16  16
282  45 YX
283  93  .
284  00  0
285  04  4
286  07  7
287  95  =
288  22 INV
289  77  GE
290  25 CLR
291  76 LBL
292  24 CE
293  01  1
294  76 LBL
295  25 CLR
296  42 STO
297  15  15
298  35 1/X
299  65  ×
300  43 RCL
301  12  12
302  95  =
303  92 RTN
```

ENTER VALVE SIZE

```
304  76 LBL
305  34 ΓX
306  13  C
307  76 LBL
308  32 X:T
309  99 PRT
```

ENTER VALVE AREA

```
310  43 RCL
311  44  44
312  17 B'
313  43 RCL
314  11  11
315  87 IFF
316  01  01
317  30 TAN
318  87 IFF
319  00  00
320  39 COS
321  76 LBL
322  30 TAN
323  91 R/S
324  76 LBL
325  39 COS
326  99 PRT
327  42 STO
328  11  11
```

CALC A VISC

```
329  13  C
330  42 STO
331  17  17
332  32 X:T
333  43 RCL
334  11  11
335  77  GE
336  33 X²
337  43 RCL
338  45  45
339  17 B'
340  61 GTO
341  34 ΓX
342  76 LBL
343  33 X²
344  43 RCL
345  12  12
346  77  GE
347  44 SUM
348  43 RCL
349  45  45
350  17 B'
351  43 RCL
352  17  17
353  99 PRT
```

MAX BACKPRESSURE

```
354  76 LBL
355  44 SUM
356  43 RCL
357  46  46
358  17 B'
359  01  1
360  93  .
361  02  2
362  05  5
363  65  ×
364  43 RCL
365  09  09
366  75  -
367  53  (
368  43 RCL
369  18  18
370  55  ÷
372  02  2
373  01  1
374  06  6
375  00  0
376  55  ÷
```

```
377  43  RCL
378  13   13
379  55   ÷
380  43  RCL
381  14   14
382  55   ÷
383  43  RCL
384  11   11
385  55   ÷
386  43  RCL
387  15   15
388  54   )
389  33  X²
390  55   ÷
391  43  RCL
392  07   07
393  95   =
394  42  STD
395  59   59
396  01   1
397  32  X:T
398  43  RCL
399  03   03
400  22  INV
401  77   GE
402  42  STD
403  01   1
404  93   .
405  03   3
406  06   6
407  75   -
408  43  RCL
409  14   14
410  65   X
411  43  RCL
412  17   17
413  55   ÷
414  43  RCL
415  11   11
416  95   =
417  65   X
418  43  RCL
419  09   09
420  55   ÷
421  01   1
422  93   .
423  02   2
424  95   =
425  32  X:T
426  43  RCL
427  59   59
428  32  X:T
429  22  INV
430  77   GE
431  43  RCL
432  32  X:T
433  76  LBL
434  43  RCL
435  42  STD
436  59   59
437  76  LBL
438  42  STD
439  43  RCL
440  59   59
441  99  PRT
442  87  IFF
443  01   01
444  38  SIN
445  22  INV
446  86  STF
447  00   00
448  76  LBL
449  38  SIN
450  16  A'
451  98  ADV
452  98  ADV
453  43  RCL
454  17   17
455  91  R/S
```

Program 24: HP 41CV Data Sheet

```
************

RV THERM EXP
  *LIQUID*

************

ENTER 8 IF ASME CODE
        8.0000    ***
ENTER 1 FOR BELLWS VALVE
        1.0000    ***
ENTER CUBICAL EXP/DEG F
        0.0008    ***
ENTER HEAT INPUT BTU/HR
   1,000,000.000  ***
ENTER SPEC HEAT BTU/P/OF
          0.5000  ***
CALC    FLOW
PPH
      1,600.0000  ***
ENTER  SG
          0.9000  ***
ENTER VISCOSITY cP
        250.0000  ***
ENTER  SET PRSS PSIG
        100.0000  ***
ENTER BACK PRSS PSIG
         20.0000  ***
CALC     AREA
SQ INS
          0.0226  ***
ENTER  VALVE AREA SQ INS
          0.0600  ***
CALC  VISCOS AREA SQ INS
          0.0337  ***
CALC  MAX BACK PRSS PSIG
         66.5583  ***

************
```

Program 24: HP 41CV Register Loading

SIZE 080

```
R00= 0.000000
R01= 0.000000
R02= 0.000000
R03= 0.000000
R04= 0.000000
R05= 0.000000
R06= 0.000000
R07= 0.000000
R08= 0.000000
R09= 0.000000
R10= 0.000000
R11= 0.000000
R12= 0.000000
R13= 0.000000
R14= 0.000000
R15= 0.000000
R16= 0.000000
R17= 0.000000
R18= 0.000000
R19= 0.000000
R20= 0.000000
R21= 0.000000
R22= 0.000000
```

```
R23=  0.000000
R24= "  *LIQ"
R25= "RV THE"
R26= "RM EXP"
R27= "1 FOR "
R28= "8 IF A"
R29= "SME CO"
R30=  25.262448
R31=  57.282973
R32=  57.275051
R33=  57.666774
R34=  57.757677
R35=  57.787949
R36=  0.000000
R37=  56.525300
R38=  57.630000
R39=  57.646500
R40=  57.546061
R41=  57.626061
R42=  0.000000
R43=  56.686900
R44=  57.516869
R45=  0.000000
R46=  56.646869
R47=  56.707172
R48= "UID*  "
R49= "U/P/OF"
R50= "BELLWS"
R51= " VALVE"
R52= "FLOW  "
R53= "PPH   "
R54= " SET P"
R55= "******"
R56= "CALC  "
R57= "ENTER "
R58=  45.000000
R59=  0.000000
R60= "RSS PS"
R61= "IG    "
R62= "BACK P"
R63= " SG   "
R64= "VISCOS"
R65= "ITY cP"
R66= "CUBICA"
R67= "L EXP/"
R68= " AREA "
R69= "SQ INS"
R70= "MAX BA"
R71= "CK PRS"
R72= "S PSIG"
R73= "DE    "
R74= "DEG F "
R75= "HEAT I"
R76= "NPUT B"
R77= "TU/HR "
R78= "SPEC H"
R79= "EAT BT"
```

Program 24: HP 41CV Listing

SUBROUTINES

```
01♦LBL "RVTHRM"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

RE-ENTER VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 RTN
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53♦LBL 01
54 XEQ J
55 GTO e
```

RE-ENTER VARIABLES

```
56♦LBL "REENTER"
57 ADV
58 1
59 +
60 STO 01
61 RCL IND 01
62 XEQ J
63 STOP
64 XEQ J
65 STO IND 01
66 ADV
67 SF 02
68 STOP
69 GTO B
```

BYPASS PRINTER

```
70♦LBL J
71 FC? 55
72 GTO 01
73 PRX
74 RTN
75♦LBL 01
76 VIEW X
77 RTN
```

```
78♦LBL C
79 5.6
80 RCL 12
81 *
82 RCL 08
83 /
84 RCL 19
85 SQRT
86 /
87 STO 18
88 50000
```

```
89 X<=Y?
90 GTO 01
91 RCL 18
92 20
93 X>Y?
94 GTO 02
95 RCL 18
96 LN
97 LN
98 LN
99 1.891822816
100 *
101 RCL 18
102 -.6
103 Y↑X
104 -
105 RCL 18
106 .047
107 Y↑X
108 /
109 1
110 X<>Y
111 X<=Y?
112 GTO 02
113♦LBL 01
114 1
115♦LBL 02
116 STO 21
117 1/X
118 RCL 20
119 *
120 RTN
```

MAIN PROGRAM

ENTER DATA

```
121♦LBL A
122 1
123 STO 01
124 29
125 STO 58
126 FS? 02
127 SF 00
128 CF 02
129 XEQ a
130 XEQ d
131 XEQ a
132 XEQ e
133 XEQ d
```

CALC FLOW

```
134 RCL 04
135 RCL 05
136 *
137 RCL 06
138 /
139 STO 12
140 XEQ J
```

ENTER PROCESS DATA

```
141 XEQ e
142 XEQ d
```

CALC K_p

```
143♦LBL B
144 43
145 STO 58
146 10
147 STO 01
148 RCL 02
149 8
150 X≠Y?
151 GTO 01
152 .6
153 GTO 02
154♦LBL 01
155 1
156♦LBL 02
157 STO 23
```

CALC K_w

```
158 RCL 03
159 1
160 X≠Y?
161 GTO 01
162 1.36
163 RCL 10
164 1.2
165 *
166 RCL 09
167 /
168 -
169 RCL 03
170 X<>Y
171 X<=Y?
172 GTO 01
173 1
174♦LBL 01
175 STO 22
```

CALC A

```
176 RCL 12
177 12160
178 /
179 RCL 23
180 /
181 RCL 22
182 /
183 STO 16
184 1.25
185 RCL 09
186 *
187 RCL 10
188 -
189 RCL 07
190 *
191 SQRT
192 /
193 STO 20
194 STO 19
195 GTO E
```

PRINT A

```
196♦LBL D
197 XEQ C
198♦LBL E
199 XEQ J
```

ENTER VALVE SIZE

```
200 43
201 STO 58
202 10
203 STO 01
204 XEQ e
205 RCL 11
206 STO 19
```

CALC VISC SIZE

```
207 XEQ C
208 STO 17
209 RCL 19
210 X>Y?
211 GTO 01
212 RCL 46
213 XEQ b
214 GTO D
215♦LBL 01
216 RCL 17
217 RCL 20
218 X=Y?
219 GTO 01
220 X>Y?
221 GTO 01
222 RCL 46
223 XEQ b
224 RCL 17
225 XEQ J
```

CALC MAX BACKPRES CONV VALVE

```
226♦LBL 01
227 RCL 47
228 XEQ b
229 1.25
230 RCL 09
231 *
232 RCL 16
233 RCL 11
234 /
235 RCL 21
236 /
237 X↑2
238 RCL 07
```

```
239 /
240 -
241 STO 15
```

CALC BACKPRES BELLOWS VALVE

```
242 1
243 RCL 03
244 X≠Y?
245 GTO 01
246 1.36
247 RCL 22
248 RCL 17
249 *
250 RCL 11
251 /
252 -
253 RCL 09
254 *
255 1.2
256 /
257 RCL 15
258 X<=Y?
259 GTO 02
260 RDN
261♦LBL 02
262 STO 15
```

COMMON END

```
263♦LBL 01
264 RCL 15
265 XEQ J
266 FS? 02
267 STOP
268 CF 00
269 XEQ a
270 RCL 17
271 VIEW X
272 BEEP
273 ADV
274 STOP
275 END
```

Program 24: Sequence of Calculations

1. Calculate flowrate.[1]

$$W_m = \frac{BH}{C} \text{ pounds per hour}$$

2. Calculate back-pressure factor.
   Conventional valves:

$$K_w = 1$$

   Bellows valves:

$$K_w = 1.36 - 1.2\left(\frac{P_{OUT}}{P_{IN}}\right)$$

3. Calculate required relief area.[1]

$$A = \frac{W_m}{12{,}160\, K_p K_w \sqrt{G_f\,(1.25\, P_{IN} - P_{OUT})}} \text{ square inches}$$

4. Calculate viscosity correction factor.

$$R_D = \frac{5.6\, W_m}{\mu_{cp}\sqrt{A}}$$

$$K_v = \frac{1.892 \ln \ln \ln R_D - R_D^{-.6}}{R_D^{.047}}$$

When $R_D > 50{,}000$, $K_v = 1$
When $R_D < 20$, an error exists

5. Divide A by K_v for viscosity correction.
6. Calculate maximum allowable back pressure for selected valve area.
Conventional valves:

$$P_{B_{\max}} = 1.25\, P_{IN} - \left(\frac{\left(\dfrac{W_m}{12{,}160\, K_p K_w A K_v} \right)^2}{G_f} \right) \text{PSIG}$$

Bellows valves: Same as for conventional valves, or

$$P_{B_{\max}} = \frac{P_{IN}\left(1.36 - \left(\dfrac{A_{\text{Visc}}}{A_{\text{Valve}}}\right)\right) K_w}{1.2} \text{ PSIG}$$

whichever is the smallest.

Program 24: Nomenclature

A	Relief area, square inches
B	Cubical expansion coefficient per °F for the liquid at flowing temperature, dimensionless
C	Specific heat of the liquid, Btu per pound per °F
G_f	Specific gravity of the liquid at flowing temperature, dimensionless
H	Heat-transfer rate, Btu per hour
K_p	Overpressure correction factor, ASME section VIII,.6, others 1.0, dimensionless
K_w	Back-pressure correction factor, dimensionless
K_v	Viscosity correction factor, dimensionless
$P_{B_{\max}}$	Maximum allowable back pressure, PSIG
P_{IN}	Set pressure, PSIG
P_{OUT}	Back pressure, PSIG
R_D	Reynolds number, dimensionless
W_m	Flow through valve, pounds per hour
μ_{cp}	Absolute viscosity, centipoises

Literature Cited

1. API RP520, Part 1, *Design,* American Petroleum Institute, Fourth Edition. 1976.

Program 25
Liquid Relief—Entrapped in Pipeline

It is customary to install 3/4-inch by 1-inch relief valves on pipe lines to relieve the expansion of blocked-in liquids caused by ambient temperature changes. This program calculates the size required and eliminates any guesswork.

Program 25: User Instructions

a) Initiate program, press A.
b) Enter:
   1. Eight (8) if the valve protects an ASME-coded vessel, any other number if not — Press R/S
   2. One (1) if the valve is to be a bellows type, any other number if not — Press R/S
   3. Line diameter, inches — Press R/S
   4. Line length, feet — Press R/S
   5. Coefficient of cubical expansion for the entrapped liquid per °F, dimensionless — Press R/S
   6. Specific gravity at relief temperature, dimensionless — Press R/S
c) Program calculates flowrate, pounds per hour.
d) Enter:
   7. Absolute viscosity, centipoises — Press R/S
   8. Valve set pressure, PSIG — Press R/S
   9. Back pressure before the valve opens, PSIG — Press R/S
e) Program calculates required relief area, square inches.
f) Enter:
   10. Selected valve area, square inches — Press R/S
g) Program calculates the maximum back pressure that maintains flow at relief conditions, PSIG.

Notes:

1. The E subroutine is available to re-enter data and recalculate.
2. After entering the valve size, a viscosity check is made. If the selected valve is too small it will ask for another size. If there is a viscosity correction but the size is acceptable, it will print out the viscous size.

Program 25: TI 59 Data Sheet

```
*******************

THERML LIQI POP VALV

*******************

ENTR 8  IF ASME CODE
          8.
ENTR 1 FOR BLWS VALV
          0.
ENTR LINE    DIA  INS
         24.
ENTR LINE LNGTH   FT
        250.
ENTR CUBICFL EXP/°F
      0.0008
ENTR     SG
         0.9
```

```
CALC  FLOW  PPH
   1412.1216
ENTR  VISC   CP
           1.
ENTR      SP PSIG
        100.
ENTR      BP PSIG
           0.
CALC  AREA  IN²
 .0182478209
ENTR  VALV AREA  IN²
        0.06
CALC  VISC AREA  IN²
 .0185040343
CALC     MX   BP PSIG
  113.111136

*******************
```

Program 25: TI 59 Register Loading

PARTITIONING
479.59

0.	00	1541142415.	29
0.	01	54.535237	30
0.	02	3044.504948	31
0.	03	1433.474237	32
0.	04	3633.262524	33
0.	05	1533.262351	34
0.	06	3622.292827	35
0.	07	21273243.35	36
0.	08	42132742.	37
0.	09	56.3641	38
0.	10	243170.2234	39
0.	11	632335.3321	40
0.	12	333323.3221	41
0.	13	14274336.	42
0.	14	56.2039	43
0.	15	57.372039	44
0.	16	56.222039	45
0.	17	56.313221	46
0.	18	200213235.	47
1.891822816	19	15321617.	48
13351713.	20	13363017.	49
33362422.	21	1100002421.	50
42243615.	22	2137.	51
2731223723.	23	1600333230.	52
243136.	24	2700272434.	53
162410.	25	3723173530.	54
2724311700.	26	5151515151.	55
3363732100.	27	1513271500.	56
1327001744.	28	1731373500.	57
		43.	58
		55.55555	59

Program 25: TI 59 Listing

SUBROUTINES

PRINT & STORE VARIABLES

```
000  76 LBL
001  10 E'
002  29 CP
003  01  1
004  44 SUM
005  58  58
006  73 RC*
007  58  58
008  22 INV
009  59 INT
010  52 EE
011  22 INV
012  52 EE
013  67  EQ
014  19 D'
015  85  ÷
016  05  5
017  07  7
018  95  =
019  17 B'
020  69 OP
021  21  21
022  73 RC*
023  01  01
024  87 IFF
025  00  00
026  00  00
027  31  31
028  91 R/S
029  72 ST*
030  01  01
031  99 PRT
032  61 GTO
033  10 E'
```

PRINT LINES

```
034  76 LBL
035  19 D'
036  01  1
037  44 SUM
038  58  58
039  73 RC*
040  58  58
041  76 LBL
042  17 B'
043  42 STO
044  59  59
045  73 RC*
046  59  59
047  69 OP
048  01  01
049  18 C'
050  69 OP
051  02  02
052  18 C'
053  69 OP
054  03  03
055  18 C'
056  69 OP
057  04  04
058  69 OP
059  05  05
060  92 RTN
```

DECODE LINES

```
061  76 LBL
062  18 C'
063  01  1
064  00  0
065  00  0
066  48 EXC
067  59  59
068  22 INV
069  59 INT
070  49 PRD
071  59  59
072  73 RC*
073  59  59
074  92 RTN
```

PRINT LINE OF STARS

```
075  76 LBL
076  16 A'
077  93  .
078  00  0
079  01  1
080  08  8
081  35 1/X
082  98 ADV
083  17 B'
084  98 ADV
085  92 RTN
```

RE-ENTER VARIABLES

```
086  76 LBL
087  15  E
088  99 PRT
089  85  +
090  01  1
091  95  =
092  42 STO
093  01  01
094  73 RC*
095  01  01
096  91 R/S
097  72 ST*
098  01  01
099  99 PRT
100  98 ADV
101  86 STF
102  00  00
103  86 STF
104  01  01
105  91 R/S
106  12  B
```

MAIN PROGRAM

ENTER DATA

```
107  76 LBL
108  11  A
109  22 INV
110  86 STF
111  01  01
112  01  1
113  42 STO
114  01  01
115  02  2
116  09  9
117  42 STO
118  58  58
119  16 A'
120  19 D'
121  16 A'
122  10 E'
```

CALC FLOW

```
123  76 LBL
124  12  B
125  43 RCL
126  04  04
127  33 X²
128  65  ×
129  43 RCL
130  05  05
131  65  ×
132  43 RCL
133  06  06
134  65  ×
135  43 RCL
136  07  07
137  65  ×
138  01  1
139  03  3
140  93  .
141  06  6
142  02  2
143  95  =
144  42 STO
```

```
145  18   18
146  99  PRT
```

CALC K_b

```
147  87  IFF
148  01   01
149  35  1/X
150  10  E'
151  76  LBL
152  35  1/X
153  08   8
154  32  X⇌T
155  43  RCL
156  02   02
157  22  INV
158  67   EQ
159  22  INV
160  93   .
161  06   6
162  65   ×
163  76  LBL
164  22  INV
165  01   1
166  95   =
167  42  STO
168  13   13
```

CALC K_w

```
169  43  RCL
170  03   03
171  32  X⇌T
172  01   1
173  22  INV
174  67   EQ
175  23  LNX
176  01   1
177  93   .
178  03   3
179  06   6
180  75   -
181  01   1
182  93   .
183  02   2
184  65   ×
185  43  RCL
186  10   10
187  55   ÷
188  43  RCL
189  09   09
190  95   =
191  22  INV
192  77   GE
193  23  LNX
194  01   1
195  76  LBL
196  23  LNX
197  42  STO
198  14   14
```

CALC A

```
199  43  RCL
200  18   18
201  55   ÷
202  01   1
203  02   2
204  01   1
205  06   6
206  00   0
207  55   ÷
208  43  RCL
209  13   13
210  55   ÷
211  43  RCL
212  14   14
213  55   ÷
214  53   (
215  43  RCL
216  07   07
217  65   ×
218  53   (
219  01   1
220  93   .
221  02   2
222  05   5
223  65   ×
224  43  RCL
225  09   09
226  75   -
227  43  RCL
228  10   10
229  54   )
230  54   )
231  34  √X
232  95   =
233  42  STO
234  12   12
235  61  GTO
236  32  X⇌T
```

SUBROUTINE TO CALC K_v

```
237  76  LBL
238  13   C
239  05   5
240  93   .
241  06   6
242  65   ×
243  43  RCL
244  18   18
245  55   ÷
246  43  RCL
247  08   08
248  55   ÷
249  43  RCL
250  11   11
251  34  √X
252  95   =
253  42  STO
254  16   16
255  32  X⇌T
256  05   5
257  00   0
258  00   0
259  00   0
260  00   0
261  22  INV
262  77   GE
263  24   CE
264  43  RCL
265  16   16
266  32  X⇌T
267  02   2
268  00   0
269  77   GE
270  37  P/R
271  01   1
272  32  X⇌T
273  43  RCL
274  16   16
275  23  LNX
276  23  LNX
277  23  LNX
278  65   ×
279  43  RCL
280  19   19
281  75   -
282  43  RCL
283  16   16
284  45  YX
285  93   .
286  06   6
287  94  +/-
288  95   =
289  55   ÷
290  43  RCL
291  16   16
292  45  YX
293  93   .
294  00   0
295  04   4
296  07   7
297  95   =
298  22  INV
299  77   GE
300  25  CLR
301  76  LBL
302  24   CE
303  01   1
304  76  LBL
```

```
305   25  CLR
306   42  STO
307   15   15
308   35  1/X
309   65   ×
310   43  RCL
311   12   12
312   95   =
313   92  RTN
```

PRINT A

```
314   76  LBL
315   34  √X
316   13   C
317   76  LBL
318   32  X:T
319   99  PRT
```

ENTER VALVE SIZE

```
320   43  RCL
321   44   44
322   17  B'
323   43  RCL
324   11   11
325   87  IFF
326   01   01
327   30  TAN
328   87  IFF
329   00   00
330   39  COS
331   76  LBL
332   30  TAN
333   91  R/S
334   76  LBL
335   39  COS
336   99  PRT
337   42  STO
338   11   11
```

CALC A VISC

```
339   13   C
340   42  STO
341   17   17
342   32  X:T
343   43  RCL
344   11   11
345   77   GE
346   33  X²
347   43  RCL
348   45   45
349   17  B'
350   61  GTO
351   34  √X
352   76  LBL
353   33  X²
354   43  RCL
355   12   12
356   77   GE
357   44  SUM
358   43  RCL
359   45   45
360   17  B'
361   43  RCL
362   17   17
363   99  PRT
```

CALC MAX BACKPRES

```
364   76  LBL
365   44  SUM
366   43  RCL
367   46   46
368   17  B'
369   01   1
370   93   .
371   02   2
372   05   5
373   65   ×
374   43  RCL
375   09   09
376   75   -
377   53   (
378   43  RCL
379   18   18
380   55   ÷
381   01   1
382   02   2
383   01   1
384   06   6
385   00   0
386   55   ÷
387   43  RCL
388   13   13
389   55   ÷
390   43  RCL
391   14   14
392   55   ÷
393   43  RCL
394   11   11
395   55   ÷
396   43  RCL
397   15   15
398   54   )
399   33  X²
400   55   ÷
401   43  RCL
402   07   07
403   95   =
404   42  STO
405   59   59
406   01   1
407   32  X:T
408   43  RCL
409   03   03
410   22  INV
411   77   GE
412   42  STO
413   01   1
414   93   .
415   03   3
416   06   6
417   75   -
418   43  RCL
419   14   14
420   65   ×
421   43  RCL
422   17   17
423   55   ÷
424   43  RCL
425   11   11
426   95   =
427   65   ×
428   43  RCL
429   09   09
430   55   ÷
431   01   1
432   93   .
433   02   2
434   95   =
435   32  X:T
436   43  RCL
437   59   59
438   32  X:T
439   22  INV
440   77   GE
441   43  RCL
442   32  X:T
443   76  LBL
444   43  RCL
445   42  STO
446   59   59
447   76  LBL
448   42  STO
449   43  RCL
450   59   59
451   99  PRT
452   87  IFF
453   01   01
454   38  SIN
455   22  INV
456   86  STF
457   00   00
458   76  LBL
459   38  SIN
460   16  A'
461   98  ADV
462   98  ADV
463   43  RCL
464   17   17
465   91  R/S
```

Program 25: HP 41CV Data Sheet

```
************

  *POP RV*
  *LIQUID*

************

ENTER 8 IF ASME CODE
        8.0000     ***
ENTER 1 FOR BELLWS VALVE
        0.0000     ***
ENTER LINE DIA INS
       24.0000     ***
ENTER LINE LENGTH FT
      250.0000     ***
ENTER CUBICAL EXP/DEG F
        0.0008     ***
ENTER  SG
        0.9000     ***
CALC   FLOW
PPH
   1,412.1216      ***
ENTER VISCOSITY cP
        1.0000     ***
ENTER  SET PRSS PSIG
      100.0000     ***
ENTER BACK PRSS PSIG
        0.0000     ***
CALC    AREA
SQ  INS
        0.0182     ***
ENTER  VALVE AREA SQ INS
        0.0600     ***
CALC  VISCOS AREA SQ INS
        0.0185     ***
CALC  MAX BACK PRSS PSIG
      113.1111     ***

************
```

Program 25: HP 41CV Register Loading

SIZE 080

```
R00=  0.000000
R01=  0.000000
R02=  0.000000
R03=  0.000000
R04=  0.000000
R05=  0.000000
R06=  0.000000
R07=  0.000000
R08=  0.000000
R09=  0.000000
R10=  0.000000
R11=  0.000000
R12=  0.000000
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  0.000000
R17=  0.000000
R18=  0.000000
R19=  0.000000
R20=  0.000000
R21=  0.000000
R22=  0.000000
R23=  0.000000
R24= "  *LIQ"
R25= "  *POP"
R26= " RV*  "
R27= "1 FOR "
R28= "8 IF A"
R29= "SME CO"
R30=  25.262448
R31=  57.282973
R32=  57.275051
R33=  57.757600
R34=  57.777879
R35=  57.666774
R36=  57.630000
R37=  0.000000
R38=  56.525300
R39=  57.646500
R40=  57.546061
R41=  57.626061
R42=  0.000000
R43=  56.686900
R44=  57.516869
R45=  0.000000
R46=  56.646869
R47=  56.707172
R48= "UID*  "
R49=  0.000000
R50= "BELLWS"
R51= " VALVE"
R52= "FLOW  "
R53= "PPH   "
R54= " SET P"
R55= "******"
R56= "CALC  "
R57= "ENTER "
R58=  45.000000
R59=  0.000000
R60= "RSS PS"
R61= "IG    "
R62= "BACK P"
R63= " SG   "
R64= "VISCOS"
R65= "ITY cP"
R66= "CUBICA"
R67= "L EXP/"
R68= " AREA "
R69= "SQ INS"
R70= "MAX BA"
R71= "CK PRS"
R72= "S PSIG"
R73= "DE    "
R74= "DEG F "
R75= "LINE D"
R76= "IA INS"
R77= "LINE L"
R78= "ENGTH "
R79= "FT    "
```

Program 25: HP 41CV Listing

SUBROUTINES

```
01♦LBL "POP RV"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
```

```
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 RTN
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53♦LBL 01
54 XEQ J
55 GTO e
```

RE-ENTER VARIABLES

```
56♦LBL "REENTER"
57 ADV
58 1
59 +
60 STO 01
61 RCL IND 01
62 XEQ J
63 STOP
64 XEQ J
65 STO IND 01
66 ADV
67 SF 02
68 STOP
69 GTO B
```

BYPASS PRINTER

```
70♦LBL J
71 FC? 55
72 GTO 01
73 PRX
74 RTN
75♦LBL 01
76 VIEW X
77 RTN
```

CALC K_v

```
78♦LBL C
79 5.6
80 RCL 12
81 *
82 RCL 08
83 /
84 RCL 19
85 SQRT
86 /
87 STO 18
88 50000
89 X<=Y?
90 GTO 01
91 RCL 18
92 20
93 X>Y?
94 GTO 02
95 RCL 18
96 LN
97 LN
98 LN
99 1.891822816
100 *
101 RCL 18
102 -.6
103 Y↑X
104 -
105 RCL 18
106 .047
107 Y↑X
108 /
109 1
110 X<>Y
111 X<=Y?
112 GTO 02
113♦LBL 01
114 1
115♦LBL 02
116 STO 21
117 1/X
118 RCL 20
119 *
120 RTN
```

MAIN PROGRAM ENTER DATA

```
121♦LBL A
122 1
123 STO 01
124 29
125 STO 58
126 FS? 02
127 SF 00
128 CF 02
129 XEQ a
130 XEQ d
131 XEQ a
132 XEQ e
133 XEQ d
```

CALC FLOW

```
134 13.62
135 RCL 04
136 X↑2
137 *
138 RCL 05
139 *
140 RCL 06
141 *
142 RCL 07
143 *
144 STO 12
145 XEQ J
```

ENTER DATA

```
146 XEQ e
147 XEQ d
```

CALC K_w

```
148♦LBL B
149 43
150 STO 58
151 10
152 STO 01
153 RCL 02
154 8
155 X≠Y?
156 GTO 01
157 .6
158 GTO 02
159♦LBL 01
160 1
161♦LBL 02
162 STO 23
```

CALC A

```
163 RCL 03
164 1
165 X≠Y?
166 GTO 01
167 1.36
168 RCL 10
169 1.2
170 *
171 RCL 09
172 /
173 -
174 RCL 03
175 X<>Y
176 X<=Y?
177 GTO 01
```

```
178 1
179♦LBL 01
180 STO 22
181 RCL 12
182 12160
183 /
184 RCL 23
185 /
186 RCL 22
187 /
188 STO 16
189 1.25
190 RCL 09
191 *
192 RCL 10
193 -
194 RCL 07
195 *
196 SQRT
197 /
198 STO 20
199 STO 19
200 GTO E
```

PRINT A

```
201♦LBL D
202 XEQ C
203♦LBL E
204 XEQ J
```

ENTER VALVE SIZE

```
205 43
206 STO 58
207 10
208 STO 01
209 XEQ e
210 RCL 11
211 STO 19
```

CALC VISC SIZE

```
212 XEQ C
213 STO 17
214 RCL 19
215 X>Y?
216 GTO 01
217 RCL 46
218 XEQ b
219 GTO D
220♦LBL 01
221 RCL 17
222 RCL 20
223 X=Y?
224 GTO 01
225 X>Y?
226 GTO 01
227 RCL 46
228 XEQ b
229 RCL 17
230 XEQ J
```

CALC MAX BACKPRES CONV VALVE

```
231♦LBL 01
232 RCL 47
233 XEQ b
234 1.25
235 RCL 09
236 *
237 RCL 16
238 RCL 11
239 /
240 RCL 21
241 /
242 X↑2
243 RCL 07
244 /
245 -
246 STO 15
```

CALC BACKPRES BELLOWS VALVE

```
247 1
248 RCL 03
249 X≠Y?
250 GTO 01
251 1.36
252 RCL 22
253 RCL 17
254 *
255 RCL 11
256 /
257 -
258 RCL 09
259 *
260 1.2
261 /
262 RCL 15
263 X<=Y?
264 GTO 02
265 RDN
266♦LBL 02
267 STO 15
```

COMMON ENDING

```
268♦LBL 01
269 RCL 15
270 XEQ J
271 FS? 02
272 STOP
273 CF 00
274 XEQ a
275 RCL 17
276 VIEW X
277 BEEP
278 ADV
279 STOP
280 .END.
```

Program 25: Sequence of Calculations

1. Calculate flowrate.

$$W_m = 13.62D^2\ LB\ G_f \text{ pounds per hour}$$

2. Calculate back-pressure factor.
   Conventional valves:

$$K_w = 1$$

Bellows valves:

$$K_w = 1.36 - 1.2\left(\frac{P_{OUT}}{P_{IN}}\right)$$

3. Calculate required relief area.[1]

$$A = \frac{W_m}{12{,}160\, K_p K_w \sqrt{G_f (1.25\, P_{IN} - P_{OUT})}} \text{ square inches}$$

4. Calculate viscosity correction factor.

$$R_D = \frac{5.6\, W_m}{\sqrt{A}\, \mu_{cp}}$$

When $R_D > 50{,}000$, $K_v = 1$
When $R_D < 20$, an error exists

$$K_v = \frac{1.892 \ln \ln \ln R_D - R_D^{-.6}}{R_D^{.047}}$$

5. Divide A by K_v for viscosity correction.
6. Calculate maximum allowable back pressure for selected valve area.
   Conventional valves:

$$P_{B_{max}} = 1.25\, P_{IN} - \left(\frac{\left(\dfrac{W_m}{12{,}160\, K_p K_w A K_v}\right)^2}{G_f}\right) \text{ PSIG}$$

Bellows valves: Same as for conventional valves, or

$$P_{B_{max}} = \frac{P_{IN}\left(1.36 - \left(\dfrac{A_{\text{visc}}}{A_{\text{valve}}}\right) K_w\right)}{1.2} \text{ PSIG}$$

whichever is the smallest.

Program 25: Nomenclature

A Relief area, square inches
B Cubical expansion coefficient per °F for the liquid at the flowing temperature, dimensionless

D Pipe diameter, inches
G_f Specific gravity of the liquid at flowing temperature, dimensionless
K_p Overpressure correction factor—.6 for ASME Section VIII; 1 for others, 1, dimensionless.
K_w Back-pressure correction factor, dimensionless
K_v Viscosity correction factor, dimensionless
L Pipe length, feet
$P_{B_{max}}$ Maximum allowable backpressure, PSIG
P_{IN} Set pressure, PSIG
P_{OUT} Back pressure, PSIG
R_D Reynolds number, dimensionless
W_m Flow through valve, pounds per hour
μ_{cp} Absolute viscosity, centipoises

Literature Cited

1. API RP520, Part 1, *Design,* American Petroleum Institute, Fourth Edition, 1976.

Program 26
Fire Sizing—Liquid Vaporization

Pressure relief valves must be capable of protecting vessels and equipment in the case of accidental external fire. The API 520 method is to determine the wetted area and a heat-transfer factor (environment factor) and calculate the amount of liquid which is vaporized and relieved.

First a fire zone must be established. It may already be designed into the plant or it may be determined by natural barriers and elevations. The area of metal wetted by both the fire and internal liquid is then determined. API suggests that the normal inventory of liquids be assumed and recommends allowance for at least 25 feet above the levels on which a reasonable fire could be sustained. Spheres should be considered at least up to their maximum diameter.

In selecting the environment factor, API 520 does not allow any credit for water deluge systems or depressuring systems. Underground storage normally does not require fire protection, and an environment factor of 0.03 is suggested for earth-covered storage above grade.

Credit for insulation requires that it be noncombustible, nonabsorbent, and strong enough to resist being dislodged by fire hoses. This eliminates all popular insulation material except cellular glass protected with a metal jacketing. This means that the environmental factor is normally taken as 1, and experience has shown that it is not unreasonable for no credit (i.e. 1) to be given for the environment factor. Contingencies other than fire usually determine the size of most relief valves. The relief temperature and latent heat of vaporization at relief conditions are not easy to find. Program 27 will assist for most pure hydrocarbon liquids.

Program 26: User Instructions

a) Initiate program, press A.

b) Enter:

1. Number of vessels exposed to fire	Press R/S
2. First vessel diameter, feet	Press R/S
3. First vessel length (tangent to tangent), feet	Press R/S
4. First vessel fraction of wetted part, dimensionless (i.e. half full = 0.5, full = 1)	Press R/S

Program will loop back to 2 to pick up vessel data for the quantity of vessels entered in 1, and then continue.

5. One (1) if the valve is to be a bellows type, any other number if not.	Press R/S
6. Environment factor, dimensionless, maximum 1	Press R/S
7. Latent heat of vaporization, Btu per pound	Press R/S
8. Valve set pressure, PSIG	Press R/S
9. Back pressure before valve opens, PSIG	Press R/S
10. Relief temperature, °F	Press R/S
11. Ratio of specific heats C_p/C_v, dimensionless	Press R/S
12. Molecular weight, dimensionless	Press R/S
13. Compressibility factor, dimensionless	Press R/S

c) Program will calculate the amount of liquid vaporized (pounds per hour) and the required relief area (square inches).

d) Enter:

14. The selected valve area, square inches	Press R/S

e) Program calculates the maximum back pressure that maintains flow at relief conditions.

Program 26: TI 59 Data Sheet

```
********************

 FIRE    RV   LIQ VAPN

********************

ENTR QUAN VESSL
          2.
ENTR VESSL  DIA    FT
         5.5
ENTR LNGTH    FT
         13.
ENTR WETTD PART
         0.6

ENTR VESSL  DIA    FT
         5.5
ENTR LNGTH    FT
         13.
ENTR WETTD PART
         0.4

ENTR 1 FOR BLWS VALV
          0.
```

```
ENTR   ENVR FACT
          1.
ENTR  ΔHV BTU/P
        198.
ENTR     SP PSIG
         50.
ENTR     BP PSIG
          2.
ENTR  TEMP    °F
        100.
ENTR CP/CV
       1.024
ENTR     MW
         58.
ENTR      Z
       0.935
CALC    LIQ VAPN   PPH
 12005.91385
CALC   AREA   IN²
 1.592580887
ENTR   VALV AREA   IN²
       1.838
CALC MX BP PSIG
 45.51278412

********************
```

Program 26: TI 59 Register Loading

PARTITIONING
559.49

0.	00	3044001433.	21
0.	01	13351713.	22
0.	02	1533631542.	23
0.	03	37173033.	24
0.	04	33362422.	25
0.	05	1437416333.	26
0.	06	75234200.	27
0.	07	21131537.	28
0.	08	17314235.	29
0.	09	42.484144	30
0.	10	46.5453	31
0.	11	7321.534036	32
0.	12	3043.5236	33
0.	13	1433.5143	34
0.	14	42132742.	35
0.	15	2137.494535	36
0.	16	3633.2928	37
0.	17	333323.2726	38
0.	18	243170.3725	39
0.	19	162413.3425	40
0.	20	272434.2432	41
		21243517.23	42
		33133537.33	43

42133331.31	44	2731223723.	52
14274336.	45	4217363627.	53
56.414438	46	3441133100.	54
56.2239	47	5151515151.	55
3542.352239	48	1513271500.	56
200213235.	49	1731373500.	57
56.2125	50	0.	58
4317373716.	51	0.	59

Program 26: TI 59 Listing

SUBROUTINES

CALC K_b CONV

000	53	(
001	53	(
002	13	C
003	65	×
004	53	(
005	43	RCL
006	12	12
007	45	Y×
008	53	(
009	02	2
010	55	÷
011	43	RCL
012	09	09
013	54	)
014	75	-
015	43	RCL
016	12	12
017	45	Y×
018	53	(
019	53	(
020	43	RCL
021	09	09
022	85	+
023	01	1
024	54	)
025	55	÷
026	43	RCL
027	09	09
028	54	)
029	54	)
030	54	)
031	34	ΓX
032	55	÷
033	43	RCL
034	16	16
035	65	×
036	07	7
037	00	0
038	00	0
039	54	)
040	92	RTN

CALC K_b BELLOWS

041	53	(
042	01	1
043	93	.
044	06	6
045	75	-
046	93	.
047	03	3
048	00	0
049	65	×
050	53	(
051	93	.
052	00	0
053	04	4
054	94	+/-
055	65	×
056	43	RCL
057	06	06
058	54	)
059	22	INV
060	23	LNX
061	75	-
062	01	1
063	93	.
064	01	1
065	08	8
066	65	×
067	43	RCL
068	12	12
069	54	)
070	92	RTN

CALC P_1

071	76	LBL
072	15	E
073	53	(
074	01	1
075	04	4
076	93	.
077	07	7
078	85	+
079	01	1
080	93	.
081	02	2
082	65	×
083	43	RCL
084	06	06
085	54	)
086	92	RTN

PRINT & STORE VARIABLES

087	76	LBL
088	10	E'
089	29	CP
090	01	1
091	44	SUM
092	58	58
093	73	RC*
094	58	58
095	22	INV
096	59	INT
097	52	EE
098	22	INV
099	52	EE
100	67	EQ
101	52	EE
102	85	+
103	05	5
104	07	7
105	95	=
106	17	B'
107	69	DP
108	21	21
109	73	RC*
110	01	01
111	91	R/S
112	72	ST*
113	01	01
114	73	RC*
115	01	01
116	99	PRT
117	61	GTO

```
118   10 E'
```

PRINT LINES

```
119   76 LBL
120   19 D'
121   01  1
122   44 SUM
123   58  58
124   73 RC*
125   58  58
126   76 LBL
127   17 B'
128   42 STO
129   59  59
130   73 RC*
131   59  59
132   69 OP
133   01  01
134   18 C'
135   69 OP
136   02  02
137   18 C'
138   69 OP
139   03  03
140   18 C'
141   69 OP
142   04  04
143   69 OP
144   05  05
145   92 RTN
```

DECODE LINES

```
146   76 LBL
147   18 C'
148   01  1
149   00  0
150   00  0
151   48 EXC
152   59  59
153   22 INV
154   59 INT
155   49 PRD
156   59  59
157   73 RC*
158   59  59
159   92 RTN
```

PRINT LINE OF STARS

```
160   76 LBL
161   16 A'
162   93  .
163   00  0
164   01  1
165   08  8
166   35 1/X
167   98 ADV
168   17 B'
169   98 ADV
170   92 RTN
```

CALC k/(k − 1)

```
171   76 LBL
172   13  C
173   53  (
174   43 RCL
175   09  09
176   55  ÷
177   53  (
178   43 RCL
179   09  09
180   75  -
181   01  1
182   54  )
183   54  )
184   92 RTN
```

MAIN PROGRAM

ENTER DATA

```
185   76 LBL
186   11  A
187   00  0
188   42 STO
189   19  19
190   42 STO
191   17  17
192   42 STO
193   20  20
194   86 STF
195   00  00
196   01  1
197   42 STO
198   01  01
199   02  2
200   09  9
201   42 STO
202   58  58
203   16 A'
204   19 D'
205   16 A'
206   61 GTO
207   10 E'
```

CALC WETTED AREA

```
208   76 LBL
209   52 EE
210   22 INV
211   87 IFF
212   00  00
213   19 D'
214   04  4
215   22 INV
216   44 SUM
217   58  58
218   03  3
219   22 INV
220   44 SUM
221   01  01
222   43 RCL
223   03  03
224   65  ×
225   53  (
226   43 RCL
227   03  03
228   85  +
229   43 RCL
230   04  04
231   54  )
232   65  ×
233   43 RCL
234   05  05
235   65  ×
236   89  π
237   95  =
238   44 SUM
239   19  19
240   98 ADV
241   97 DSZ
242   02  02
243   10 E'
244   04  4
245   44 SUM
246   58  58
247   22 INV
248   86 STF
249   00  00
```

CALC C

```
250   10 E'
251   02  2
252   55  ÷
253   53  (
254   43 RCL
255   09  09
256   85  +
257   01  1
258   54  )
259   95  =
260   45 YX
261   13  C
262   95  =
263   42 STO
264   18  18
265   01  1
```

```
266  93  .
267  02  2
268  01  1
269  03  3
270  75  -
271  43  RCL
272  18  18
273  95  =
274  65  ×
275  04  4
276  09  9
277  05  5
278  93  .
279  05  5
280  06  6
281  95  =
282  42  STO
283  16  16
```

CALC FLOW

```
284  43  RCL
285  19  19
286  45  YX
287  93  .
288  08  8
289  02  2
290  65  ×
291  43  RCL
292  04  04
293  65  ×
294  02  2
295  01  1
296  00  0
297  00  0
298  00  0
299  55  ÷
300  43  RCL
301  05  05
302  95  =
303  42  STO
304  02  02
305  99  PRT
```

DECODE

```
306  01  1
307  32  X:T
308  43  RCL
309  03  03
310  67  EQ
311  67  EQ
312  07  7
313  03  3
314  42  STO
315  19  19
316  01  1
317  04  4
318  93  .
319  07  7
320  44  SUM
321  07  07
322  42  STO
323  17  17
324  61  GTO
325  32  X:T
326  76  LBL
327  67  EQ
328  08  8
329  03  3
330  42  STO
331  19  19
332  04  4
333  01  1
334  42  STO
335  20  20
```

CALC r

```
336  76  LBL
337  32  X:T
338  43  RCL
339  07  07
340  55  ÷
341  71  SBR
342  40  IND
343  19  19
344  95  =
345  32  X:T
346  43  RCL
347  18  18
348  42  STO
349  12  12
350  77  GE
351  42  STO
352  01  1
353  32  X:T
354  42  STO
355  12  12
```

CALC K_b

```
356  71  SBR
357  40  IND
358  20  20
359  22  INV
360  77  GE
361  43  RCL
362  76  LBL
363  42  STO
364  01  1
365  76  LBL
366  43  RCL
367  42  STO
368  13  13
369  19  D'
370  43  RCL
371  02  02
372  55  ÷
373  43  RCL
374  16  16
375  55  ÷
376  43  RCL
377  13  13
378  55  ÷
379  15  E
380  65  ×
381  53  (
382  53  (
383  43  RCL
384  08  08
385  85  +
386  04  4
387  06  6
388  00  0
389  54  )
390  65  ×
391  43  RCL
392  11  11
393  55  ÷
394  43  RCL
395  10  10
396  54  )
397  34  ΓX
398  95  =
399  42  STO
400  14  14
401  99  PRT
```

CALC MAX BACKPRES

```
402  10  E'
403  43  RCL
404  14  14
405  55  ÷
406  43  RCL
407  12  12
408  65  ×
409  43  RCL
410  13  13
411  95  =
412  42  STO
413  15  15
414  43  RCL
415  18  18
416  42  STO
417  12  12
418  76  LBL
```

```
419   35  1/X
420   43  RCL
421   18   18
422   85   +
423   01   1
424   95   =
425   34  ΓX
426   34  ΓX
427   49  PRD
428   12   12
429   93   .
430   00   0
431   00   0
432   01   1
433   32  X:T
434   71  SBR
435   40  IND
436   20   20
437   75   -
438   43  RCL
439   15   15
440   95   =
441   42  STO
442   18   18
443   66  PAU
444   50  IXI
445   77   GE
446   35  1/X
447   43  RCL
448   12   12
449   65   ×
450   71  SBR
451   40  IND
452   19   19
453   75   -
454   43  RCL
455   17   17
456   95   =
457   99  PRT
458   16  A'
459   43  RCL
460   14   14
461   98  ADV
462   98  ADV
463   91  R/S
```

Program 26: HP 41CV Data Sheet

```
************

RV FIRE LIQD

************

ENTER QUANT VESSL
         2.0000    ***
ENTER VESSL DIA FT
         5.5000    ***
ENTER LENGTH FT
        13.0000    ***
ENTER WETTED PART
         0.5000    ***

ENTER VESSL DIA FT
         5.5000    ***
ENTER LENGTH FT
        13.0000    ***
ENTER WETTED PART
         0.5000    ***

ENTER 1 FOR BELLWS VALVE
         0.0000    ***
ENTER ENVIRN FACT
         1.0000    ***
ENTER  dHV  BTU/P
       198.0000    ***
ENTER SET PRS PSIG
        50.0000    ***
ENTER BCK PRS PSIG
         2.0000    ***
ENTER DSCH TEMP OF
       100.0000    ***
ENTER  Z
         0.9350    ***
ENTER CP/CV
         1.0240    ***
ENTER MW
        58.0000    ***
CALC    FLOW
PPH
    12,005.9139    ***
CALC    AREA
SQ INS
         1.5926    ***
ENTER  VALVE AREA SQ INS
         1.8380    ***
CALC   MAX BA
CK PRSS PSIG
        45.5539    ***

************
```

Program 26: HP 41CV Register Loading

SIZE 080

```
R00=  0.0000
R01=  0.0000
R02=  0.0000
R03=  0.0000
R04=  0.0000
R05=  0.0000
R06=  0.0000
R07=  0.0000
R08=  0.0000
R09=  0.0000
R10=  0.0000
R11=  0.0000
R12=  0.0000
R13=  0.0000
R14=  0.0000
R15=  0.0000
R16=  0.0000
R17=  0.0000
R18=  0.0000
R19=  0.0000
R20=  0.0000
R21=  0.0000
R22=  0.0000
R23=  0.0000
R24= "CK PRS"
R25= "RV FIR"
R26= "E LIQD"
R27= "QUANT "
R28= "VESSL "
R29= "DIA FT"
R30=  25.2600
R31=  57.2728
R32=  57.2829
R33=  57.5152
R34=  57.5354
R35=  0.0000
R36=  57.6062
R37=  57.6364
R38=  57.6566
R39=  57.6769
R40=  57.6869
R41=  57.7172
R42=  57.7400
R43=  57.7500
```

```
R44=  57.7600
R45=  0.0000
R46=  56.7778
R47=  56.7973
R48=  57.6280
R49=  0.0000
R50=  56.7025
R51= "LENGTH"
R52= " FT   "
R53= "WETTED"
R54= " PART "
R55= "******"
R56= "CALC  "
R57= "ENTER "
R58=  0.0000
R59=  0.0000
R60= "1 FOR "
R61= "BELLWS"
R62= " VALVE"
R63= "ENVIRN"
R64= " FACT "
R65= " dHV  "
R66= "BTU/P "
R67= "SET PR"
R68= "BCK PR"
R69= "S PSIG"
R70= "MAX BA"
R71= "DSCH T"
R72= "EMP OF"
R73= "SQ INS"
R74= " Z    "
R75= "CP/CV "
R76= "MW    "
R77= " FLOW "
R78= "PPH   "
R79= " AREA "
```

Program 26: HP 41CV Listing

SUBROUTINES

```
01♦LBL "RVFRELQ"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 RTN
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53♦LBL 01
54 XEQ J
55 GTO e
```

RE-ENTER VARIABLES

```
56♦LBL "REENTER"
57 ADV
58 2
59 -
60 STO 01
61 RCL IND 01
62 XEQ J
63 STOP
64 XEQ J
65 STO IND 01
66 ADV
67 SF 02
68 STOP
69 GTO E
```

BYPASS PRINTER

```
70♦LBL J
71 FC? 55
72 GTO 01
73 PRX
74 RTN
75♦LBL 01
76 VIEW X
77 RTN
```

CALC P_1

```
78♦LBL F
79 RCL 06
80 1.2
81 *
82 14.7
83 +
84 RTN
```

CALC K_b

```
85♦LBL G
86 RCL 16
87 RCL 19
88 Y↑X
89 RCL 16
90 RCL 20
91 Y↑X
92 -
93 RCL 22
94 *
95 SQRT
96 735
97 *
98 XEQ H
99 /
100 RTN
```

CALC C

```
101♦LBL H
102 XEQ B
103 CHS
```

```
104 1.213
105 +
106 520
107 *
108 RTN
```

CALC $(2/(k+1)^{k/(k-1)}$

```
109♦LBL B
110 2
111 RCL 10
112 1
113 +
114 /
115 RCL 22
116 Y↑X
117 RTN
```

REPRINT

```
118♦LBL "AA"
119 2
120 STO 01
121 35
122 STO 58
123 56.285379
124 XEQ b
125 RCL 02
126 XEQ J
127 XEQ e
128 XEQ d
129 RCL 00
130 XEQ J
131 GTO E
```

MAIN PROGRAM
ENTER DATA

```
132♦LBL A
133 FS? 02
134 SF 00
135 CF 02
136 1
137 STO 01
138 29
139 STO 58
140 XEQ a
141 XEQ d
142 XEQ a
143 FS? 00
144 GTO "AA"
145 0
146 STO 06
```

CALC WETTED AREA

```
147♦LBL "AB"
148 XEQ e
149 ADV
150 2
151 STO 01
152 31
153 STO 58
154 RCL 03
155 RCL 04
156 +
157 RCL 03
158 *
159 RCL 05
160 *
161 PI
162 *
163 ST+ 06
164 DSE 02
165 GTO "AB"
```

ENTER DATA

```
166 RCL 06
167 STO 02
168 2
169 STO 01
170 35
171 STO 58
172 XEQ e
```

CALC FLOW

```
173 XEQ d
174 RCL 02
175 .82
176 Y↑X
177 RCL 04
178 *
179 21000
180 *
181 RCL 05
182 /
183 STO 00
184 XEQ J
```

CALC k/(k − 1)

```
185♦LBL E
186 11
187 STO 01
188 46
189 STO 58
190 XEQ d
191 RCL 10
192 RCL 10
193 1
194 -
195 /
196 STO 22
197 RCL 10
198 1
199 +
200 RCL 10
201 /
202 STO 20
```

CALC 2/k

```
203 2
204 RCL 10
205 /
206 STO 19
```

CALC $_r$

```
207 RCL 03
208 1
209 X=Y?
210 GTO 01
211 RCL 07
212 14.7
213 +
214 XEQ F
215 /
216 STO 23
217 XEQ B
218 STO 16
219 STO 21
220 RCL 23
221 X<>Y
222 X>Y?
223 GTO 03
224 RCL 23
225 STO 16
```

CALC K_b

```
226 XEQ G
227 GTO 02
228♦LBL 01
229 RCL 06
230 -.04
231 *
232 E↑X
233 -.3
234 *
235 1.6
236 +
237 STO 17
238 RCL 07
239 RCL 06
240 /
241 1.18
242 *
243 -
244♦LBL 02
```

```
245 1
246 X<>Y
247 X<=Y?
248 GTO 01
249♦LBL 03
250 1
251♦LBL 01
252 STO 13
```

CALC A

```
253 RCL 08
254 460
255 +
256 RCL 09
257 *
258 RCL 11
259 /
260 SQRT
261 RCL 00
262 *
263 XEQ H
264 /
265 .953
266 /
267 XEQ F
268 /
269 RCL 13
270 /
271 STO 14
272 XEQ J
```

ENTER VALVE SIZE

```
273 XEQ e
```

CALC MAX BACKPRES CONV VALVE

```
274 XEQ d
275 RCL 21
276 STO 16
277 RCL 14
278 RCL 12
279 /
280 RCL 13
281 *
282 STO 15
283 1
284 RCL 03
285 X≠Y?
286 GTO C
287 RCL 17
288 RCL 15
289 -
290 1.18
291 /
292 RCL 06
293 *
294 GTO I
```

BELLOWS VALVE

```
295♦LBL C
296 RCL 21
297 1
298 +
299 SQRT
300 ST* 16
301 XEQ G
302 RCL 15
303 -
304 PSE
305 STO 21
306 ABS
307 .001
308 X<>Y
309 X>Y?
310 GTO C
311 RCL 16
312 XEQ F
313 *
314 14.7
315 -
```

COMMON ENDING

```
316♦LBL I
317 STO 18
318 XEQ J
319 FS? 02
320 STOP
321 CF 00
322 XEQ a
323 RCL 14
324 VIEW X
325 BEEP
326 ADV
327 STOP
328 .END.
```

Program 26: Sequence of Calculations

1. Calculate wetted area.

$$A_w = \pi \times D(D + L) \text{ square feet}$$

2. Calculate vaporized liquid.[1]

$$W_m = \frac{21{,}000\, FA_w^{.82}}{dHV} \quad \text{pounds per hour}$$

3. Calculate pressure ratio

$$r = \frac{P_2}{P_1} \quad \text{limited to a minimum of} \quad \left(\frac{2}{k+1}\right)^{k/(k-1)}$$

4. Calculate the specific heat ratio coefficient[1]

$$C = 520 \sqrt{k\left(\frac{2}{k+1}\right)^{(k+1)/(k-1)}} = 520\,(1.213 - r)$$

5. Calculate the back-pressure correction factor.
   Conventional valves:[1]

$$K_b = \frac{735F_2}{C}\sqrt{(1-r)}$$

where

$$F_2 = \sqrt{\left(\frac{k}{k-1}\right)(r^{2/k})\left(\frac{1-(r^{(k-1)/k})}{1-r}\right)}$$

Bellows valves:

$$K_b = 1.6 - .3e^{-.04}P_{IN} - 1.18r$$

6. Calculate required relief area.

$$A = \frac{W_m}{.953\,CP_1K_b}\sqrt{\frac{T_fZ}{M}} \quad \text{square inches}^1$$

7. Calculate maximum allowable back pressure for selected valve area.

$$\text{maximum } K_b = \frac{A}{\text{selected } A} \times K_b$$

Conventional valves: Iterate 5*a* to find *r*, then

$$\text{maximum back pressure} = (r\,P_1) - 14.7 \text{ PSIG}$$

Bellows valves:

$$\text{maximum back pressure} = \frac{P_{IN}\,(1.6 - .3e^{-.04}\,P_{IN} - \max K_b)}{1.18} \text{ PSIG}$$

Program 26: Nomenclature

A Relief area, square inches
A_w Wetted area, square feet

C	Specific heat ratio coefficient, dimensionless
D	Vessel diameter, feet
dHV	Latent heat of vaporization at flow conditions, Btu per pound
F	Environment factor, dimensionless
K_b	Back-pressure correction factor, dimensionless
k	Ratio of specific heats C_p/C_v, dimensionless
L	Vessel length, tangent to tangent, feet
M	Molecular weight, dimensionless
P_{IN}	Set pressure, PSIG
P_1	Relieving pressure ($P_{IN} \times 1.2 + 14.7$), PSIA
P_2	Back pressure, PSIA
r	Pressure ratio, dimensionless
T_f	Relief temperature, °R
W_m	Flow through valve, pounds per hour
Z	Compressibility factor, dimensionless

Literature Cited

1. API PR520, Part 1, *Design,* American Petroleum Institute, Fourth Edition, 1976.

Program 27
Relief Temperature and Latent Heat of Vaporization for Program 26: Pressure Relief Valve Sizing, Fire Conditions

This program will calculate the relief temperature and the latent heat of vaporization at relieving conditions for pure hydrocarbon liquids. Note that the pressure at relief conditions is 1.2 times the set pressure.

Program 27: User Instructions

a) Initiate program, press A.
b) Enter:
   1. Critical temperature of liquid, °R — Press R/S
   2. Critical pressure of liquid, PSIA — Press R/S
   3. Normal boiling point of liquid, °F — Press R/S
   4. Valve set pressure, PSIG — Press R/S
   5. The latent heat of vaporization at the normal boiling point, Btu per pound. — Press R/S

c) Program calculates the discharge temperature, °F, and the latent heat of vaporization at relief conditions, Btu per pound.

Program 27: TI 59 Data Sheet

```
********************

   RV  ΔHV   DSCH TEMP

********************


ENTR  CRIT TEMP    °R
          914.5
ENTR  CRIT PRSS PSIA
          439.7

ENTR NORM BOIL PT °F
          156.
ENTR    SET PRSS PSIG
          110.3
ENTR   NBP   ΔHV BTU/P
          144.2
CALC   DSCH TEMP    °F
  330.2050313
CALC    ΔHV BTU/P
  103.5475299

********************
```

Program 27: TI 59 Register Loading

PARTITIONING
479.59

0.	00	0.169347	29
0.	01	1.28862	30
0.	02	6.09648	31
0.	03	5.92714	32
0.	04	0.	33
0.	05	1437416333.	34
0.	06	31143300.	35
0.	07	33362422.	36
0.	08	361737.	37
0.	09	3337007321.	38
0.	10	1432242700.	39
0.	11	45.545352	40
0.	12	0.515244	41
0.	13	0.515049	42
0.	14	7321.463938	43
0.	15	7335.375036	44
0.	16	3542.355434	45
0.	17	3132353000.	46
0.	18	56.535243	47
0.	19	56.5434	48
0.08970251	20	33362413.	49
0.	21	33353636.	50
0.	22	15352437.	51
0.	23	37173033.	52
273.16	24	16361523.	53
0.43577	25	75234200.	54
13.4721	26	5151515151.	55
15.6875	27	1513271500.	56
15.2518	28	1731373500.	57
		0.	58
		0.	59

Program 27: TI 59 Listing

SUBROUTINES

PRINT & STORE VARIABLES

```
000   76  LBL
001   10  E'
002   29  CP
003   01   1
004   44  SUM
005   58   58
006   73  RC*
007   58   58
008   22  INV
009   59  INT
010   52  EE
011   22  INV
012   52  EE
013   67   EQ
014   19  D'
015   85   +
016   05   5
017   07   7
018   95   =
019   17  B'
020   69  OP
021   21   21
022   73  RC*
023   01   01
024   87  IFF
025   00   00
026   00   00
027   31   31
028   91  R/S
029   72  ST*
030   01   01
031   99  PRT
032   61  GTO
033   10  E'
```

PRINT LINES

```
034   76  LBL
035   19  D'
036   01   1
037   44  SUM
038   58   58
039   73  RC*
040   58   58
041   76  LBL
042   17  B'
043   42  STO
044   59   59
045   73  RC*
046   59   59
047   69  OP
048   01   01
049   18  C'
050   69  OP
051   02   02
052   18  C'
053   69  OP
054   03   03
055   18  C'
056   69  OP
057   04   04
058   69  OP
059   05   05
060   92  RTN
```

DECODE LINES

```
061   76  LBL
062   18  C'
063   01   1
064   00   0
065   00   0
066   48  EXC
067   59   59
068   22  INV
069   59  INT
070   49  PRD
071   59   59
072   73  RC*
073   59   59
074   92  RTN
```

PRINT LINE OF STARS

```
075   76  LBL
076   16  A'
077   93   .
078   00   0
079   01   1
080   08   8
081   35  1/X
082   98  ADV
083   17  B'
084   98  ADV
085   92  RTN
```

RE-ENTER VARIABLES

```
086   76  LBL
087   15   E
088   99  PRT
089   85   +
090   05   5
091   95   =
092   42  STO
093   01   01
094   73  RC*
095   01   01
096   91  R/S
097   72  ST*
098   01   01
099   99  PRT
100   98  ADV
101   86  STF
102   00   00
103   91  R/S
104   12   B
```

CALC f^0

```
105   76  LBL
106   38  SIN
107   53   (
108   43  RCL
109   32   32
110   75   -
111   53   (
112   43  RCL
113   31   31
114   55   ÷
115   43  RCL
116   17   17
117   54   )
118   75   -
119   53   (
120   43  RCL
121   17   17
122   23  LNX
123   65   ×
124   43  RCL
125   30   30
126   54   )
127   85   +
128   53   (
129   43  RCL
130   17   17
131   45  Yˣ
132   06   6
133   65   ×
134   43  RCL
135   29   29
136   54   )
137   54   )
138   92  RTN
```

CALC f^1

```
139   76  LBL
140   30  TAN
141   53   (
142   53   (
143   43  RCL
144   28   28
```

```
145  75   -
146  53   (
147  43  RCL
148  27   27
149  55   ÷
150  43  RCL
151  17   17
152  54   )
153  75   -
154  43  RCL
155  17   17
156  23  LNX
157  65   ×
158  43  RCL
159  26   26
160  54   )
161  85   +
162  53   (
163  43  RCL
164  17   17
165  45  YX
166  06   6
167  65   ×
168  43  RCL
169  25   25
170  54   )
171  54   )
172  92  RTN
```

CALC P FROM DATA

```
173  76  LBL
174  37  P/R
175  53   (
176  53   (
177  71  SBR
178  30  TAN
179  65   ×
180  43  RCL
181  22   22
182  85   +
183  71  SBR
184  38  SIN
185  54   )
186  22  INV
187  23  LNX
188  65   ×
189  43  RCL
190  03   03
191  54   )
192  92  RTN
```

CONVERGE T

```
193  76  LBL
194  47  CMS
195  53   (
196  53   (
197  53   (
198  53   (
199  53   (
200  43  RCL
201  11   11
202  75   -
203  43  RCL
204  12   12
205  54   )
206  55   ÷
207  53   (
208  43  RCL
209  13   13
210  75   -
211  43  RCL
212  14   14
213  54   )
214  54   )
215  65   ×
216  53   (
217  43  RCL
218  13   13
219  75   -
220  43  RCL
221  05   05
222  54   )
223  54   )
224  94  +/-
225  85   +
226  43  RCL
227  11   11
228  54   )
229  42  STO
230  12   12
231  55   ÷
232  43  RCL
233  02   02
234  54   )
235  42  STO
236  17   17
237  92  RTN
```

MAIN PROGRAM
ENTER DATA

```
238  76  LBL
239  11   A
240  05   5
241  42  STO
242  01   01
243  03   3
244  09   9
245  42  STO
246  58   58
247  16  A'
248  19  D'
249  16  A'
250  10  E'
251  22  INV
252  86  STF
253  00   00
```

CONVERT T_b

```
254  76  LBL
255  12   B
256  43  RCL
257  08   08
258  85   +
259  04   4
260  06   6
261  00   0
262  95   =
263  55   ÷
264  01   1
265  93   .
266  08   8
267  95   =
268  42  STO
269  04   04
```

CONVERT T_c

```
270  43  RCL
271  06   06
272  55   ÷
273  01   1
274  93   .
275  08   8
276  95   =
277  42  STO
278  02   02
```

CONVERT P_c

```
279  43  RCL
280  07   07
281  55   ÷
282  01   1
283  04   4
284  93   .
285  07   7
286  95   =
287  42  STO
288  03   03
```

CONVERT P

```
289  43  RCL
290  09   09
291  55   ÷
```

292	01	1
293	02	2
294	93	.
295	02	2
296	05	5
297	85	+
298	01	1
299	95	=
300	42	STO
301	05	05

CALC T_{rb}

302	76	LBL
303	13	C
304	93	.
305	00	0
306	01	1
307	32	X⇌T
308	43	RCL
309	04	04
310	55	÷
311	43	RCL
312	02	02
313	95	=
314	42	STO
315	17	17
316	42	STO
317	21	21

CALC ω

318	43	RCL
319	03	03
320	23	LNX
321	94	+/-
322	75	-
323	71	SBR
324	38	SIN
325	95	=
326	55	÷
327	71	SBR
328	30	TAN
329	95	=
330	42	STO
331	22	22

ESTIMATE T & P

332	43	RCL
333	05	05
334	55	÷
335	53	(
336	43	RCL
337	03	03
338	75	-
339	01	1
340	54	)
341	95	=
342	34	ΓX
343	65	×
344	53	(
345	43	RCL
346	02	02
347	75	-
348	43	RCL
349	04	04
350	54	)
351	85	+
352	43	RCL
353	04	04
354	95	=
355	42	STO
356	12	12
357	85	+
358	02	2
359	00	0
360	95	=
361	42	STO
362	11	11
363	55	÷
364	43	RCL
365	02	02
366	95	=
367	42	STO
368	17	17
369	71	SBR
370	37	P/R
371	42	STO
372	13	13
373	43	RCL
374	12	12
375	55	÷
376	43	RCL
377	02	02
378	95	=
379	42	STO
380	17	17
381	71	SBR
382	37	P/R
383	42	STO
384	14	14

ITERATE FOR T_r

385	76	LBL
386	44	SUM
387	71	SBR
388	47	CMS
389	71	SBR
390	37	P/R
391	42	STO
392	14	14
393	75	-
394	43	RCL
395	05	05
396	95	=
397	50	I×I
398	66	PAU
399	77	GE
400	44	SUM

CALC DISH TEMP

401	43	RCL
402	12	12
403	65	×
404	01	1
405	93	.
406	08	8
407	75	-
408	04	4
409	06	6
410	00	0
411	95	=
412	99	PRT

CALC dHV

413	43	RCL
414	48	48
415	17	B'
416	43	RCL
417	10	10
418	65	×
419	53	(
420	53	(
421	01	1
422	75	-
423	43	RCL
424	17	17
425	54	)
426	55	÷
427	53	(
428	01	1
429	75	-
430	43	RCL
431	21	21
432	54	)
433	54	)
434	77	GE
435	61	GTO
436	00	0
437	76	LBL
438	61	GTO
439	45	Y^X
440	93	.
441	03	3
442	07	7
443	08	8
444	95	=
445	99	PRT
446	32	X⇌T
447	16	A'
448	98	ADV
449	32	X⇌T
450	91	R/S

Program 27: HP 41CV Data Sheet

```
************

RV dHV +TEMP

************

ENTER CRIT TEMP DEG R
        914.5     ***
ENTER CRIT PRSS PSIA
        439.7     ***
ENTER NORM BOIL PT DEG F
        156.0     ***
ENTER RV SET PRSS PSIG
        110.3     ***
ENTER NORM BP dHV  BTU/P
        144.2     ***
CALC  RV DIS
CH TEMP DEGF
        330.2     ***
CALC  RV DIS
CH dHV BTU/P
        103.5     ***

************
```

Program 27: HP 41CV Register Loading

SIZE 080

```
R00=  0.000000
R01=  0.000000
R02=  0.000000
R03=  0.000000
R04=  0.000000
R05=  0.000000
R06=  0.000000
R07=  0.000000
R08=  0.000000
R09=  0.000000
R10=  0.000000
R11=  0.000000
R12=  0.000000
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  0.000000
R17=  0.000000
R18=  0.000000
R19=  0.000000
R20=  0.000000
R21=  0.000000
R22=  0.000000
R23=  0.000000
R24=  0.000000
R25= "RV dHV"
R26= " +TEMP"
R27=  0.000000
R28=  0.000000
R29=  0.000000
R30=  25.260000
R31=  57.505152
R32=  57.535460
R33=  57.616263
R34=  57.646566
R35=  57.616869
R36=  0.000000
R37=  56.707172
R38=  56.707369
R39=  0.000000
R40=  0.000000
R41=  0.000000
R42=  0.000000
R43=  0.000000
R44=  0.000000
R45=  0.000000
R46=  0.000000
R47=  0.000000
R48=  0.000000
R49=  0.000000
R50= "CRIT T"
R51= "EMP DE"
R52= "G R   "
R53= "CRIT P"
R54= "RSS PS"
R55= "******"
R56= "CALC  "
R57= "ENTER "
R58=  38.000000
R59=  0.000000
R60= "IA    "
R61= "NORM B"
R62= "OIL PT"
R63= " DEG F"
R64= "RV SET"
R65= " PRSS "
R66= "PSIG  "
R67=  0.000000
R68= "P dHV "
R69= " BTU/P"
R70= "RV DIS"
R71= "CH TEM"
R72= "P DEGF"
R73= "CH dHV"
R74=  0.000000
R75=  0.000000
R76=  0.000000
R77=  0.000000
R78=  0.000000
R79=  0.000000
```

Program 27: HP 41CV Listing

SUBROUTINES

```
01♦LBL "dHV+T"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
```

```
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 GTO d
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53♦LBL 01
54 XEQ J
55 GTO e
```

RE-ENTER VARIABLES

```
56♦LBL "REENTER"
57 ADV
58 5
59 +
60 STO 01
61 RCL IND 01
62 XEQ J
63 STOP
64 XEQ J
65 STO IND 01
66 ADV
67 SF 02
68 STOP
69 GTO B
```

BYPASS PRINTER

```
70♦LBL J
71 FC? 55
72 GTO 01
73 PRX
74 RTN
75♦LBL 01
76 VIEW X
77 RTN
```

CALC f^0

```
78♦LBL G
79 6.09648
80 RCL 17
81 /
82 CHS
83 5.92714
84 +
85 RCL 17
86 LN
87 1.28862
88 *
89 -
90 RCL 17
91 6
92 Y↑X
93 .169347
94 *
95 +
96 RTN
```

CALC f^1

```
97♦LBL D
98 15.6875
99 RCL 17
100 /
101 CHS
102 15.2518
103 +
104 RCL 17
105 LN
106 13.4721
107 *
108 -
109 RCL 17
110 6
111 Y↑X
112 .43577
113 *
114 +
115 RTN
```

CALC P

```
116♦LBL E
117 XEQ D
118 RCL 22
119 *
120 XEQ G
121 +
122 E↑X
123 RCL 03
124 *
125 RTN
```

CONVERGE T

```
126♦LBL F
127 RCL 11
128 RCL 12
129 -
130 RCL 13
131 RCL 14
132 -
133 /
134 RCL 13
135 RCL 05
136 -
137 *
138 CHS
139 RCL 11
140 +
141 STO 12
142 RCL 02
143 /
144 STO 17
145 RTN
```

MAIN PROGRAM ENTER DATA

```
146♦LBL A
147 5
148 STO 01
149 29
150 STO 58
151 FS? 02
152 SF 00
153 CF 02
154 XEQ a
155 XEQ d
156 XEQ a
157 XEQ e
```

CONVERT T_b

```
158♦LBL B
159 37
160 STO 58
161 RCL 08
162 460
163 +
164 1.8
165 /
166 STO 04
```

CONVERT T_c

```
167 RCL 06
168 1.8
169 /
170 STO 02
```

CONVERT P_c

```
171 RCL 07
172 14.7
173 /
174 STO 03
```

CONVERT P

```
175 RCL 09
176 12.25
177 /
```

```
178 1
179 +
180 STO 05
```

CALC T_{rb}

```
181♦LBL C
182 RCL 04
183 RCL 02
184 /
185 STO 17
186 STO 21
```

CALC ω

```
187 RCL 03
188 LN
189 CHS
190 XEQ G
191 -
192 XEQ D
193 /
194 STO 22
```

ESTIMATE T & P

```
195 RCL 05
196 RCL 03
197 1
198 -
199 /
200 SQRT
201 RCL 02
202 RCL 04
203 -
204 *
205 RCL 04
206 +
207 STO 12
208 20
209 +
210 STO 11
211 RCL 02
212 /
213 STO 17
214 XEQ E
215 STO 13
216 RCL 12
217 RCL 02
218 /
219 STO 17
220 XEQ E
221 STO 14
```

ITERATE FOR DISCH TEMP

```
222♦LBL H
223 XEQ F
224 XEQ E
225 STO 14
226 RCL 05
227 -
228 ABS
229 PSE
230 .01
231 X<>Y
232 X>Y?
233 GTO H
234 RCL 12
235 1.8
236 *
237 460
238 -
239 STO 27
240 XEQ J
```

CALC dHV

```
241 XEQ d
242 1
243 RCL 17
244 -
245 1
246 RCL 21
247 -
248 /
249 .01
250 X<>Y
251 X>Y?
252 GTO 01
253 0
254♦LBL 01
255 .378
256 Y↑X
257 RCL 10
258 *
259 STO 28
260 XEQ J
261 FS? 02
262 STOP
263 CF 00
264 XEQ a
265 RCL 27
266 RCL 28
267 VIEW X
268 BEEP
269 ADV
270 STOP
271 .END.
```

Program 27: Sequence of Calculations

This program calculates relief temperature using the Lee and Kesler relationship for single-component liquids.

1. Iterate to find reduced temperature T_r.[1]

$$\ln P_r = f^{\circ}T_r + \omega f^{1}T_r$$

where

$$f^{\circ} = 5.92174 - \frac{6.09648}{T_r} - 1.28862 \ln T_r + .16934T_r^6$$

$$f^1 = 15.2518 + \frac{15.6875}{T_r} - 13.4721 \ln T_r + .43577 T_r^6$$

$$\omega = \frac{-\ln P_c - f_b^\circ}{f_b^1}$$

Estimate

$$T_H = \sqrt{\frac{P}{(P_c - 1)}}\,(T_c - \mathrm{T}zb) + T_b + 20$$

If calculated P (which is equal to $P_c e(\omega f^1 + f^\circ)$) differs from entered P by more than .01, subtract

$$\left(\frac{T_H - T_{\text{iterated}}}{P_H - P_{\text{iterated}}}\right)(P_H - P)$$

from estimated T_H and repeat until the error is less than .01.

2. Calculate the discharge temperature.

$$T = 1.8\, T_r T_c - 460°\mathrm{F}$$

Calculate the latent heat of vaporization using the Watson correlation for single-component liquids.[2]

$$dHV = dHV_b \left(\frac{1 - T_r}{1 - T_{rb}}\right)^{.378} \quad \text{Btu per pound}$$

Program 27: Nomenclature

dHV	Latent heat of vaporization at relief conditions, Btu per pound
dHV_b	Latent heat of vaporization at normal boiling point, Btu per pound
f°	Function calculated at relief temperature, dimensionless
f^1	Function calculated at relief temperature, dimensionless
f_b°	Function calculated at normal boiling point, dimensionless
f_b^1	Function calculated at normal boiling point, dimensionless
P	Relief pressure (set pressure × 1.2 + 1), atmospheres
P_H	Pressure corresponding to T_H in iterative calculation
P_c	Critical pressure, atmospheres
P_r	Reduced pressure, dimensionless
T	Relief temperature, °F
T_b	Normal boiling point, °K

T_c	Critical temperature, °K
T_H	Starting point to iterate T
T_r	Reduced relief temperature $(T + 460)/1.8T$, dimensionless
T_{rb}	Reduced normal boiling point temperature T_b/T_c, dimensionless
ω	Acentricity factor, dimensionless

Note that these units differ from those entered into the calculator. The program converts as necessary.

Literature Cited

1. Lee, B. I., and Kesler, M. G., *AIChE J.*, Vol. 21, 1975, p. 510.
2. Watson, K. M., *Ind. Eng. Chem.*, Vol. 25, 1943, p. 398.

Program 28
Pressure Relief Valves, Fire Sizing—Gas or Vapor Expansion

Program 26 calculated the size required for vessels containing liquids; this program is for vessels containing gases. The quantity of vessels and their wetted areas are arrived at in the same way as described for program 26.

There is an inherent pitfall in the sizing technique used here. If close attention is not paid to the ratio of accumulated pressure to operating pressure, the vessel is likely to fail because of overtemperature rather than overpressure. The program will print the discharge temperature as a guide. The discharge temperature is calculated by the ideal gas law and should be limited to something less than the maximum metal temperature by lowering the set pressure.

Program 28: User Instructions

a) Initiate program, press A.
b) Enter:
   1. Quantity of vessels exposed to fire — Press R/S
   2. First vessel diameter, feet — Press R/S
   3. First vessel length (tangent to tangent), feet — Press R/S
   4. First vessel fraction of wetted part, dimensionless (i.e. half full = .5, full = 1) — Press R/S

   Program will loop back to 2 to pick up vessel data for the quantity of vessels entered in 1 and then continue.

5. One (1) if the valve is to be a bellows type, any other number if not — Press R/S
6. Valve set pressure, PSIG — Press R/S
7. Operating pressure, PSIG — Press R/S
8. Back pressure before valve opens, PSIG — Press R/S
9. Operating temperature, °F — Press R/S
10. Maximum allowable metal temperature, °F — Press R/S
11. Ratio of specific heats C_p/C_v, dimensionless — Press R/S
12. Molecular weight, dimensionless — Press R/S

c) Program calculates flowrate caused by gas expansion, pounds per hour; relief temperature, °F; and relief area required, square inches.

d) Enter:

13. Selected valve area, square inches — Press R/S

e) Program calculates the maximum back pressure which maintains flow at relief conditions.

Typical allowable maximum metal temperatures are:

Carbon steel	1100°F
304SS and 316SS	1500°F
Inconel	1300°F
Monel	1000°F
T6 Aluminum	400°F

Program 28: TI 59 Data Sheet

```
********************

 FIRE   RV  GAS EXPN

********************

ENTR QUAN VESSL
          2.
ENTR VESSL  DIA   FT
          8.
ENTR LNGTH    FT
         15.
ENTR WETTD PART
        0.2

ENTR VESSL  DIA   FT
          8.

ENTR LNGTH    FT
         15.
ENTR WETTD PART
        0.8
ENTR 1 FOR BLWS VALV
          0.
ENTR     SP PSIG
        150.
ENTR     OP PSIG
        120.
ENTR     BP PSIG
          2.
ENTR   OP TMP °F
        200.
ENTR    MX MTL TMP °F
       1100.
ENTR CP/CV
       0.93
```

```
ENTR     MW
         44.
CALC   GAS EXPN  PPH
 8437.304461
CALC RLF TMP °F
  493.986637
CALC   AREA   IN²
 .6894331302
```

```
ENTR   VALV AREA   IN²
         0.785
CALC    MX     BP PSIG
  142.925073

*******************
```

Program 28: TI 59 Register Loading

PARTITIONING
479.59

0.	00	42.473941	29
0.	01	3043.5453	30
0.	02	3233.53384	31
0.	03	333323.524	32
0.	04	304400.515	33
0.	05	42132742.	34
0.	06	3633.484334	35
0.	07	243170.3528	36
0.	08	1433.3128	37
0.	09	162413.3728	38
0.	10	221336.2726	39
0.	11	2137.332526	40
0.	12	17443331.22	41
0.	13	21243517.3	42
.0002834677	14	14274336.	43
0.	15	56.394132	44
0.6506	16	56.2426	45
0.	17	56.2336	46
1.413461538	18	3542.342336	47
0.	19	200213235.	48
0.	20	56.333728	49
0.	21	33133537.	50
1533631542.	22	4317373716.	51
13351713.	23	2731223723.	52
3527210037.	24	4217363627.	53
3037270037.	25	3441133100.	54
3033007321.	26	5151515151.	55
32330037.	27	1513271500.	56
33362422.	28	1731373500.	57
		0.	58
		0.	59

Program 28: TI 59 Listing

SUBROUTINES

```
000  53  (
001  53  (
002  13  C
003  65  ×
004  53  (
005  43  RCL
006  12  12
007  45  Yˣ
008  53  (
009  02  2
010  55  ÷
011  43  RCL
012  09  09
013  54  )
014  75  -
015  43  RCL
016  12  12
017  45  Yˣ
018  53  (
019  53  (
020  43  RCL
021  09  09
022  85  +
023  01  1
```

```
024  54  )
025  55  ÷
026  43  RCL
027  09  09
028  54  )
029  54  )
030  54  )
031  34  ΓX
032  65  ×
033  43  RCL
034  18  18
035  55  ÷
036  71  SBR
037  24  CE
038  54  )
039  92  RTN
```

CALC K_b BELLOWS

```
040  53  (
041  01  1
042  93  .
043  06  6
044  75  -
045  93  .
046  03  3
047  55  ÷
048  53  (
049  93  .
050  00  0
051  04  4
052  65  ×
053  43  RCL
054  04  04
055  54  )
056  22  INV
057  23  LNX
058  75  -
059  01  1
060  93  .
061  01  1
062  08  8
063  65  ×
064  43  RCL
065  12  12
066  54  )
067  92  RTN
```

CALC P_1

```
068  76  LBL
069  15  E
070  53  (
071  01  1
072  04  4
073  93  .
074  07  7
075  85  +
076  01  1
077  93  .
078  02  2
079  65  ×
080  43  RCL
081  04  04
082  54  )
083  92  RTN
```

PRINT & STORE VARIABLES

```
084  76  LBL
085  10  E'
086  29  CP
087  01  1
088  44  SUM
089  58  58
090  73  RC*
091  58  58
092  22  INV
093  59  INT
094  52  EE
095  22  INV
096  52  EE
097  67  EQ
098  52  EE
099  85  +
100  05  5
101  07  7
102  95  =
103  17  B'
104  69  OP
105  21  21
106  73  RC*
107  01  01
108  91  R/S
109  72  ST*
110  01  01
111  99  PRT
112  61  GTO
113  10  E'
```

PRINT LINES

```
114  76  LBL
115  19  D'
116  01  1
117  44  SUM
118  58  58
119  73  RC*
120  58  58
121  76  LBL
122  17  B'
123  42  STO
124  59  59
125  73  RC*
126  59  59
127  69  OP
128  01  01
129  18  C'
130  69  OP
131  02  02
132  18  C'
133  69  OP
134  03  03
135  18  C'
136  69  OP
137  04  04
138  69  OP
139  05  05
140  92  RTN
```

DECODE LINES

```
141  76  LBL
142  18  C'
143  01  1
144  00  0
145  00  0
146  48  EXC
147  59  59
148  22  INV
149  59  INT
150  49  PRD
151  59  59
152  73  RC*
153  59  59
154  92  RTN
```

PRINT LINE OF STARS

```
155  76  LBL
156  16  A'
157  93  .
158  00  0
159  01  1
160  08  8
161  35  1/X
162  98  ADV
163  17  B'
164  98  ADV
165  92  RTN
```

CALC

```
166  76  LBL
167  24  CE
168  53  (
169  01  1
170  93  .
171  02  2
172  01  1
173  03  3
174  75  -
175  12  B
176  54  )
177  92  RTN
```

CALC r

```
178   76  LBL
179   12   B
180   53   (
181   53   (
182   02   2
183   55   ÷
184   53   (
185   43  RCL
186   09   09
187   85   +
188   01   1
189   54   )
190   54   )
191   45  Yˣ
192   13   C
193   54   )
194   92  RTN
```

CALC T_1

```
195   76  LBL
196   13   C
197   53   (
198   43  RCL
199   09   09
200   55   ÷
201   53   (
202   24  CE
203   75   -
204   01   1
205   54   )
206   54   )
207   92  RTN
```

CALC T_1

```
208   76  LBL
209   14   D
210   53   (
211   15   E
212   55   ÷
213   43  RCL
214   05   05
215   65   ×
216   43  RCL
217   07   07
218   54   )
219   92  RTN
```

MAIN PROGRAM
ENTER DATA

```
220   76  LBL
221   11   A
226   17   17
227   42  STO
228   20   20
229   86  STF
230   00   00
231   01   1
232   42  STO
233   01   01
234   02   2
235   08   8
236   42  STO
237   58   58
238   16  A'
239   19  D'
240   16  A'
241   61  GTO
242   10  E'
```

CALC WETTED AREA

```
243   76  LBL
244   52  EE
245   22  INV
246   87  IFF
247   00   00
248   19  D'
249   04   4
250   22  INV
251   44  SUM
252   58   58
253   03   3
254   22  INV
255   44  SUM
256   01   01
257   43  RCL
258   03   03
259   65   ×
260   53   (
261   43  RCL
262   03   03
263   85   +
264   43  RCL
265   04   04
266   54   )
267   65   ×
268   43  RCL
269   05   05
270   65   ×
271   89   π
272   95   =
273   44  SUM
274   19   19
275   98  ADV
276   97  DSZ
277   02   02
278   10  E'
279   04   4
280   44  SUM
281   58   58
282   22  INV
283   86  STF
284   00   00
285   10  E'
286   01   1
287   04   4
288   93   .
289   07   7
290   44  SUM
291   05   05
292   04   4
293   06   6
294   00   0
295   44  SUM
296   07   07
297   44  SUM
298   08   08
```

CALC K_b

```
299   01   1
300   32  X⇌T
301   43  RCL
302   03   03
303   67   EQ
304   67   EQ
305   01   1
306   05   5
307   44  SUM
308   06   06
309   42  STO
310   17   17
311   07   7
312   00   0
313   61  GTO
314   32  X⇌T
315   76  LBL
316   67   EQ
317   04   4
318   00   0
319   42  STO
320   20   20
321   08   8
322   00   0
```

CALC r

```
323   76  LBL
324   32  X⇌T
325   42  STO
326   21   21
```

```
327  43  RCL
328  06   06
329  55   ÷
330  71  SBR
331  40  IND
332  21   21
333  95   =
334  32  X:T
335  71  SBR
336  12   B
337  42  STO
338  12   12
339  77   GE
340  42  STO
341  01   1
342  32  X:T
343  42  STO
344  12   12
```

CALC K_b

```
345  71  SBR
346  40  IND
347  20   20
348  22  INV
349  77   GE
350  43  RCL
351  76  LBL
352  42  STO
353  01   1
354  76  LBL
355  43  RCL
356  42  STO
357  13   13
```

CALC FLOW

```
358  93   .
359  00   0
360  01   1
361  32  X:T
362  43  RCL
363  08   08
364  75   -
365  14   D
366  95   =
367  45  Y×
368  93   .
369  08   8
370  35  1/X
371  55   ÷
372  14   D
373  45  Y×
374  43  RCL
375  16   16
376  65   ×
377  43  RCL
378  14   14
379  55   ÷
380  71  SBR
381  24  CE
382  95   =
383  77   GE
384  34  √X
385  32  X:T
386  76  LBL
387  34  √X
388  65   ×
389  43  RCL
390  19   19
391  55   ÷
392  15   E
393  34  √X
394  55   ÷
395  43  RCL
396  13   13
397  95   =
398  42  STO
399  15   15
400  65   ×
401  71  SBR
402  24  CE
403  65   ×
404  15   E
405  65   ×
406  43  RCL
407  13   13
408  65   ×
409  43  RCL
410  10   10
411  34  √X
412  55   ÷
413  14   D
414  34  √X
415  65   ×
416  04   4
417  09   9
418  06   6
419  95   =
420  99  PRT
```

CALC DISCH TEMP

```
421  19  D'
422  14   D
423  75   -
424  04   4
425  06   6
426  00   0
427  95   =
428  99  PRT
429  19  D'
430  43  RCL
431  15   15
432  49  PRD
433  13   13
434  99  PRT
```

CALC MAX BACKPRES

```
435  10  E'
436  43  RCL
437  11   11
438  22  INV
439  49  PRD
440  13   13
441  76  LBL
442  35  1/X
443  43  RCL
444  14   14
445  32  X:T
446  71  SBR
447  40  IND
448  20   20
449  75   -
450  43  RCL
451  13   13
452  95   =
453  55   ÷
454  03   3
455  95   =
456  44  SUM
457  12   12
458  66  PAU
459  50  I×I
460  77   GE
461  35  1/X
462  43  RCL
463  12   12
464  65   ×
465  71  SBR
466  40  IND
467  21   21
468  75   -
469  43  RCL
470  17   17
471  95   =
472  99  PRT
473  16  A'
474  43  RCL
475  15   15
476  98  ADV
477  98  ADV
478  91  R/S
```

Program 28: HP 41CV Data Sheet

```
************

RV FIRE GAS

************


ENTER QUANT VESSL
         2.0000    ***
ENTER VESSL DIA FT
         8.0000    ***
ENTER LENGTH FT
        15.0000    ***
ENTER WETTED PART
         0.2000    ***

ENTER VESSL DIA FT
         8.0000    ***
```

```
ENTER LENGTH FT
        15.0000    ***
ENTER WETTED PART
         0.8000    ***

ENTER 1 FOR BELLWS VALVE
         0.0000    ***
ENTER SET PRESS PSIG
       150.0000    ***
ENTER OPER PRESS PSIG
       120.0000    ***
ENTER BACK PRESS PSIG
         2.0000    ***
ENTER OPER TEMP DEGF
       200.0000    ***
ENTER MAX METAL TMP DEGF
     1,100.0000    ***
ENTER CP/CV
         0.9300    ***
```

```
ENTER MW
        44.0000    ***
CALC    FLOW
PPH
    8,437.3045     ***
CALC  DISCH
TEMP  DEGF
       493.9866    ***
CALC    AREA
SQ  INS
         0.6900    ***
ENTER  VALVE AREA SQ INS
         0.7850    ***
CALC   MAX BK
CK PRSS PSIG
       143.0310    ***


************
```

Program 28: HP 41CV Register Loading

SIZE 080

```
R00=  0.000000
R01=  0.000000
R02=  0.000000
R03=  0.000000
R04=  0.000000
R05=  0.000000
R06=  0.000000
R07=  0.000000
R08=  0.000000
R09=  0.000000
R10=  0.000000
R11=  0.000000
R12=  0.000000
R13=  0.000000
R14=  0.000000
R15=  0.000000
R16=  0.000000
R17=  0.000000
R18=  0.000000
R19=  0.000000
R20=  0.000000
R21=  0.000000
R22=  0.000000
R23=  0.000000
R24= "CK PRS"
R25= "RV FIR"
R26= "E GAS"
R27= "QUANT "
R28= "VESSL "
R29= "DIA FT"
R30=  25.260000
R31=  57.272800
R32=  57.282900
R33=  57.515200
R34=  57.535400
R35=  0.000000
R36=  57.606162
R37=  57.676869
R38=  57.636869
R39=  57.746869
R40=  57.637266
R41=  57.646566
R42=  57.750000
R43=  57.760000
R44=  0.000000
R45=  56.777800
R46=  56.717266
R47=  56.797300
R48=  57.627973
R49=  0.000000
R50=  56.702469
R51= "LENGTH"
R52= " FT   "
R53= "WETTED"
R54= " PART "
R55= "******"
R56= "CALC  "
R57= "ENTER "
R58=  50.000000
R59=  0.000000
R60= "1 FOR "
R61= "BELLWS"
R62= " VALVE"
R63= "OPER "
R64= "MAX ME"
R65= "TAL TM"
R66= "P DEGF"
R67= "SET "
R68= "PRES"
R69= "S PSIG"
R70= "MAX BK"
R71= "DISCH "
R72= "TEM"
R73= "SQ INS"
R74= "BACK "
R75= "CP/CV "
R76= "MW    "
R77= " FLOW "
R78= "PPH   "
R79= " AREA "
```

Program 28: HP 41CV Listing

SUBROUTINES

```
01♦LBL "RVFREGS"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 RTN
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53♦LBL 01
54 XEQ J
55 GTO e
```

RE-ENTER VARIABLES

```
56♦LBL "REENT
57 ADV
58 2
59 -
60 STO 01
61 RCL IND 01
62 XEQ J
63 STOP
64 XEQ J
65 STO IND 01
66 ADV
67 SF 02
68 STOP
69 GTO E
```

BYPASS PRINTER

```
70♦LBL J
71 FC? 55
72 GTO 01
73 PRX
74 RTN
75♦LBL 01
76 VIEW X
77 RTN
```

CALC P_1

```
78♦LBL F
79 RCL 04
80 1.2
81 *
82 14.7
83 +
84 RTN
```

CALC K_b

```
85♦LBL G
86 RCL 16
87 RCL 19
88 Y↑X
89 RCL 16
90 RCL 20
91 Y↑X
92 -
93 RCL 22
94 *
95 SQRT
96 735
97 *
98 XEQ H
99 /
100 RTN
```

CALC C

```
101♦LBL H
102 XEQ B
103 CHS
104 1.213
105 +
106 520
107 *
108 RTN
```

REPRINT

```
109♦LBL B
110 2
111 RCL 09
112 1
113 +
114 /
115 RCL 22
116 Y↑X
117 RTN
```

MAIN PROGRAM ENTER DATA

```
118♦LBL "AA"
119 2
120 STO 01
121 35
122 STO 58
123 56.285379
124 XEQ b
125 RCL 02
126 XEQ J
127 XEQ e
128 GTO E
129♦LBL A
130 FS? 02
131 SF 00
132 CF 02
133 1
134 STO 01
135 29
136 STO 58
137 XEQ a
138 XEQ d
139 XEQ a
140 FS? 00
141 GTO "AA"
142 0
143 STO 06
```

CALC WETTED AREA

```
144♦LBL "AB"
145 XEQ e
146 ADV
147 2
148 STO 01
149 31
150 STO 58
151 RCL 03
152 RCL 04
153 +
154 RCL 03
155 *
156 RCL 05
157 *
158 PI
159 *
160 ST+ 06
161 DSE 02
162 GTO "AB"
```

ENTER DATA

```
163 RCL 06
164 STO 02
165 2
166 STO 01
167 35
168 STO 58
169 XEQ e
170♦LBL E
171 10
172 STO 01
173 44
174 STO 58
175 RCL 09
176 RCL 09
177 1
178 -
179 /
180 STO 22
```

CALC (k + 1)/k

```
181 RCL 09
182 1
183 +
184 RCL 09
185 /
186 STO 20
```

CALC 2/k

```
187 2
188 RCL 09
189 /
190 STO 19
```

CALC $_r$

```
191 RCL 03
192 1
193 X=Y?
194 GTO 01
195 RCL 06
196 14.7
197 +
198 XEQ F
199 /
200 STO 23
201 XEQ B
202 STO 16
203 STO 21
204 RCL 23
205 X<>Y
206 X>Y?
207 GTO 03
208 RCL 23
209 STO 16
```

CALC K_b

```
210 XEQ G
211 GTO 02
212♦LBL 01
213 RCL 04
214 -.04
215 *
216 E↑X
217 -.3
218 *
219 1.6
220 +
221 STO 17
222 RCL 06
223 RCL 04
224 /
225 1.18
226 *
227 -
228♦LBL 02
229 1
230 X<>Y
231 X<=Y?
232 GTO 01
233♦LBL 03
234 1
235♦LBL 01
236 STO 13
```

CALC T_1

```
237 XEQ F
238 RCL 05
239 14.7
240 +
241 /
242 RCL 07
243 460
244 +
245 *
246 STO 12
```

CALC A

```
247 RCL 08
248 RCL 12
249 -
250 460
251 +
252 0
253 X<>Y
254 X<=Y?
255 GTO 05
256 1.25
257 Y↑X
258 RCL 12
259 .6506
260 Y↑X
261 /
262 .1406
263 *
264 .953
265 /
266 XEQ H
267 /
268 .01
269 X<=Y?
270 RDN
271 RCL 02
272 *
273 XEQ F
274 SQRT
275 /
276 STO 14
```

CALC FLOW

```
277 RCL 10
278 RCL 12
279 /
280 SQRT
281 .953
282 *
283 RCL 14
284 *
285 XEQ H
286 *
287 XEQ F
288 *
289 RCL 13
290 *
291 STO 00
```

PRINT FLOW

```
292 XEQ d
293 RCL 00
294 XEQ J
```

```
295 XEQ d
296 RCL 12
297 460
298 -
299 XEQ J
300 XEQ d
301 RCL 14
302 XEQ J
```

ENTER VALVE SIZE

```
303 XEQ e
```

CALC BACKPRES CONV VALVE

```
304 XEQ d
305 RCL 21
306 STO 16
307 RCL 14
308 RCL 11
309 /
310 RCL 13
311 *
312 STO 15
313 1
314 RCL 03
315 X≠Y?
316 GTO C
317 RCL 17
318 RCL 15
319 -
320 1.18
321 /
322 RCL 04
323 *
324 GTO I
```

BELLOWS VALVE

```
325♦LBL C
326 RCL 21
327 1
328 +
329 SQRT
330 ST* 16
331 XEQ G
332 RCL 15
333 -
334 PSE
335 STO 21
336 ABS
337 .001
338 X<>Y
339 X>Y?
340 GTO C
341 RCL 16
342 XEQ F
343 *
344 14.7
345 -
```

COMMON ENDING

```
346♦LBL I
347 STO 18
348 XEQ J
349 FS? 02
350 STOP
351 CF 00
352 XEQ a
353 RCL 14
354 VIEW X
355 BEEP
356 ADV
357 STOP
```

DISCH TEMP TOO HIGH

```
358♦LBL 05
359 64.6566
360 XEQ b
361 RCL 08
362 XEQ J
363 RCL 46
364 XEQ b
365 RCL 12
366 460
367 -
368 GTO I
369 END
```

Program 28: Sequence of Calculations

1. Calculate wetted area.

$$A_w = \pi \times D(D + L) \text{ square feet}$$

2. Calculate pressure ratio.[1]

$$r = \frac{P_2}{P_1} \text{ limited to a minimum of } \left(\frac{2}{k+1}\right)^{k/(k-1)}$$

3. Calculate the specific heat ratio coefficient.[1]

$$C = 520\sqrt{k\left(\frac{2}{k+1}\right)^{(k+1)/(k-1)}} = 520\,(1.213 - r)$$

4. Calculate the back-pressure correction factor.

Conventional valves:[1]

$$K_b = \frac{735F_2}{C}\sqrt{1 - r}$$

where

$$F_2 = \sqrt{\left(\frac{k}{k-1}\right)^{r^{2/k}} \left(\frac{1 - (r^{(k-1)/k})}{1 - r}\right)}$$

Bellows valves:

$$K_b = 1.6 - .3e^{-.04P_{IN}} - 1.18r$$

5. Calculate relief temperature.[1]

$$T_f = \frac{P_1}{(P_n + 14.7)}(T_n + 460)\ °\text{R}$$

6. Calculate relief valve factor F^1.

$$F^1 = \frac{.1406}{.953C}\left(\frac{(T_w - T_f)^{1.25}}{T_f^{.6506}}\right)$$

7. Calculate required relief area.[1]

$$A = \frac{F^1 A_w}{\sqrt{P_1}} \quad \text{square inches}$$

8. Calculate flow.[1]

$$W_m = .953\,ACP_1K_b\sqrt{\frac{M}{T_f}} \quad \text{pounds per hour}$$

9. Calculate maximum allowable back pressure for selected valve area.

$$\text{maximum } K_b = \frac{A}{\text{selected } A} \times K_b$$

Conventional valves: Iterate 5a to find r, then

$$\text{maximum back pressure} = (r \times P_1) - 14.7 \text{ PSIG}$$

Bellows valves:

$$\text{maximum back pressure} = \frac{P_{IN}\,(1.6 - .3e^{-.04}\,P_{IN}) - \text{maximum } K_b}{1.18} \text{ PSIG}$$

Program 28: Nomenclature

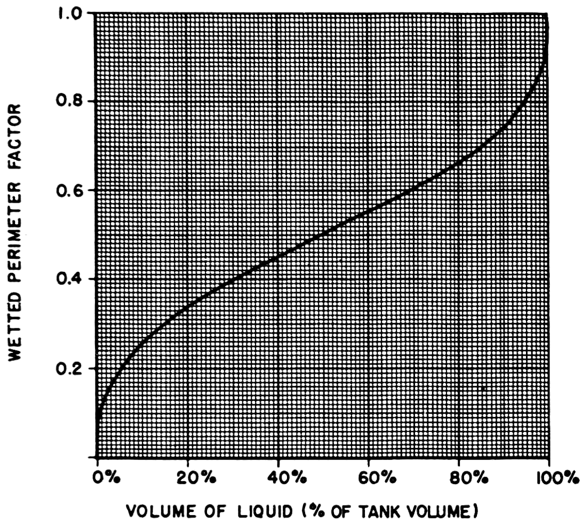
A	Relief area, square inches
A_w	Wetted area, square feet
C	Specific heat ratio coefficient, dimensionless
D	Vessel diameter, feet
F^1	Relief valve factor, dimensionless
K_b	Back-pressure correction factor, dimensionless
k	Ratio of specific heats C_p/C_v, dimensionless
L	Vessel length, feet
M	Molecular weight, dimensionless
P_1	Relieving pressure (set pressure × 1.2 + 14.7) PSIA
P_2	Back pressure, PSIA
P_{IN}	Set pressure, PSIG
P_n	Normal operating pressure, PSIG
r	Pressure ratio, dimensionless
T_f	Relief temperature, °R
T_n	Normal operating temperature, °F
T_w	Maximum allowable vessel metal temperature, °F
W_m	Flow through valve, pounds per hour

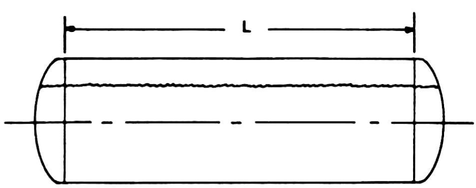
Literature Cited

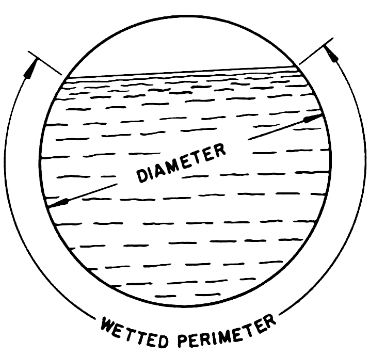
1. API RP520, Part 1, *Design,* American Petroleum Institute, Fourth Edition, 1976.

Typical Data

Wetted Perimeter Factor vs. Volume of Liquid





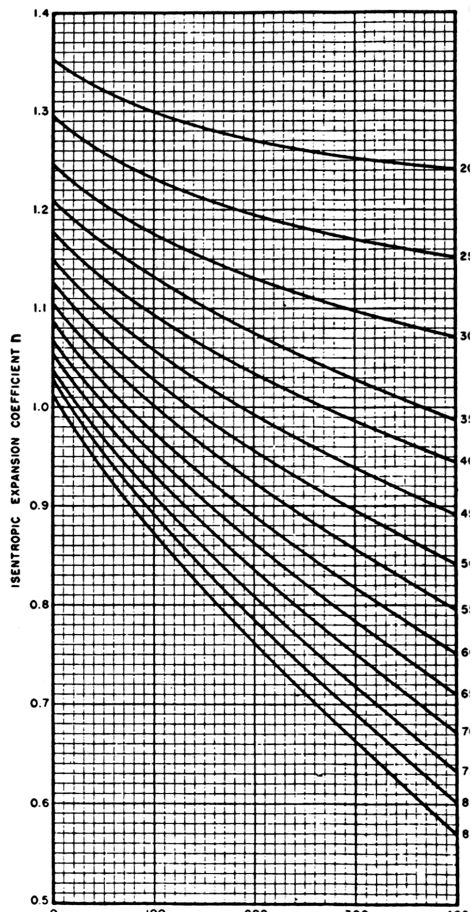


Use of Isentropic Coefficient in Flow Formula for Determining Capacity of Safety-Relief Valves*

Formula 1 provides a convenient means for determining the flow of gas through a safety-relief valve between any given upstream pressure and the critical-flow pressure in the throat of the nozzle. The derivation of the formula is based on the Perfect Gas Laws in which it is assumed that the flow is adiabatic and reversible. In other words, it is assumed that the gas neither gains nor loses heat and that the energy of expansion is converted into kinetic energy. With the exception of a few diatomic gases, a gas that expands in accordance with the Perfect Gas Laws is rarely encountered in refinery practice. The deviation from the Perfect Gas Laws becomes greater as the actual gas approaches a condition of saturation, which is the usual condition for safety-relief valves in refinery service.

The flow of actual gases is complicated because the isentropic coefficient varies throughout the expansion, whereas for an ideal gas the isentropic expansion coefficient remains constant. Consequently, for actual gases, an isentropic coefficient can be used based on an average value between the upstream pressure and the pressure in the throat of the nozzle which, in the case of maximum flow, is the critical-flow pressure. This has been done for the lighter hydrocarbons, as shown in this figure. The chart gives average values of the isentropic coefficient for various molecular weights of paraffin hydrocarbons expanding through an orifice or nozzle of a safety-relief valve in which the upstream pressure is at saturation and the pressure in the throat of the orifice or nozzle is the critical-flow pressure. The letter *n* is used for the isentropic coefficient of the actual gas to distinguish it from *k*, the isentropic coefficient of an ideal gas which is equal to the ratio of specific heats C_p/C_v.

$$W = CKAP_1\sqrt{\frac{M}{ZT}} \qquad (1)$$



Curves for Paraffin Hydrocarbons Expanding from Reliev
Pressures At or Near Saturation to Critical-Flow Pressur

(Reprinted courtesy of the American Petroleum Institute, Technical Data Book.)

Physical Properties

No.	Compound	Formula	Critical Constants: Pressure, PSIA (P_c)	Critical Constants: Temperature, °R (T_c)	Molecular Weight (M)	Ratio of Specific Heats C_p/C_v at 14.7 PSIA and 60°F (k)	Heat of Vaporization, 14.696 PSIA at Boiling Point, Btu/lb ($NBP\ \Delta HV$)
1	Methane	CH_4	667.8	343.4	16.043	1.311	219.22
2	Ethane	C_2H_6	707.8	550.0	30.070	1.193	210.41
3	Propane	C_3H_8	616.3	666.0	44.097	1.136	183.05
4	*n*-Butane	C_4H_{10}	550.7	765.0	58.124	1.094	165.65
5	Isobutane	C_4H_{10}	529.1	735.0	58.124	1.097	157.53
6	*n*-Pentane	C_5H_{12}	488.6	845.7	72.151	1.074	153.59
7	Isopentane	C_5H_{12}	490.4	829.1	72.151	1.075	147.13
8	Neopentane	C_5H_{12}	464.0	781.0	72.151	1.074	135.58
9	*n*-Hexane	C_6H_{14}	436.9	913.7	86.178	1.062	143.95
10	2-Methylpentane	C_6H_{14}	436.6	895.8	86.178	1.063	138.67
11	3-Methylpentane	C_6H_{14}	453.1	908.3	86.178	1.064	140.09
12	Neohexane	C_6H_{14}	446.8	860.1	86.178	1.064	131.24
13	2,3-Dimethylbutane	C_6H_{14}	453.5	900.3	86.178	1.065	136.08
14	*n*-Heptane	C_7H_{16}	396.8	972.8	100.205	1.054	136.01
15	2-Methylhexane	C_7H_{16}	396.5	955.0	100.205	1.054	131.59
16	3-Methylhexane	C_7H_{16}	408.1	963.8	100.205	1.054	132.11
17	3-Ethylpentane	C_7H_{16}	419.3	973.5	100.205	1.054	132.83
18	2,2-Dimethylpentane	C_7H_{16}	402.2	937.2	100.205	1.053	125.13
19	2,4-Dimethylpentane	C_7H_{16}	396.9	936.0	100.205	1.053	126.58
20	3,3-Dimethylpentane	C_7H_{16}	427.2	965.9	100.205	1.053	127.21
21	Triptane	C_7H_{16}	428.4	956.4	100.205	1.055	124.21
22	*n*-Octane	C_8H_{18}	360.6	1024.2	114.232	1.046	129.53
23	Diisobutyl	C_8H_{18}	360.6	990.4	114.232	1.049	122.80

(table continued on next page)

Physical Properties (continued)

No.	Compound	Formula	Critical Constants: Pressure, PSIA (P_c)	Critical Constants: Temperature, °R (T_c)	Molecular Weight (M)	Ratio of Specific Heats C_p/C_v at 14.7 PSIA and 60°F (k)	Heat of Vaporization, 14.696 PSIA at Boiling Point, Btu/lb ($NBP\ \Delta HV$)
24	Isooctane	C_8H_{18}	372.4	979.5	114.232	1.049	116.71
25	*n*-Nonane	C_9H_{20}	332.0	1070.7	128.259	1.042	123.76
26	*n*-Decane	$C_{10}H_{22}$	304.0	1112.1	142.286	1.038	118.68
27	Cyclopentane	C_5H_{10}	653.8	921.5	70.135	1.117	167.34
28	Methylcyclopentane	C_6H_{12}	548.9	959.4	84.162	1.085	147.83
29	Cyclohexane	C_6H_{12}	591.0	996.7	84.162	1.089	153.00
30	Methylcyclohexane	C_7H_{14}	503.5	1030.3	98.189	1.068	136.30
31	Ethylene	C_2H_4	729.8	506.6	28.054	1.243	207.57
32	Propene	C_3H_6	669.0	656.9	42.081	1.154	188.18
33	*1*-Butene	C_4H_8	583.0	755.6	56.108	1.111	167.94
34	*cis*-*2*-Butene	C_4H_8	610.0	784.4	56.108	1.121	178.91
35	*trans*-*2*-Butene	C_4H_8	595.0	771.9	56.108	1.107	174.39
36	Isobutene	C_4H_8	580.0	752.6	56.108	1.106	169.48
37	*1*-Pentene	C_5H_{10}	590.0	836.9	70.135	1.084	154.46
38	*1,2*-Butadiene	C_4H_6	653.0	799.0	54.092	1.118	181.00
39	*1,3*-Butadiene	C_4H_6	628.0	766.0	54.092	1.120	174.00
40	Isoprene	C_5H_8	558.4	872.0	68.119	1.089	153.00
41	Acetylene	C_2H_2	890.4	555.3	26.038	1.238	—
42	Benzene	C_6H_6	710.4	1012.2	78.114	1.117	169.31
43	Toluene	C_7H_8	595.9	1065.6	92.141	1.091	154.84
44	Ethylbenzene	C_8H_{10}	523.5	1111.2	106.168	1.072	144.00
45	*o*-Xylene	C_8H_{10}	541.4	1135.0	106.168	1.069	149.10
46	*m*-Xylene	C_8H_{10}	513.6	1111.0	106.168	1.072	147.20

(table continued on next page)

Physical Properties (continued)

No.	Compound	Formula	Critical Constants: Pressure, PSIA (P_c)	Critical Constants: Temperature, °R (T_c)	Molecular Weight (M)	Ratio of Specific Heats C_p/C_v at 14.7 PSIA and 60°F (k)	Heat of Vaporization, 14.696 PSIA at Boiling Point, Btu/lb ($NBP\ \Delta HV$)
47	*p*-Xylene	C_8H_{10}	509.2	1109.6	106.168	1.072	144.52
48	Styrene	C_8H_8	580.0	1166.0	104.152	1.076	151.00
49	Isopropylbenzene	C_9H_{12}	465.4	1136.4	120.195	1.060	134.30
50	Methyl Alcohol	CH_4O	1174.2	923.0	32.042	1.237	473.0
51	Ethyl Alcohol	C_2H_6O	925.3	929.6	46.069	1.149	367.0
52	Carbon Monoxide	CO	507.0	240.0	28.010	1.403	92.7
53	Carbon Dioxide	CO_2	1071.0	547.9	44.010	1.293	238.2
54	Hydrogen Sulfide	H_2S	1306.0	672.7	34.076	1.323	235.6
55	Sulfur Dioxide	SO_2	1145.1	775.5	64.059	1.272	166.7
56	Ammonia	NH_3	1636.1	730.3	17.031	1.304	587.2
57	Air	N_2O_2	547.0	238.7	28.964	1.395	92.0
58	Hydrogen	H_2	188.1	60.2	2.016	1.408	193.9
59	Oxygen	O_2	736.9	278.9	31.999	1.401	91.6
60	Nitrogen	N_2	493.0	227.4	28.013	1.402	87.8
61	Chloride	Cl_2	1118.4	751.0	70.906	1.330	123.8
62	Water	H_2O	3208.0	1165.6	18.015	1.335	970.3
63	Helium	He	—	—	4.003	1.660	—
64	Hydrogen Chloride	HCl	1198.0	584.5	36.461	1.410	185.5

Note: C_p/C_v calculated by the formula $k = C_p/(C_p - 1.1987/M)$.

CHAPTER ELEVEN

Tank Vents

Program 29 Pressure and Vacuum Flows
Typical Data

Large storage tanks generally have floating roofs and thus do not require venting; smaller tanks having conical roofs will require venting. All tanks should be designed to API 650 and vented according to API 2000. Emergency pressure relief is provided in the tank design by the frangible characteristics of the shell-to-roof seam.

Tanks designed to API 650 are limited to a maximum pressure of 2.5 pounds per square inch. This pressure is largely determined by the thickness of the roof material. The minimum requirement for products of low volatility is 3/16-inch steel, which weighs 0.84 ounces per square inch. The roof is supported by an inside frame, and it is usually stronger under vacuum than under pressure. A limit of 0.5 ounces per square inch for both pressure and vacuum is quite common for a 3/16-inch thick steel roof.

Underpressure can cause the tank walls to buckle, which is more difficult to repair than a weak seam splitting from overpressure. Underpressure may typically be caused by a thunderstorm on a hot day, sometimes causing a temperature drop of 40°F. If product is being withdrawn at the same time, the in-breathing requirement can be quite high.

The API code states that free vents shall not be used when the contents have a flashpoint below 100°F. Only breather valves are acceptable under this curcumstance. Flame arrestors should be used when the product flashpoint is below 100°F or when the bulk of the contents can be heated to the flashpoint under operating conditions (refer to Figure 11-1).

The size of the assembly is selected so that both the pressure flow and the vacuum flow keep the vessel pressure within the prescribed limits.

The program uses the worst conditions from Varec Venting Formula[1] and the API 650.[2] It is recommended that copies of API 650 and the Varec Technical Bulletin CP1001 be obtained for reference purposes.

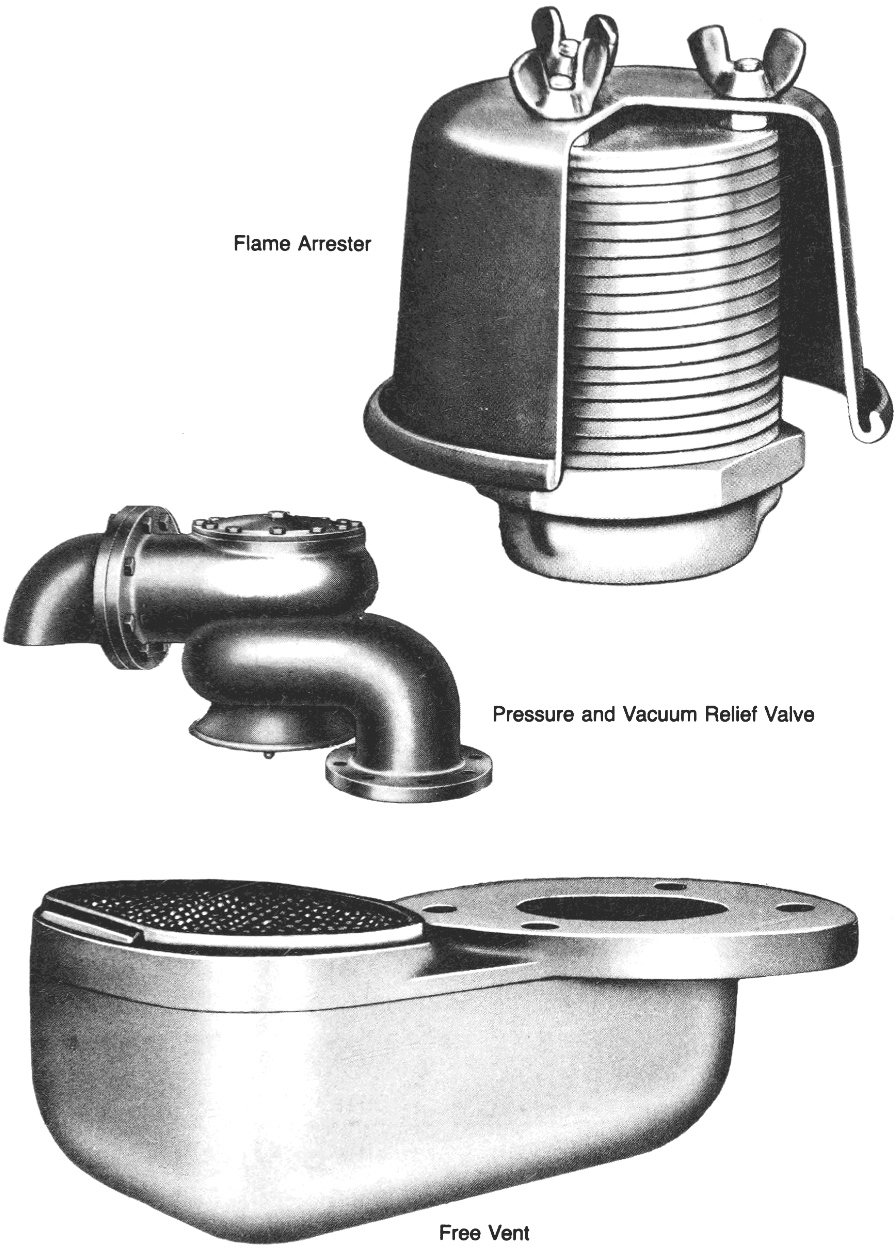


Figure 11-1. Typical venting devices.

Program 29
Pressure and Vacuum Flows

Program 29: User Instructions

a) Initiate program, press A.
b) Enter:
   1. Tank size in barrels — Press R/S
   2. Coefficient of cubical expansion of stored product per °F, dimensionless — Press R/S
   3. Expected ambient temperature change, °F — Press R/S
   4. Tank fill rate, barrels per hour — Press R/S
   5. Tank empty rate, barrels per hour — Press R/S
   6. Reid vapor pressure of product at 100°F PSIA (if zero is entered, the program goes to the calculation; if not, it continues.) — Press R/S
   7. Vapor molecular weight, dimensionless — Press R/S
   8. Product specific gravity, dimensionless — Press R/S
c) Program calculates pressure venting flow, SCFH, and vacuum venting flow, SCFH.

Notes:
1. Select size from manufacturers' catalogs.
2. The E subroutine is available to change data and recalculate.

Program 29: TI 59 Data Sheet

```
********************

     TANK VENTS

********************

ENTR TANK SIZE   BBL
      80000.
ENTR CUBICAL  EXP/°F
        0.002
ENTR TEMP CHNGE °F/H
         40.
ENTR FILL  RATE  BPH
        1000.
ENTR EMPTY RATE  BPH
        2000.
ENTR 100°F RVP  PSIA
          5.
ENTR  MW    VAP
         43.
ENTR  SG    LIQ
         0.4
CALC  PRSS FLOW  CFH
 59884.06508
CALC  VAC  FLOW  CFH
 66813.02326

********************
```

```
********************

     TANK VENTS

********************
ENTR TANK SIZE   BBL
        80000.
ENTR CUBICAL  EXP/°F
         0.002
ENTR TEMP CHNGE °F/H
           40.
```

```
ENTR FILL  RATE  BPH
         1000.
ENTR EMPTY RATE  BPH
         2000.
ENTR 100°F RVP  PSIA
            0.
CALC  PRSS FLOW  CFH
        41440.
CALC  VAC  FLOW  CFH
   52572.57979

********************
```

Program 29: TI 59 Register Loading

PARTITIONING
479.59

0.	00	42131500.	29
0.	01	152123.	30
0.	02	21273243.	31
0.	03	33353636.	32
0.	04	27243400.	33
0.	05	36220000.	34
0.	06	42133300.	35
0.	07	30430000.	36
0.	08	33362413.	37
0.	09	35423300.	38
0.	10	201017321.	39
0.	11	1730333745.	40
0.	12	143323.	41
0.	13	35133717.	42
0.	14	2124272700.	43
0.	15	73216323.	44
0.	16	1523312217.	45
0.	17	3717303300.	46
56.29313	18	4433637321.	47
56.32313	19	1327000017.	48
34.33	20	1541142415.	49
36.35	21	141427.	50
39.3837	22	3624461700.	51
40.4241	23	4217313736.	52
43.4241	24	3713312600.	53
46.4544	25	55.555555	54
49.4847	26	5151515151.	55
53.515	27	1513271500.	56
0.5352	28	1731373500.	57
		0.	58
		0.	59

Program 29: TI 59 Listing

SUBROUTINES

PRINT LINE OF STARS

```
000  76 LBL
001  42 STO
002  42 STO
003  59  59
004  43 RCL
005  57  57
006  69 OP
007  01  01
008  73 RC*
009  59  59
010  69 OP
011  02  02
012  71 SBR
013  43 RCL
014  69 OP
015  03  03
016  71 SBR
```

```
017  43  RCL
018  69  OP
019  04   04
020  69  OP
021  05   05
022  69  OP
023  21   21
024  73  RC*
025  01   01
026  87  IFF
027  00   00
028  00   00
029  31   31
030  91  R/S
031  99  PRT
032  72  ST*
033  01   01
034  92  RTN
```

DECODE LINES

```
035  76  LBL
036  43  RCL
037  43  RCL
038  59   59
039  22  INV
040  59  INT
041  65   ×
042  01   1
043  00   0
044  00   0
045  95   =
046  42  STO
047  59   59
048  73  RC*
049  59   59
050  92  RTN
```

PRINT LINES

```
051  76  LBL
052  61  GTO
053  42  STO
054  59   59
055  73  RC*
056  59   59
057  69  OP
058  01   01
059  71  SBR
060  43  RCL
061  69  OP
062  02   02
063  71  SBR
064  43  RCL
065  69  OP
066  03   03
067  71  SBR
068  43  RCL
069  69  OP
070  04   04
071  69  OP
072  05   05
073  92  RTN
```

DECODE ADDRESS

```
074  76  LBL
075  59  INT
076  22  INV
077  59  INT
078  52  EE
079  06   6
080  95   =
081  22  INV
082  52  EE
083  42  STO
084  58   58
085  92  RTN
```

CALC FLOW ZERO VP

```
086  76  LBL
087  22  INV
088  53   (
089  53   (
090  24  CE
091  85   +
092  43  RCL
093  02   02
094  65   ×
095  43  RCL
096  03   03
097  65   ×
098  43  RCL
099  04   04
100  54   )
101  65   ×
102  05   5
103  93   .
104  06   6
105  54   )
106  92  RTN
```

RE-ENTER VARIABLES

```
107  76  LBL
108  15   E
109  99  PRT
110  85   +
111  01   1
112  95   =
113  42  STO
114  01   01
115  73  RC*
116  01   01
117  91  R/S
118  22  INV
119  86  STF
120  00   00
121  72  ST*
122  01   01
123  99  PRT
124  98  ADV
125  86  STF
126  01   01
127  29  CP
128  43  RCL
129  07   07
130  67  EQ
131  39  COS
132  87  IFF
133  02   02
134  30  TAN
135  71  SBR
136  80  GRD
137  76  LBL
138  30  TAN
139  86  STF
140  00   00
141  73  RC*
142  01   01
143  91  R/S
144  61  GTO
145  12   B
146  76  LBL
147  39  COS
148  22  INV
149  86  STF
150  02   02
151  86  STF
152  00   00
153  73  RC*
154  01   01
155  91  R/S
156  61  GTO
157  23  LNX
```

ENTER DATA VOLATILE LIQ

```
158  76  LBL
159  80  GRD
160  43  RCL
161  21   21
162  71  SBR
163  42  STO
164  43  RCL
165  20   20
166  71  SBR
```

```
167   42  STO
168   86  STF
169   02   02
170   92  RTN
```

MAIN PROGRAM
ENTER DATA

```
171   76  LBL
172   11   A
173   22  INV
174   86  STF
175   01   01
176   98  ADV
177   01   1
178   42  STO
179   01   01
180   43  RCL
181   54   54
182   71  SBR
183   61  GTO
184   98  ADV
185   43  RCL
186   28   28
187   71  SBR
188   61  GTO
189   98  ADV
190   43  RCL
191   54   54
192   71  SBR
193   61  GTO
194   98  ADV
195   43  RCL
196   27   27
197   71  SBR
198   42  STO
199   43  RCL
200   26   26
201   71  SBR
202   42  STO
203   43  RCL
204   25   25
205   71  SBR
206   42  STO
207   43  RCL
208   24   24
209   71  SBR
210   42  STO
211   43  RCL
212   23   23
213   71  SBR
214   42  STO
215   43  RCL
216   22   22
217   71  SBR
218   42  STO
219   29  CP
220   43  RCL
221   07   07
222   67  EQ
223   23  LNX
224   71  SBR
225   80  GRD
```

CALC PRES FLOW
VOLATILE LIQ

```
226   76  LBL
227   12   B
228   43  RCL
229   05   05
230   71  SBR
231   22  INV
232   85   +
233   53   (
234   43  RCL
235   05   05
236   65   ×
237   53   (
238   43  RCL
239   07   07
240   45  YX
241   01   1
242   93   .
243   04   4
244   07   7
245   08   8
246   55   ÷
247   06   6
248   02   2
249   00   0
250   00   0
251   85   +
252   93   .
253   00   0
254   00   0
255   04   4
256   05   5
257   54   )
258   65   ×
259   01   1
260   03   3
261   02   2
262   08   8
263   06   6
264   07   7
265   65   ×
266   43  RCL
267   09   09
268   55   ÷
269   43  RCL
270   08   08
271   95   =
272   65   ×
273   53   (
274   43  RCL
275   08   08
276   55   ÷
277   02   2
278   08   8
279   93   .
280   09   9
281   07   7
282   54   )
283   34  √X
284   95   =
285   42  STO
286   10   10
```

CALC VAC FLOW
VOLATILE LIQ

```
287   43  RCL
288   06   06
289   71  SBR
290   22  INV
291   85   +
292   43  RCL
293   02   02
294   65   ×
295   02   2
296   06   6
297   93   .
298   05   5
299   07   7
300   65   ×
301   43  RCL
302   09   09
303   55   ÷
304   43  RCL
305   08   08
306   95   =
307   42  STO
308   11   11
309   61  GTO
310   24  CE
```

CALC FLOWS
NONVOLATILE LIQ

```
311   76  LBL
312   23  LNX
313   43  RCL
314   05   05
315   71  SBR
316   22  INV
317   95   =
318   42  STO
319   10   10
320   43  RCL
```

```
321   06   06
322   71  SBR
323   22  INV
324   95   =
325   42  STO
326   11   11
```

API CALCS NONVOLATILE

```
327   76  LBL
328   24  CE
329   02   2
330   00   0
331   00   0
332   00   0
333   00   0
334   32  X:T
335   43  RCL
336   02   02
337   77   GE
338   52  EE
339   61  GTO
340   49  PRD
341   76  LBL
342   52  EE
343   45  YX
344   93   .
345   06   6
346   04   4
347   04   4
348   09   9
349   65   X
350   03   3
351   06   6
352   93   .
353   02   2
354   00   0
355   04   4
356   95   =
357   61  GTO
358   49  PRD
```

VOLATILE

```
359   76  LBL
360   35  1/X
361   29  CP
362   43  RCL
363   07   07
364   22  INV
365   67   EQ
366   33  X²
367   02   2
368   05   5
369   00   0
370   00   0
371   00   0
372   32  X:T
373   43  RCL
374   02   02
375   22  INV
376   77   GE
377   34  ΓX
378   45  YX
379   93   .
380   06   6
381   02   2
382   05   5
383   65   X
384   02   2
385   07   7
386   93   .
387   05   5
388   01   1
389   05   5
390   09   9
391   95   =
392   61  GTO
393   44  SUM
394   76  LBL
395   34  ΓX
396   65   X
397   93   .
398   06   6
399   95   =
400   61  GTO
401   44  SUM
```

VOLATILE PRES FLOW

```
402   76  LBL
403   33  X²
404   43  RCL
405   17   17
406   61  GTO
407   44  SUM
```

VAC FLOW SELECT AND PRINT LARGEST

```
408   76  LBL
409   49  PRD
410   42  STO
411   17   17
412   32  X:T
413   43  RCL
414   11   11
415   77   GE
416   35  1/X
417   32  X:T
418   42  STO
419   11   11
420   61  GTO
421   35  1/X
```

PRES FLOW SELECT & PRINT THE LARGEST

```
422   76  LBL
423   44  SUM
424   32  X:T
425   43  RCL
426   10   10
427   77   GE
428   45  YX
429   32  X:T
430   42  STO
431   10   10
432   76  LBL
433   45  YX
434   43  RCL
435   19   19
436   71  SBR
437   61  GTO
438   43  RCL
439   10   10
440   99  PRT
```

PRINT VACUUM FLOW

```
441   43  RCL
442   18   18
443   71  SBR
444   61  GTO
445   43  RCL
446   11   11
447   99  PRT
448   98  ADV
449   43  RCL
450   54   54
451   71  SBR
452   61  GTO
453   98  ADV
454   98  ADV
455   98  ADV
456   87  IFF
457   01   01
458   38  SIN
459   22  INV
460   86  STF
461   00   00
462   76  LBL
463   38  SIN
464   43  RCL
465   10   10
466   91  R/S
```

Program 29: HP 41CV Data Sheet

```
************

*TANK VENTS*

************

ENTER TANK SIZE BBL
      80,000.000    ***
ENTER CUBICAL EXP/DEG F
           0.002    ***
ENTER TEMP CHANGE DEGF/H
          40.000    ***
ENTER FILL RATE BPH
       1,000.000    ***
ENTER EMPTY RATE BPH
       2,000.000    ***
ENTER 100DEGF RVP PSIA
           5.000    ***
ENTER MW VAP
          43.000    ***
ENTER SG LIQ
           0.400    ***
CALC PRSS
FLOW SCFH
      59,884.065    ***
CALC VACUUM
FLOW SCFH
      66,813.023    ***

************


************

*TANK VENTS*

************

ENTER TANK SIZE BBL
      80,000.000    ***
ENTER CUBICAL EXP/DEG F
           0.002    ***
ENTER TEMP CHANGE DEGF/H
          40.000    ***
ENTER FILL RATE BPH
       1,000.000    ***
ENTER EMPTY RATE BPH
       2,000.000    ***
ENTER 100DEGF RVP PSIA
           0.000    ***
CALC PRSS
FLOW SCFH
      41,440.000    ***
CALC VACUUM
FLOW SCFH
      52,572.580    ***

************
```

Program 29: HP 41CV Register Loading

SIZE 080

```
R00= 0.000000
R01= 0.000000
R02= 0.000000
R03= 0.000000
R04= 0.000000
R05= 0.000000
R06= 0.000000
R07= 0.000000
R08= 0.000000
R09= 0.000000
R10= 0.000000
R11= 0.000000
R12= 0.000000
R13= 0.000000
R14= 0.000000
R15= 0.000000
R16= 0.000000
R17= 0.000000
R18= 0.000000
R19= 0.000000
R20= 0.000000
R21= 0.000000
R22= 0.000000
R23= 0.000000
R24= 0.000000
R25= "*TANK "
R26= "VENTS*"
R27= 0.000000
R28= 0.000000
R29= 0.000000
R30= 25.260000
R31= 57.505152
R32= 57.535460
R33= 57.616263
R34= 57.646566
R35= 57.676566
R36= 57.686970
R37= 0.000000
R38= 57.710000
R39= 57.720000
R40= 0.000000
R41= 56.767374
R42= 56.757374
R43= 0.000000
R44= 0.000000
R45= 0.000000
R46= 0.000000
R47= 0.000000
R48= 0.000000
R49= 0.000000
R50= "TANK "
R51= "SIZE B"
R52= "BL "
R53= "CUBICA"
R54= "L EXP/"
R55= "******"
R56= "CALC "
R57= "ENTER "
R58= 42.000000
R59= 0.000000
R60= "DEG F"
R61= "TEMP C"
R62= "HANGE "
R63= "DEGF/H"
R64= "FILL "
R65= "RATE B"
R66= "PH"
R67= "EMPTY "
R68= "100DEG"
R69= "F RVP "
R70= "PSIA"
R71= "MW VAP"
R72= "SG LIQ"
R73= " FLOW "
R74= "SCFH"
R75= "VACUUM"
R76= "PRSS  "
R77= 0.000000
R78= 0.000000
R79= 0.000000
```

Program 29: HP 41CV Listing

SUBROUTINES

```
01♦LBL "VENTS"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT & STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 RTN
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53♦LBL 01
54 XEQ J
55 GTO e
```

RE-ENTER VARIABLES

```
56♦LBL "REENTER"
57 ADV
58 1
59 +
60 STO 01
61 7
62 RCL 01
63 X≠Y?
64 GTO 01
65 RCL 07
66 X=0?
67 SF 03
68♦LBL 01
69 RCL IND 01
70 XEQ J
71 STOP
72 XEQ J
73 STO IND 01
74 ADV
75 SF 02
76 RCL 07
77 X=0?
78 GTO 02
79 FC? 03
80 GTO 02
81 7
82 STO 01
83 37
84 STO 58
85 XEQ e
86♦LBL 02
87 CF 03
88 STOP
89 RCL 07
90 X=0?
91 GTO C
92 GTO B
```

BYPASS PRINTER

```
93♦LBL J
94 FC? 55
95 GTO 01
96 PRX
97 RTN
98♦LBL 01
99 VIEW X
100 RTN
```

COMMON CALC

```
101♦LBL F
102 RCL 02
103 RCL 03
104 *
105 RCL 04
106 *
107 RCL 10
108 +
109 5.6
110 *
111 RTN
```

MAIN PROGRAM ENTER DATA

```
112♦LBL A
113 1
114 STO 01
115 29
116 STO 58
117 XEQ a
118 XEQ d
119 XEQ a
120 FS? 02
121 SF 00
122 CF 02
123 XEQ e
124 RCL 07
125 X=0?
126 GTO C
127 XEQ e

128♦LBL B
129 RCL 05
130 STO 10
131 RCL 07
132 1.478
133 Y↑X
134 6200
135 /

136 .0045
137 +
138 RCL 05
139 *
140 132867
141 *
142 RCL 09
143 *
144 RCL 08
145 /
146 XEQ F
147 +
```

```
148 RCL 08
149 28.97
150 /
151 SQRT
152 *
153 STO 11
```

**VAC FLOW
VOLATILE LIQ**

```
154 RCL 06
155 STO 10
156 26.57
157 RCL 02
158 *
159 RCL 09
160 *
161 RCL 08
162 /
163 XEQ F
164 +
165 STO 12
166 GTO D
```

**PRES FLOW
NONVOLATILE LIQ**

```
167♦LBL C
168 RCL 05
169 STO 10
170 XEQ F
171 STO 11
```

**VAC FLOW
NONVOLATILE LIQUID**

```
172 RCL 06
173 STO 10
174 XEQ F
175 STO 12
```

**API TANK 20,000
VOLATILE LIQ**

```
176♦LBL D
177 RCL 07
178 X=0?
179 GTO G
180 20000
181 RCL 02
182 X<=Y?
183 GTO 01
184 .6449
185 Y↑X
186 36.204
187 *
188 STO 13
189 STO 14
190 GTO I
191♦LBL 01
192 RCL 02
193 STO 13
194 STO 14
195 GTO I
```

**NONVOLATILE LIQ
PRES FLOWS**

```
196♦LBL G
197 25000
198 RCL 02
199 X<=Y?
200 GTO 02
201 .625
202 Y↑X
203 27.5195
204 *
205 STO 13
206 GTO H
207♦LBL 02
208 .6
209 *
210 STO 13
```

VACUUM FLOWS

```
211♦LBL H
212 20000
213 RCL 02
214 X<=Y?
215 GTO 03
216 .6449
217 Y↑X
218 36.204
219 *
220 STO 14
221 GTO I
222♦LBL 03
223 STO 14
```

**PRES FLOW
SELECT & PRINT
LARGEST**

```
224♦LBL I
225 40
226 STO 58
227 XEQ d
228 RCL 11
229 RCL 13
230 X<=Y?
231 RDN
232 STO 15
233 XEQ J
```

**VAC FLOW
SELECTION
OF THE LARGEST**

```
234 XEQ d
235 RCL 12
236 RCL 14
237 X<=Y?
238 RDN
239 STO 16
240 XEQ J
241 FS? 02
242 STOP
243 CF 00
244 XEQ a
245 RCL 15
246 RCL 16
247 VIEW X
248 BEEP
249 ADV
250 STOP
251 .END.
```

Program 29: Sequence of Calculations

Nonvolatile liquids

1. Calculate flow caused by internal pressure.

   a) $Q_p = 5.6D\,(D + ABC)$ SCFH[1]

b) Tank less than 25,000 barrels:

$Q_p = .6A$ SCFH[2]

Tank more than 25,000 barrels:

$Q_p = 27.5159A^{.625}$ SCFH[2]

c) Select the largest Q_p.

2. Calculate flow caused by internal vacuum.

a) $Q_v = 5.6E\,(D + ABC)$ SCFH.[1]

b) Tank less than 20,000 barrels:

$Q_v = A$ SCFH[2]

Tank more than 20,000 barrels:

$Q_v = 36.204A^{.6447}$ SCFH[2]

c) Select the largest Q_v.

Volatile liquids

1. Calculate flow caused by internal pressure.

a) $Q_p = (5.6\,D(D + ABC) + (D((F^{1.478}/6200) + .0045) \times 132{,}867\,G/M))\,\sqrt{M/28.97}$ SCFH[1]

b) Tank size less than 20,000 barrels:

$Q_p = A$, SCFH[2]

Tank size more than 20,000 barrels:

$Q_p = 36.204A^{.6449}$ SCFH[2]

c) Select the largest Q_p.

2. Calculate flow caused by internal vacuum.

a) $Q_v = 5.6E\,(D + ABC) + 26.57AG$ SCFH[1]

b) Tank size less than 20,000 barrels:

$Q_v =$ ASCFH[2]

Tank size more than 20,000 barrels:

$$Q_v = 36.204A^{.6449} \text{ SCFH}^2$$

c) Select the largest Q_v.

Program 29: Nomenclature

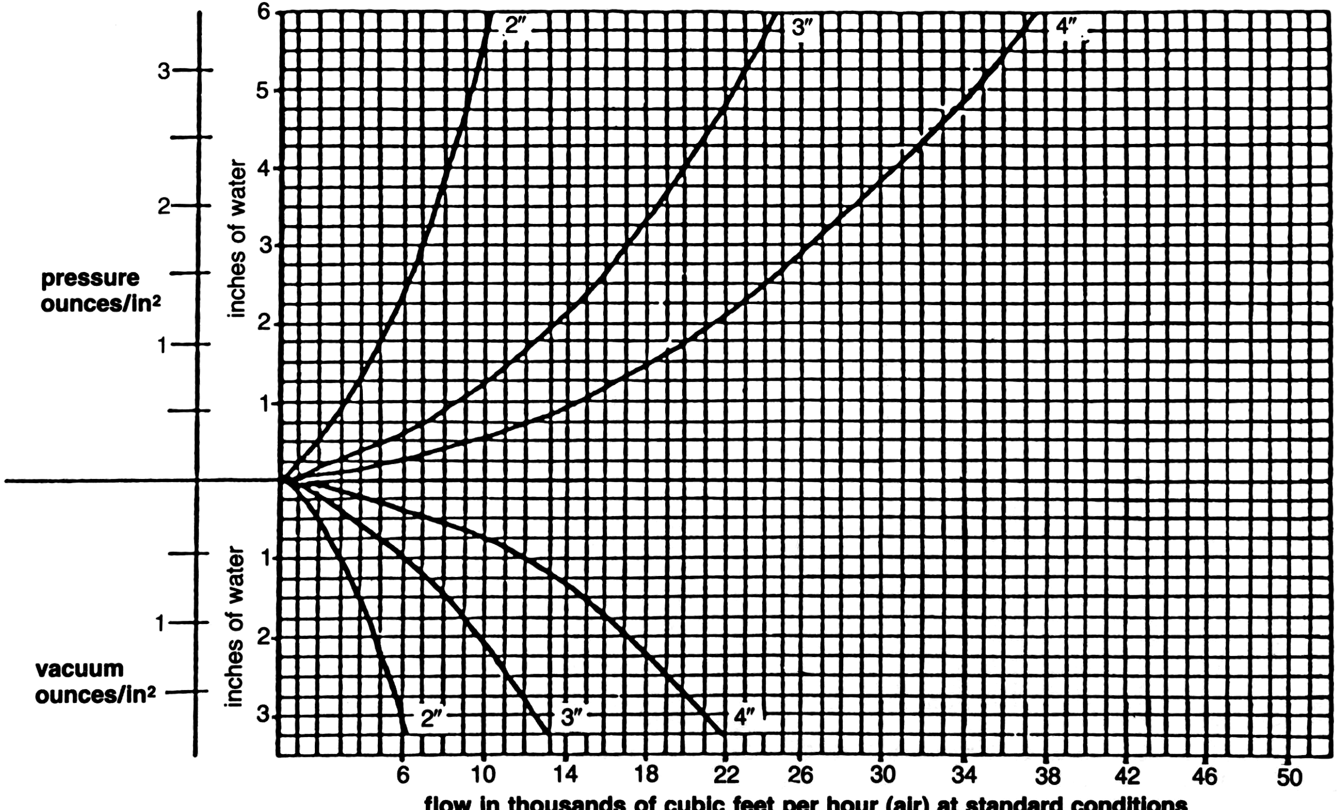
A Tank size, barrels
B Liquid cubical expansion coefficient per °F
C Temperature change, °F per hour
D Tank fill rate, barrels per hour
E Tank empty rate, barrels per hour
F Reid vapor pressure at 100°F, PSIA
G Liquid specific gravity, dimensionless
M Vapor molecular weight, dimensionless
Q_p Pressure flowrate, SCFH
Q_v Vacuum flowrate, SCFH

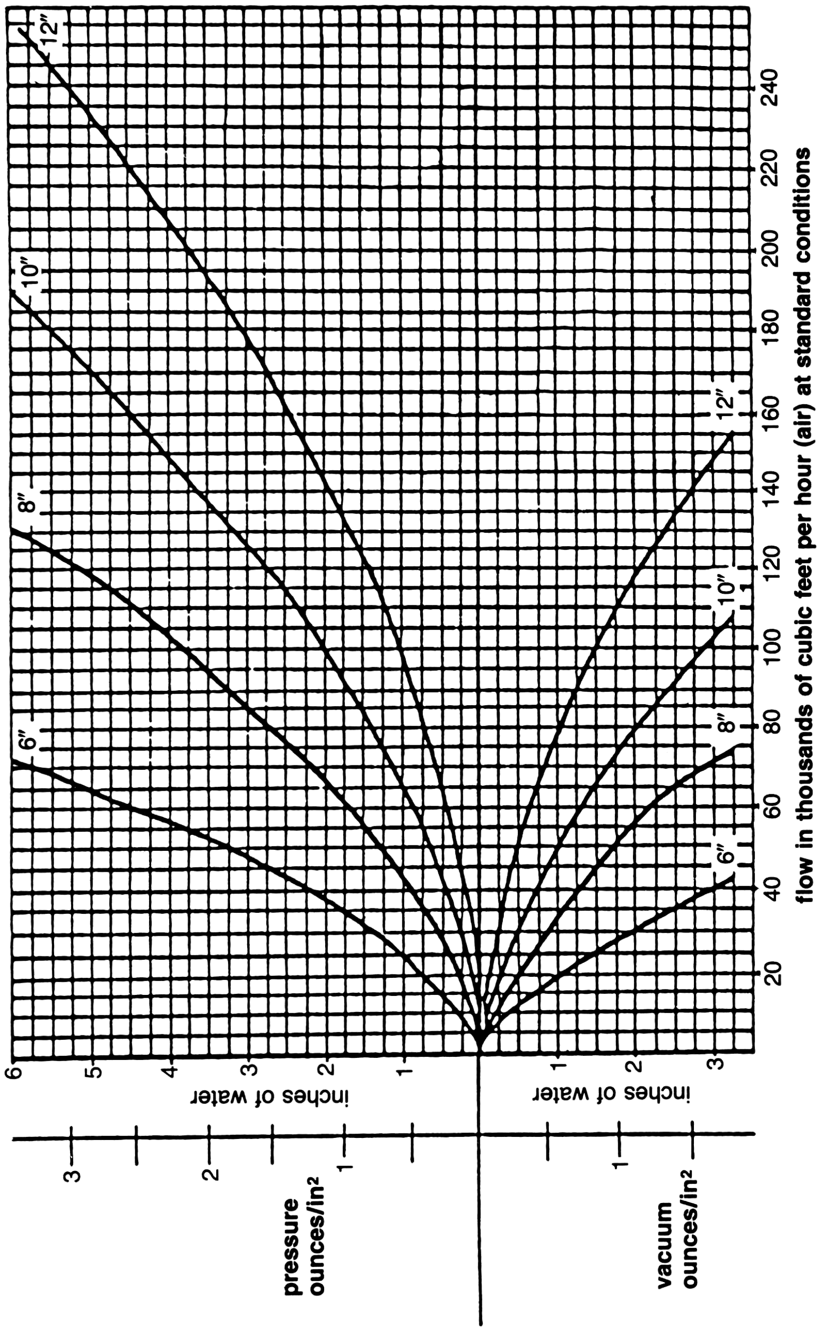
Literature Cited

1. *Varec Technical Bulletin CP1001,* 10800 Valleyview Street, Cypress, California 90630.
2. *API 650,* American Petroleum Institute, Refining Department, 2101 L. Street Northwest, Washington, D.C. 20037.

Typical Data

Typical Flame Arrester Capacity Chart

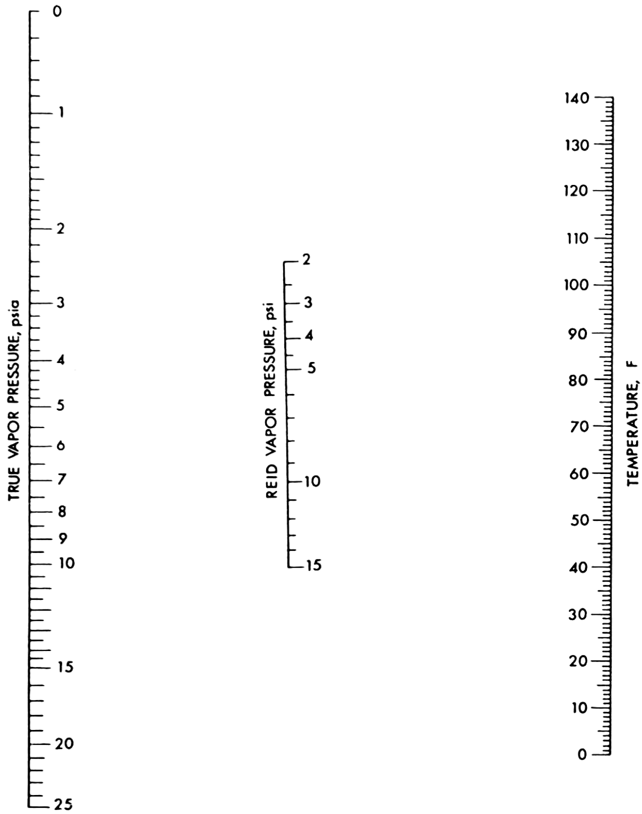



flow in thousands of cubic feet per hour (air) at standard conditions
20
40
60
80
100
120
140
160
180
200
220
240
6"
8"
10"
12"
inches of water
pressure ounces/in²
vacuum ounces/in²
1
2
3
4
5
6

Physical Properties of Typical Liquids Stored in Closed Roof Tanks

Liquid	Cubical Expansion Per °F at 60°F	Vapor Pressure PSIA at 100°F	Molecular Weight	Liquid Specific Gravity 29.9 in. Hg. Pressure, 60°F
Acetone	.00083	7.5	58.08	.792
Acetic Acid	.00053	.7	60.50	1.049
Benzene (Benzol)	.00069	3.2	78.11	.880
1,3-Butadiene	.00113	58.0	54.09	.621
n-Butane	.00117	52.0	58.12	.584
Butyl Alcohol	.0005	1.84	74.1	.814
Butylene (*1*-Butene)	.0116	66.0	56.10	.601
Carbon Disulphide	.00068	11.0	76.13	1.300
Cyclohexane	.00068	3.3	84.16	.779
n-Decane	.00055	.064	142.28	.730
Ethyl-Acetate	.00074	3.3	88.10	.899
Ethyl-Alcohol	.00062	2.26	46.07	.790
Ethyl-Ether	.0009	16.0	74.12	.710
Gasoline	.00053	5.3		.750
n-Hexane	.00075	4.8	86.17	.664
n-Heptane	.00069	1.63	100.20	.688
Hydrochloric Acid 30%	.00027	.58	72.50	1.460
Isobutane	.0012	72.2	58.12	.563
Isobutene (Methyl Propene)	.0012	65.1	56.10	.626
Isopentane	.0009	20.3	72.15	.625
Isopropyl-Alcohol	.00057	1.85	60.09	.789
Methyl-Alcohol	.00067	4.6	32.04	.792
Nitric Acid 50%	.00053	.6	81.03	1.500
Nonane-*n*	.00063	.19	128.25	.718
n-Octane	.00062	.54	114.22	.706
n-Pentane	.00089	15.5	72.15	.613
Propane	.00152	189.5	44.09	.507
Sulphuric Acid 50%	.0002	.6	116.05	1.84
Styrene	.00057	.275	104.14	.907
Toluene	.0006	1.05	92.13	.866
Water	.00012	.949	18.02	1.000
o-Xylene	.00055	.42	106.16	.880

True Vapor Pressure of Crude Oils



Reprinted courtesy of the American Petroleum Institute, *Technical Data Book*.

CHAPTER TWELVE

Safety Heads

Program 30A Liquid Flow
Program 30B Gas or Vapor Flow

A safety head is a rupture-disc assembly. This arrangement is preferable to mounting the rupture disc between flanges because it assures proper alignment, proper seating, and a low probability of damage.

The rupture disc is a reliable, accurate, and low-cost method of preventing overpressure. It can be used as a stand-alone device or in combination with a relief valve when bubble-tight shutoff is required during normal operations, and when some resealing capability is required after overpressuring has occurred.

B S & B publication 77-1000 is recommended for more details.

Program 30
Safety Heads

Program 30: User Instruction

Liquid calculation, press A.

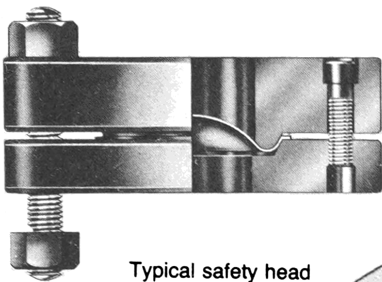
a) Enter:
   1. Required flowrate, pounds per hour — Press R/S
   2. Pressure drop across rupture disc, PSI — Press R/S

b) Program prints required diameter, inches.

Gas and Vapor calculation, press B.

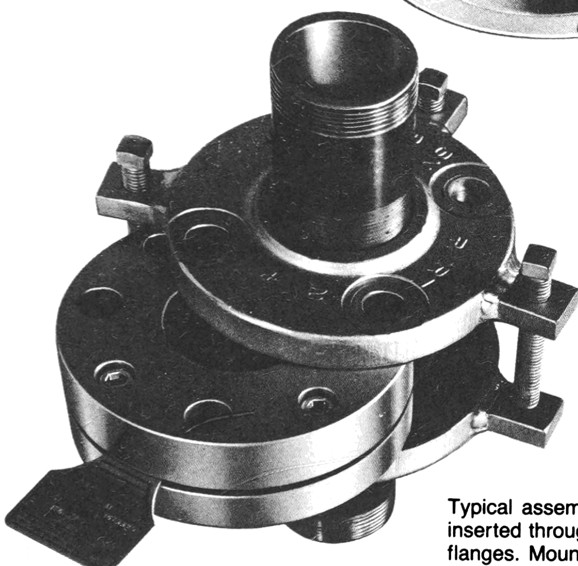
a) Enter:
   1. Required flowrate, pounds per hour — Press R/S
   2. Flow temperature, °F — Press R/S
   3. Rupture pressure, PSIG — Press R/S
   4. Molecular weight, dimensionless — Press R/S

b) Program prints required diameter.



Typical safety head

Typical rupture disc



Typical assembly in pipe. Jack screws are inserted through lugs welded to OD of pipe flanges. Mounting can be either vertical or horizontal.

Flange-Type Safety Head Fittings Sizes 1/2″ through 44″

Flange-type heads normally conform to ASA bolting patterns. Standard connections are welded, threaded, and flat-faced. The flat-faced fittings can be mated to or inserted between ASA pipe flanges. Nominal pressure ratings for standard flanges:

1/2″ through 4″	—up to 6000 psi @ 100° F.
6″	—up to 2160 psi @ 100° F.
8″ through 12″	—up to 720 psi @ 100° F.
14″ through 44″	—up to 275 psi @ 100° F.

Safety head flanges with higher pressure ratings are available.

Program 30: TI 59 Data Sheet

```
*******************
SAFETY HEAD SIZE
LIQUID RELIEF

ENTER FLOW RATE  PPH
   12245100.
ENTER SPEC GRAV
          1.
ENTER PRSS DROP  PSI
         80.
CALC DIAMETER    INS

 12.35758267

*******************
```

```
*******************
SAFETY HEAD SIZE
GAS RELIEF

ENTER FLOW RATE  PPH
      10000.
ENTER FLOW TEMP   °F
        338.
ENTER RUPT PRSS PSIG
        100.
ENTER  MOL WGHT
         18.
CALC DIAMETER    INS
 1.826527703

*******************
```

Program 30: TI 59 Register Loading

PARTITIONING
479.59

0.	00	5151515151.	29
0.	01	54.535251	30
0.	02	59.585655	31
0.	03	43222337.	32
0.	04	303227.	33
0.	05	35413337.	34
0.	06	7321.	35
0.	07	37173033.	36
0.	08	1513271500.	37
0.	09	243136.	38
0.	10	3717350000.	39
0.	11	1624133017.	40
0.	12	333624.	41
0.	13	16353233.	42
0.	14	33353636.	43
0.	15	22351342.	44
0.	16	36331715.	45
0.5049	17	333323.	46
33.32	18	35133717.	47
34.4328	19	21273243.	48
48.3635	20	1727241721.	49
37.403938	21	2213360035.	50
0.	22	1721000000.	51
0.	23	35172724.	52
29.292929	24	3441241600.	53
43.4241	25	2724.	54
45.44	26	2446170000.	55
48.4746	27	1713160036.	56
33362422.	28	1731371735.	57
		1737450023.	58
		361321.	59

Program 30: TI 59 Listing

SUBROUTINES PRINT & STORE VARIABLES

```
000  76 LBL
001  42 STO
002  42 STO
003  23  23
004  43 RCL
005  57  57
006  69 OP
007  01  01
008  73 RC*
009  23  23
010  69 OP
011  02  02
012  71 SBR
013  43 RCL
014  69 OP
015  03  03
016  71 SBR
017  43 RCL
018  69 OP
019  04  04
020  69 OP
021  05  05
022  73 RC*
023  01  01
024  69 OP
025  21  21
026  91 R/S
027  99 PRT
028  72 ST*
029  01  01
030  92 RTN
```

DECODE LINES

```
031  76 LBL
032  43 RCL
033  43 RCL
034  23  23
035  22 INV
036  59 INT
037  65  ×
038  01  1
039  00  0
040  00  0
041  95  =
042  42 STO
043  23  23
044  73 RC*
045  23  23
046  92 RTN
047  76 LBL
048  61 GTO
049  42 STO
050  23  23
051  73 RC*
052  23  23
053  69 OP
054  01  01
055  71 SBR
056  43 RCL
057  69 OP
058  02  02
059  71 SBR
060  43 RCL
061  69 OP
062  03  03
063  71 SBR
064  43 RCL
065  69 OP
066  04  04
067  69 OP
068  05  05
069  92 RTN
```

PRINT COMMON HEADING

```
070  76 LBL
071  90 LST
072  01  1
073  42 STO
074  01  01
075  98 ADV
076  43 RCL
077  24  24
078  71 SBR
079  61 GTO
080  98 ADV
081  43 RCL
082  31  31
083  71 SBR
084  61 GTO
085  92 RTN
086  76 LBL
087  11  A
088  71 SBR
089  90 LST
090  43 RCL
091  30  30
092  71 SBR
093  61 GTO
094  98 ADV
095  43 RCL
096  27  27
097  71 SBR
098  42 STO
099  43 RCL
100  26  26
101  71 SBR
102  42 STO
103  43 RCL
104  25  25
105  71 SBR
106  42 STO
107  43 RCL
108  21  21
109  71 SBR
110  61 GTO
111  43 RCL
112  02  02
113  55  ÷
114  08  8
115  09  9
116  06  6
117  05  5
118  55  ÷
119  53  (
120  43 RCL
121  03  03
122  65  ×
123  43 RCL
124  04  04
125  54  )
126  34 ΓX
127  95  =
128  34 ΓX
129  95  =
130  42 STO
131  05  05
132  99 PRT
133  76 LBL
134  95  =
135  98 ADV
136  43 RCL
137  24  24
138  71 SBR
139  61 GTO
140  98 ADV
141  98 ADV
142  98 ADV
143  43 RCL
144  05  05
145  91 R/S
```

GAS CALC

```
146  76 LBL
147  12  B
```

```
148  71 SBR     172  21  21     196  55  ÷
149  90 LST     173  71 SBR     197  01  1
150  43 RCL     174  61 GTO     198  07  7
151  17  17     175  43 RCL     199  04  4
152  71 SBR     176  03  03     200  55  ÷
153  61 GTO     177  85  +      201  43 RCL
154  98 ADV     178  04  4      202  04  04
155  43 RCL     179  06  6      203  65  ×
156  27  27     180  00  0      204  53  (
157  71 SBR     181  95  =      205  43 RCL
158  42 STO     182  42 STO     206  03  03
159  43 RCL     183  03  03     207  55  ÷
160  20  20     184  43 RCL     208  43 RCL
161  71 SBR     185  04  04     209  05  05
162  42 STO     186  85  +      210  54  )
163  43 RCL     187  01  1      211  34 √X
164  19  19     188  04  4      212  95  =
165  71 SBR     189  93  .      213  34 √X
166  42 STO     190  07  7      214  95  =
167  43 RCL     191  95  =      215  42 STO
168  18  18     192  42 STO     216  05  05
169  71 SBR     193  04  04     217  99 PRT
170  42 STO     194  43 RCL     218  61 GTO
171  43 RCL     195  02  02     219  95  =
```

Program 30: HP 41CV Data Sheet

```
*************

SAFETY HEAD
 *LIQUID*

*************

ENTER FLOW PPH
   12,245,100.00     ***
ENTER SG
        1.000000     ***
ENTER PRSS DROP PSI
       80.000000     ***
CALC   DIAMET
ER INS
       12.357583     ***

*************
*************

SAFETY HEAD
   *GAS*

*************

ENTER FLOW PPH
    10,000.00000     ***
ENTER TEMP DEG F
      338.000000     ***
ENTER RUPTURE PRSS PSIG
      100.000090     ***
ENTER MW
       18.300000     ***
CALC   DIAMET
ER INS
        1.826528     ***

*************
```

Program 30: HP 41CV Register Loading

SIZE 080

```
R00= 0.000000     R10= 0.000000     R21= 0.000000
R01= 0.000000     R11= 0.000000     R22= 0.000000
R02= 0.000000     R12= 0.000000     R23= 0.000000
R03= 0.000000     R13= 0.000000     R24= 0.000000
R04= 0.000000     R14= 0.000000     R25= "SAFETY"
R05= 0.000000     R15= 0.000000     R26= " HEAD"
R06= 0.000000     R16= 0.000000     R27= "  *LIQ"
R07= 0.000000     R17= 0.000000     R28= "UID*"
R08= 0.000000     R18= 0.000000     R29= "   *GA"
R09= 0.000000     R19= 0.000000     R30= 0.000000
                  R20= 0.000000     R31= 25.262728
```

```
R32=  57.515200
R33=  57.530000
R34=  57.546061
R35=  0.000000
R36=  56.626300
R37=  0.000000
R38=  25.262950
R39=  57.515200
R40=  57.646500
R41=  57.666768
R42=  57.690000
R43=  0.000000
R44=  56.626300
R45=  0.000000
R46=  0.000000
R47=  0.000000
```

```
R48=  0.000000
R49=  0.000000
R50= "S*"
R51= "FLOW P"
R52= "PH"
R53= "SG"
R54= "PRSS "
R55= "******"
R56= "CALC  "
R57= "ENTER "
R58=  35.000000
R59=  0.000000
R60= "DROP "
R61= "PSI "
R62= "DIAMET"
R63= "ER INS"
```

```
R64= "TEMP D"
R65= "EG F"
R66= "RUPTUR"
R67= "E PRSS"
R68= " PSIG"
R69= "MW "
R70=  0.000000
R71=  0.000000
R72=  0.000000
R73=  0.000000
R74=  0.000000
R75=  0.000000
R76=  0.000000
R77=  0.000000
R78=  0.000000
R79=  0.000000
```

Program 30: HP 41CV Listing

SUBROUTINES

```
01♦LBL "SFTYHD"
02 GTO A
```

PRINT LINE OF STARS

```
03♦LBL a
04 FC? 55
05 RTN
06 55.55
07 ADV
08 SF 12
09 XEQ b
10 ADV
11 RTN
```

PRINT LINES

```
12♦LBL d
13 SF 12
14 1
15 ST+ 58
16 RCL IND 58
17♦LBL b
18 STO 59
19 CLA
20♦LBL c
21 ARCL IND 59
22 RCL 59
23 FRC
24 100
25 *
26 STO 59
27 X≠0?
28 GTO c
29 FC? 55
30 GTO 01
31 PRA
32 CF 12
33 RTN
34♦LBL 01
35 CF 12
36 AVIEW
37 RTN
```

PRINT AND STORE VARIABLES

```
38♦LBL e
39 1
40 ST+ 58
41 RCL IND 58
42 X=0?
43 GTO d
44 XEQ b
45 1
46 ST+ 01
47 RCL IND 01
48 TONE 9
49 FS? 00
50 GTO 01
51 STOP
52 STO IND 01
53♦LBL 01
54 XEQ J
55 GTO e
```

RE-ENTER VARIABLES

```
56♦LBL "REENTER"
57 ADV
58 FS? 03
59 GTO 01
60 1
61 GTO 02
62♦LBL 01
63 5
64♦LBL 02
65 +
66 STO 01
67 RCL IND 01
68 XEQ J
69 STOP
70 XEQ J
71 STO IND 01
72 ADV
73 SF 02
74 STOP
75 FS? 01
76 GTO F
77 GTO G
```

BYPASS PRINTER

```
78♦LBL J
79 FC? 55
80 GTO 01
81 PRX
82 RTN
83♦LBL 01
84 VIEW X
85 RTN
```

MAIN PROGRAM LIQUID

```
86♦LBL A
87 FC? 02
88 CF 03
89 FS? 03
90 GTO "GAS"
91 FS? 02
92 SF 00
93 SF 01
94 CF 02
95 1
96 STO 01
97 30
```

```
98 STO 58
99 XEQ a
100 XEQ d
101 XEQ a
102 XEQ e
103♦LBL F
104 RCL 02
105 8965
106 /
107 RCL 03
108 SQRT
109 /
110 RCL 04
111 SQRT
112 /
113 SQRT
114 GTO H
```

GAS

```
115♦LBL "GAS"
116 FC? 02
117 CF 01
118 FS? 01
119 GTO A
120 FS? 02
121 SF 00
122 SF 03
123 CF 02
124 37
125 STO 58
126 5
127 STO 01
128 XEQ a
129 XEQ d
130 XEQ a
131 XEQ e
132♦LBL G
133 RCL 06
134 174
135 /
136 RCL 08
137 14.7
138 +
139 /
140 RCL 07
141 460
142 +
143 SQRT
144 *
145 RCL 09
146 SQRT
147 /
148 SQRT
```

COMMON ENDING

```
149♦LBL H
150 STO 05
151 XEQ J
152 FS? 02
153 STOP
154 CF 00
155 XEQ a
156 RCL 05
157 VIEW X
158 ADV
159 BEEP
160 STOP
161 .END.
```

Program 30: Sequence of Calculations

Liquids

1. Calculate required diameter.

$$D = \sqrt{\frac{W_m}{8965\sqrt{G_f \Delta P}}} \text{ inches}$$

Gas and Vapor

1. Calculate required diameter.

$$D = \sqrt{\frac{W_m}{174\, P_1}\sqrt{\frac{T_f}{M}}}$$

Program 30: Nomenclature

D Required diameter for flow conditions, inches
G_f Liquid specific gravity, dimensionless

M Gas molecular weight, dimensionless
P_1 Gas flowing pressure, PSIA
ΔP Liquid pressure drop (inlet pressure − back pressure), PSI
T_f Gas flowing temperature, °R
W_m Flow through rupture disc, pounds per hour

Index

TI-59 and HP-41CV Instrument Engineering Programs

This book lets instrument engineers fully exploit the programmable calculator to quickly and accurately determine instrumentation requirements. No longer must you perform tedious manual calculations or rely on costly, inflexible time-sharing computers. The programmable calculator has changed all that, and *TI-59 and HP-41CV Instrument Engineering Programs* makes it an even more effective tool for solving an array of complex instrumentation problems—including those requiring successive iterations.

The text contains programs for sizing control valves and pressure-relief valves for liquid and gas flows; calculating flow for orifice plates with flange, pipe, and corner taps; and converting flow from one unit of measurement to another. Storage-tank vents, breather valves, and flame arrestors with volatile and nonvolatile liquids are covered, along with programs for hard-to-find instrument process data, such as compressibility factors and specific weights.

Each program presented offers a sample problem, user instructions, a program printout, a derivation of the final mathematical analysis, and standard data for common liquids and gases.

The immediate access, instant answers, and ease of recalculation give the programmable calculator the edge over all methods of determining instrumentation requirements. *TI-59 and HP-41CV Instrument Engineering Programs* shows the instrument engineer how to derive the greatest cost benefits and time savings from using these sophisticated, inexpensive programmable calculators to perform complex engineering calculations.

Stanley W. Thrift, P.E., is an instrumentation engineer with Catalytic Enterprises Limited in Sarnia, Ontario, and a senior member of the Instrument Society of America.

GULF PUBLISHING COMPANY
Book Division
P.O. Box 2608
Houston, Texas 77001

Cover Design by Terry J. Moore

ISBN 0-87201-387-1