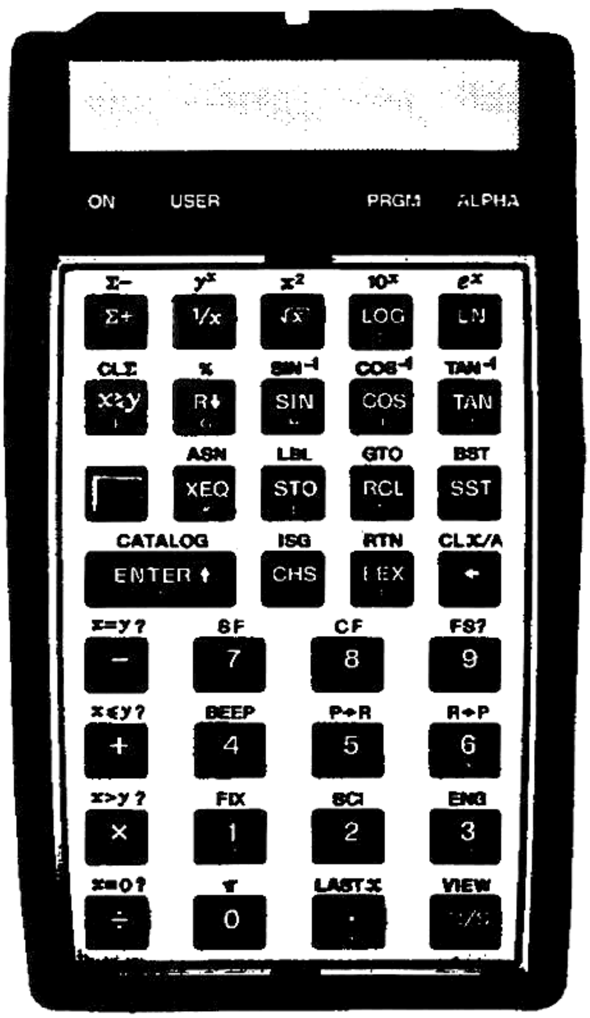
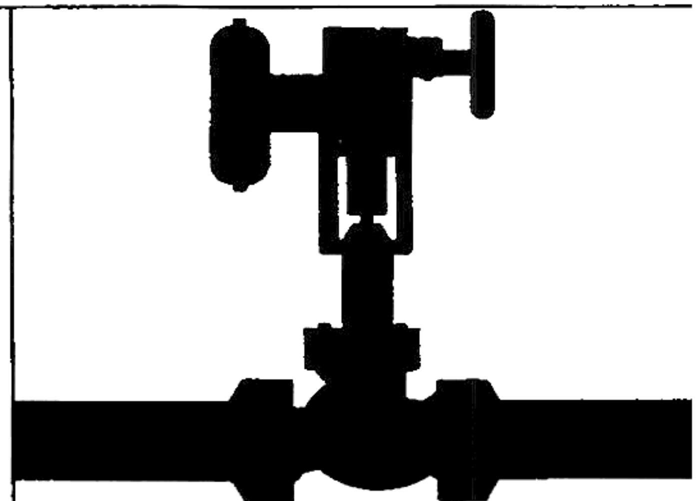
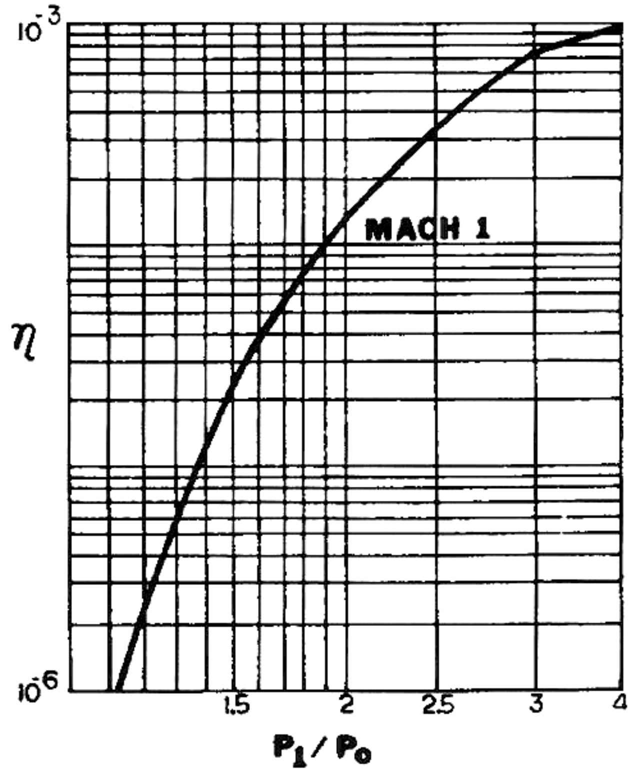
Cv-PAK

USER'S MANUAL







INSTALLING THE ROM MODULE

WARNING ! Always turn your HP-41 and peripherals off before inserting or removing the ROM module! Failure to do so will most likely damage the calculator and the Cv-PAK.

The Cv-PAK is compatible with all models of HP-41 - however, if extended memory modules are installed, the Cv-PAK ROM must always be placed in a higher numbered port than the last memory module.

CARE

The Cv-PAK module needs no maintenance. If it is removed from the HP-41, reasonable care should be taken to avoid getting the module wet or dusty. Avoid prolonged storage at temperatures above 90 degrees F.

DISCLAIMER

The Cv-PAK is offered as an aid to engineers, technicians, manufacturers sales representatives, and other professionals strictly on an "as-is" basis. The formulas and techniques included are accepted industry standards. In some instances, proprietary methods are used, with the permission of the originator.

There are no express or implied warranties as to the accuracy of this material, or to its suitability for any particular purpose. The seller accepts no liability for damages resulting from the use or misuse of this software.

INTRODUCTION

The Cv-PAK has been designed to be totally self - prompting. If you are already familiar with HP-41 operation and I.S.A. valve sizing terminology, you will quickly become accustomed to using this package. Take a few moments to read the manual and work the sample problems.

A loose leaf binder was selected for this manual so that you may easily add your own supplementary programs, table and notes, making the Cv-PAK an excellent single point control valve reference source.

BASIC FORMAT

Each program in the Cv-PAK has been assigned a short, easy to remember Alpha label which is also an acronym for the program function. (Note - If you are unfamiliar with HP-41 operation, program labels are equivalent to "file names" in BASIC.)

Program Labels

VCV	(Volume Cv -for gas)
WCV	(Weight Cv -for gas or steam)
LCV	(Liquid Cv)
2PH	(2 Phase flow)
LAM	(Laminar flow)

REGISTER SIZE

Minimum register size is 30. Execute SIZE 030 if fewer than 30 memory registers are available. Failure to do so will result in a NONEXISTANT message when the program tries to store data into a nonexistant register.

HELPFUL HINTS

- Do not interrupt running programs, since this tends to affect flag status and proper recovery from subroutines.

- The display will not operate properly during "pause" operations if the printer is attached, but turned off.

- The HP-41 runs noticeably faster without the printer connected, whether or not the printer is switched on.

- On rare occasions, you may suffer what HP-41 owners (as well as operators of other computers) refer to as a "crash". If this happens, you will lose control over the keyboard and strange characters may appear in the display - or it may blank out altogether. Don't panic, and don't send your calculator off for repair until you try the following procedure:

  1) Remove the batteries for 5 minutes and then replace them. Perform a "master reset" by holding down the [←] key while pressing the [ON] key. When you release the [←] key, you should see a MEMORY LOST message on the display. Re-execute SIZE 030 and you should be ready to go again.

TO START A PROGRAM

Programs in the Cv-PAK may be executed by their labels in exactly the same way as other programs in memory. For example, press [XEQ] [ALPHA] VCV [ALPHA] to execute the program labeled "VCV". To make the Cv-PAK even more convenient, you may assign each program to a single key so that pressing the key in **USER** mode selects and starts the program. This technique saves several keystrokes per execution.

Example: (Shift) ■ [ASN] VCV [V]. Now the program labeled "**VCV**" is assigned to the V key *. Hereafter, you may simply press the reassigned key in **USER** mode to begin the program. (Refer to the HP-41 users manual for additional information on **USER** mode and key assignments.) The Cv-PAK is designed to facilitate execution of programs in this manner by cancelling **USER** mode automatically at the start of each routine. This avoids conflicts with other reassigned keys while entering data.

* Any program may be assigned to any key.

DETAILED INSTRUCTIONS

All programs and subroutines follow the same general format. Answer prompts with the requested information and press [R/S] (RUN/STOP). The software guides the sequence of operation, and the user need only be familiar with I.S.A. terminology. Therefore, a detailed set of instructions will only be given for one program, using "VCV" as an example.

VOLUME Cv

Program label:	VCV
Description :	Calculates required Cv and/or aerodynamic sound level, exit velocity, pressure drop, and flow at any percentage of valve travel.

The program prompts for all required inputs. Enter the requested information after the prompt and press [R/S] to continue. It is not necessary to re-enter variables for subsequent calculations within the same program. The HP-41 will remember the previous values as long as no number keys are pressed in response to a prompt. To step past inputs without changing the value of a variable, just press [R/S] after the prompt. This feature is useful due to the iterative nature of ISA SP-75.01 valve sizing procedures. To review the value of a variable, press the [←] key once. If the value is satisfactory, press [R/S] to proceed to the next prompt. To make a change, enter the new value after the prompt & press [R/S] . If you make a mistake while entering data, you may press (shift) ■ [RTN] , or execute the program to re-start the prompting routine. In this way, you may enter, edit, or review all inputs in a few seconds.

(VOLUME Cv)

ISA GAS (VOL)	Displayed for 0.5 seconds.
S.C.F.H. ?	Flow volume, standard cubic feet per hour.
P1? (PSIA)	Absolute pressure at valve inlet.
P2? (PSIA)	Absolute pressure at valve outlet.
MOL. WT.?	Molecular weight.
"Z" FACTOR?	Compressibility.
TEMP.? (F)	Inlet fluid temperature, Fahrenheit.
K? (CP/CV)	Ratio of specific heats, cp/cv.
VALVE XT?	Valve pressure recovery factor for gas/vapor.
CALC. FP? Y/N	Do you want to calculate Fp? (Yes/No).
FP=nn	Current value of Fp in register.
CV= nn	Valve Cv required at given conditions.

After the required Cv is displayed, the program halts. To calculate another Cv value, start the program over by pressing (shift) ■ [RTN] . If [R/S] is pressed, the following options will be offered:

1) Print results of the Cv calculation.
   (If the Hewlett-Packard thermal printer is attached.)

2) Predict aerodynamic sound level
   (followed by another print option if a printer is attached).

3) Calculate the valve body exit velocity (Mach number).

4) Calculate flow at any percentage of valve travel.

5) Calculate pressure drop across the valve.

Option prompts are accompanied by a "Y/N" to indicate that they are a yes/no choice. To select the option, press Y, then [R/S] . Pressing any other key, or just pressing [R/S] will cause the program to skip to the next option or prompt.

(OPTIONS - CONTINUED)

If sound level prediction is requested, the program assumes that a new valve is being sized and does not offer a flow or pressure drop calculation. Options 4 & 5 are for predicting flow rates for relief valve sizing, or to predict pressure drop across a valve at some % travel. If the user intends to solve for pressure drop or flow, the appropriate variables for the valve under consideration should be entered during the initial prompts (i.e.; valve Fl or Xt at the % of travel). In all cases, required Cv must be calculated first.

PROMPTS:

OPTIONS: R/S	Press [R/S] for option menu.
TRIM dBA: Y/N	Press Y (Yes), [R/S] to calculate noise.
MACH NO.: Y/N	Press Y (Yes), [R/S] to calculate exit mach number.
FLOW: Y/N	Press Y (Yes), [R/S] to calculate flow.
PR. DROP: Y/N	Press Y (Yes), [R/S] to calculate pressure drop across the valve.

Fp CALCULATION

Program label: FP
Description : Calculates piping geometry factor, Fp.

The Fp calculation may be bypassed for initial sizing and selection by pressing [R/S] after the Fp option prompt. The current value of Fp is then displayed as Fp=nn . You may override this by entering 1, or any other number, and proceed with the calculation. After final valve selection has been made, the exact value of Fp may be determined for the final Cv calculation. The Fp correction subroutine is based on a valve installed between two concentric reducers of the same size.

PROMPTS:

VALVE SIZE?	Nominal valve size in inches 2, 3, etc.
NOM PIPE D?	Nominal pipe size in inches.
100 % CV?	Valve Cv at 100% travel.

AERODYNAMIC SOUND PREDICTION

Program label: SL
Description : This subroutine is based on a non-proprietary technique developed by Dr. Hans Baumann. It is applicable to single stage valves of any design, and has demonstrated a high degree of accuracy in ASME tests. The Baumann technique calculates the acoustical efficiency factor as a function of valve FL and pressure drop ratio. The resulting sound power generated is a product of this factor and the mechanical power produced across the valve orifice by the dominant noise source. This source is turbulent shear at subsonic and transitional flow; sonic shock waves at low sonic flow; and severe shock waves with shock cell formation at supersonic flow. The program also indicates whether flow at the vena contracta is subsonic, sonic, or in the supersonic region.

PROMPTS:

FL @ TRAVEL?	Manufacturer's pressure recovery coefficient at the valve position indicated by the required Cv.
SUBSONIC	Display: flow is subsonic @ vena contracta
SONIC	Display: flow is sonic @ vena contracta
>>> SONIC	Display: flow is supersonic @ vena contracta
VALVE SIZE?	Nominal valve size in inches.
PARABOL.? Y/N	This prompt appears when reduced flow relative to the valve capacity is indicated, Answer yes only if the valve has a parabolic plug and is flowed to open.
NO. ORIFICES?	Number of apparent flow producing orifices. (Ball valve has 1, butterfly 2, etc.)
PIPE OD? (")	Nominal pipe size in inches.
WALL THK? (")	Pipe wall thickness in inches.
G? (ADJ.,dB)	Specific gravity adjustment factor - see Baumann's table.

MACH NUMBER

Program label:	MACH
Description :	Predicts valve outlet mach number for compressible fluids using results from the Cv calculation.

OUT. d? (")	Valve outlet diameter in inches.
OUTLET T? (F)	Fluid temperature at valve outlet, degrees F.
MOL. WT?	Molecular weight.
Z @ OUTLET?	Compressibility at downstream conditions.
OUTLET VEL.:	Display.
MACH nn	Outlet mach number.

Note: Outlet velocities below Mach 0.33 are usually considered acceptible. Consult the manufacturers literature for recommendations.

WEIGHT Cv

Program label:	WCV
Description :	Calculates required Cv and/or aerodynamic sound level, exit velocity,pressure drop, and flow at any percentage of valve travel based on weight units.

PROMPTS:

ISA GAS (WT)	Displayed for 0.5 seconds.
#/HOUR?	Mass flow rate in pounds per hour.
P1? (PSIA)	Absolute pressure at valve inlet.
P2? (PSIA)	Absolute pressure at valve outlet.
DENS.? (#/FT3)	Fluid density in lb/cubic feet.
K? (CP/CV)	Ratio of specific heats, cp/cv.
VALVE XT?	Pressure recovery factor - consult manufacturers literature.
CALC. FP? Y/N	Press Y [R/S] to calculate Fp; just [R/S] to bypass the calculation.
FP= nn	Current value of Fp.
CV= nn	Required valve Cv at the given conditions.

Note- See detailed instructions for program "VCV" regarding noise prediction and other options.

LIQUID Cv

Program label:	LCV
Description :	Calculates required Cv and/or flow noise, pressure drop, and flow at any percentage of valve travel. Halts and warns of flashing or cavitation.

PROMPTS:

ISA LIQUID	Displayed for 0.5 seconds.
GPM?	Flow rate in U.S. gallons per minute.
P1? (PSIA)	Absolute pressure at valve inlet.
P2? (PSIA)	Absolute pressure at valve outlet.
SP GRAVITY?	Liquid specific gravity.
VAPOR PR.?	Fluid vapor pressure, psia.
CRITICAL PR.?	Fluid critical pressure, psia.
VALVE FL?	Valve pressure recovery coefficient. Consult manufacturers literature.
CALC. FP? Y/N	Press Y [R/S] to calculate Fp; just [R/S] to bypass the calculation.
FP= nn	Current value of Fp.
CV= nn	Required valve Cv at the given conditions.
FF=nn	Display of Ff factor (curve is programmed in).

At this point the program will either display the required Cv, or warn of choked flow conditions. If the flow is choked, the program halts and displays either FLASHING or CAVITATING. Press [R/S] once to continue. For flashing conditions, the required Cv will be displayed.

For cavitating conditions, an audible warning is sounded along with the display. Press [R/S] once to display the allowable pressure drop in psi. Press [R/S] again to display the required Cv at that pressure drop.

TWO PHASE FLOW

Program label:	2PH
Description :	Estimates required Cv for mixed phase flow - either a liquid and non - condensing gas, or liquid and its vapor. Adapted from Fisher Catalog 10. Original method was developed by Dr. A.C. Fagerlund of Fisher Controls Company.

PROMPTS:

2 PHASE FLOW	Displayed for 0.5 seconds.
L & G:1 L & V:2	Enter "1" to calculate Cv for liquid/gas mixtures, or "2" for liquid/vapor - then press [R/S] .
LIQUID & GAS	Displayed for 0.5 seconds.
SCFH GAS?	Gas flow component, scfh
P1? (PSIA)	Absolute pressure at inlet
P2? (PSIA)	Absolute pressure at outlet
MOL WT?	Molecular weight
"Z" FACTOR?	Compressibility
TEMP? (F)	Inlet temperature, Fahrenheit
K? (SP.HTS)	Ratio of specific heats, cp/cv
VALVE "XT"?	Gas pressure recovery factor
CV (G)=nn	Display: Cv required for gas portion
LIQUID GPM?	Liquid flow component, US gallons/minute
LIQ GRAVITY?	Liquid specific gravity
PV? (PSIA)	Fluid vapor pressure, psia
Pc? (PSIA)	Fluid critical pressure, psia
VALVE "FL"?	Liquid pressure recovery factor
CV (L)=nn	Display: Cv required for liquid portion

TWO PHASE FLOW - LIQUID & GAS
(continued)

VR=nn	Display: gas volume ratio
FM=nn	Display: correction factor, Fm
CVR=nn	Display: (Total required Cv)

<u>If 2 is selected</u>:

LIQ. & VAPOR	Displayed for 0.5 seconds.
#/HR VAPOR?	Pounds/hour of vapor
P1? (PSIA)	Absolute inlet pressure
P2? (PSIA)	Absolute outlet pressure
DENS., #/FT3?	Vapor density, pounds/cubic foot
K? (SP.HTS)	Ratio of specific heats, cp/cv
VALVE "XT"?	Gas pressure recovery factor
CV (G)=nn	Display: Cv required for vapor portion
LIQUID GPM?	Gallons per minute of liquid
LIQ. GRAVITY?	Liquid specific gravity
PV? (PSIA)	Liquid fluid vapor pressure
Pc? (PSIA)	Liquid fluid critical pressure
VALVE "FL"?	Valve liquid pressure recovery factor
CV (L)=nn	Display: Cv required for liquid portion
#/HR TOTAL?	Total pounds/hour of mixture
VR=nn	Display: gas volume ratio
FM=nn	Display: correction factor, Fm
CVR=nn	Display (Total Cv required for mixture)

LAMINAR FLOW

Program label:	LAM
Description :	Program tests for laminar flow conditions, and displays Reynolds number if flow is laminar. Calculates non-turbulent Cv.

PROMPTS:

LAMINAR FLOW	Displayed for 0.5 seconds.
GPM?	Flow rate, US gallons/minute
P1? (PSIA)	Absolute inlet pressure
P2? (PSIA)	Absolute outlet pressure
SP GRAVITY	Liquid specific gravity
VALVE FL?	Liquid recovery factor
VISC, (CST.)?	Viscosity in centistokes
DESIGN? (Fd)	I.S.A. design factor
CALC. FP? Y/N	Press y R/S to calculate Fp; just R/S to bypass the calculation.
FP= nn	Current value of Fp.
NON LAMINAR	Displayed when Rev is > 100,000
XEQ "LCV"	Display - execute program "LCV"
ReV=nn	Valve Reynolds no.
FR?	Reynolds number correction factor (from chart)
CV=nn	Laminar flow Cv

Sample problem no. 1
Liquid service

A control valve in HVAC service is required for a chilled water return loop. The following service conditions are given:

Normal flow is 250 gallons per minute of water at 56 degrees F . Inlet pressure is 75 psia. The pressure drop for sizing purposes is 5 psi. Piping is 6" schedule 40. Use a thin disc butterfly valve, sized to pass the normal flow at 60 degrees of travel.

Use program "LCV". (Fix 2 decimal places)
[XEQ] [ALPHA] LCV [ALPHA]

GPM?	250		[R/S]
P1? (PSIA)	75		[R/S]
P2? (PSIA)	70		[R/S]
SP. GRAVITY?	1		[R/S]
VAPOR PR. ?	.22	(From chart)	[R/S]
CRITICAL PR.?	3206	(From chart)	[R/S]
VALVE FL ?	.7	(Assumption-from chart)	[R/S]
CALC FP? Y/N		(Bypass this for 1st trial)	[R/S]
FF=nn			
	1		[R/S]
FF=0.96 RQ'D CV= 111.80			

Now that a required Cv has been estimated, consult the manufacturer's literature to see which valve has the required Cv of 111 at 60 degrees of travel. A 3" thin disc butterfly appears to be adequate, with a Cv of 132 at 60 degrees. Now that we have selected a valve model and size, we will go back and do a more precise calculation to insure that a 3 inch valve will be the correct choice.

Sample problem no. 2:
<u>Gas service, volume flow units</u>

The Joule-Thompson valve for a natural gas liquids plant has the following service conditions:

Required plant capacity is 25 million standard cubic feet per day of 25 molecular weight natural gas. Inlet pressure is 814.7 psia. Outlet pressure is 225 psia. Compressibility is 0.88. Valve inlet temperature is 20 degrees Fahrenheit, and outlet is (-) 60 F. Ratio of specific heats (K) is 1.32. Piping is 6" schedule 80S. Try a 3" globe valve.

Use program "VCV". (Fix 2 decimal places)
[XEQ] [ALPHA] VCV [ALPHA]

ISA GAS (VOL)		
SCFH ?	25 [EEX] 6 [ENTER] 24 [÷]	[R/S]
P1? (PSIA)	814.70	[R/S]
P2? (PSIA)	225.00	[R/S]
MOL WT ?	25.00	[R/S]
"Z" FACTOR ?	0.88	[R/S]
TEMP? (F)	20	[R/S]
K? (SP. HTS)	1.32	[R/S]
VALVE "XT"?	0.64 (From mfg. catalogue)	[R/S]
CALC FP? Y/N	Y	[R/S]
VALVE SIZE?	3	[R/S]
NOM PIPE D?	6	[R/S]
100% CV?	136 (From mfg. catalogue)	[R/S]
FP=0.[illegible]		[R/S]
CRITICAL RQ'D CV=37.60		

Conclusion - The 3" valve passes the required amount at between 50 % and 60 % of travel.

Sample problem 2, continued

What is the predicted noise level for this valve?

			R/S
OPTIONS: R/S			R/S
TRIM dBA: Y/N	Y		R/S
FL @ TRAVEL?	.8		R/S
>>> SONIC			indicates supersonic flow @ vena contracta, n factor above the break @ P1/P2>2.8.
VALVE SIZE?	3		R/S
PARABOL.?(Y/N)			R/S
NO. ORIFICES?	2		R/S
PIPE OD? (")	6		R/S
"WALL THK?	0.432		R/S
G? (ADJ., dB)	1		R/S
SL= 112.00 dBA		This is the predicted sound level for a single stage valve when measured in accordance with ISA recommendations.	

Conclusion: Sound attenuation is required. Contact the valve manufacturer for recommendations.

Now lets calculate outlet velocity.
First re-calculate the Cv, since the noise program and the Mach program overlap some data registers.

ISA GAS (VOL)		
SCFH ?		R/S
P1? (PSIA)		R/S
P2? (PSIA)		R/S
MOL WT ?		R/S
"Z" FACTOR ?	0.88	R/S
TEMP? (F)	20	R/S
K? (SP. HTS)	1.32	R/S
VALVE "XT"?	0.64 (From mfg. catalogue)	R/S
CALC FP? Y/N	Y	R/S
VALVE SIZE?	3	R/S
NOM PIPE D?	6	R/S
100% CV?	136 (From mfg. catalogue)	R/S
FP=0.9)		
		R/S
CRITICAL RQ'D CV=37.60		
		R/S
OPTIONS: R/S		R/S
TRIM dBA: Y/N		R/S
MACH NO: Y/N	Y	R/S
OUT. d? (")	7 ENTER 16 ÷ 3 +	R/S
		R/S
OUTLET T? (F)	60 CHS	R/S
MOL WT?	25	R/S
Z @ OUTLET?	0.98	R/S
OUTLET VEL: MACH 0.22		

Note: Outlet velocities of less than MACH 0.33 are considered acceptable. The 3" valve will be sufficient.

Sample problem no. 3
<u>Saturated steam</u>

A pressure control valve for utility steam has these service requirements:

Flow is 25,000 #/hour of saturated steam. Upstream pressure is 125 psia. Downstream pressure is 30 psia. Piping is 6 inch schedule 40 . Use program "WCV". Try a 4 inch globe valve.

[XEQ] [ALPHA] WCV [ALPHA]

#/HOUR ?	25000		[R/S]
P1? (PSIA)	125		[R/S]
P2? (PSIA)	30		[R/S]
DENS.? (#/FT3)	.28	(From steam tables)	[R/S]
K? (CP/CV)	1.28		[R/S]
VALVE XT?	.67	(From mfg. literature)	[R/S]
CALC FP? Y/N	Y		[R/S]
VALVE SIZE?	4		[R/S]
NOM PIPE D?	6		[R/S]
100% CV ?	224	(From mfg. literature)	[R/S]
FP=0.95			[R/S]
CRITICAL RQ'D CV= 135.67			

The 4" globe valve will pass the required flow at just over 70% travel.

Sample problem no. 4
<u>Laminar flow</u>

Size a V-notch ball valve for controlling the flow of a highly viscous Newtonian lubricating oil, given the following conditions:

Flow is 100 gallons per minute; P1=116 psia; P2=87 psia; specific gravity=0.908; viscosity= 3000 centistokes. Assume line-sized valve.

Use program "LAM".
[XEQ] [ALPHA] LAM [ALPHA]

GPM?	100		[R/S]
P1? (PSIA)	116		[R/S]
P2? (PSIA)	87		[R/S]
SP GRAVITY	.908		[R/S]
VALVE FL ?	.8		[R/S]
VISC. (CST)?	3000		[R/S]
DESIGN? (fd)	1	(From chart)	[R/S]
CALC FP? Y/N	(NO)		[R/S]
FP=nn	1		[R/S]
ReV= 153.61			[R/S]
FR?	.55	(From chart)	[R/S]
CV= 32.03			

This is the "pseudo sizing coefficient", which may be used to select a valve size. The catalogue data indicates that a 2 inch valve should be sufficient for this application. Now the exact Cv may be calculated, based on this preliminary selection, by an iterative process of calculating the required Cv and then re-calculating based on the projected angle of valve travel.

APPENDIX A
EQUATIONS USED IN THE Cv-PAK

Incompressible fluids - Program LCV

$$C_v = \frac{q}{\cancel{N1}\,1.0 \quad F_{Lp} \quad \cancel{F_r}\,1.0 \quad \sqrt{\dfrac{\Delta P \ (\text{or } \Delta P_t)}{G_f}}}$$

q = Flow, U.S. gallons per minute
Fr = Reynolds number correction, assumed = 1.0
Pt = Pressure drop effective in producing flow (P allowable)
Fp = Piping geometry correction factor
Fl = Liquid pressure recovery factor
FLp = Liquid pressure recovery factor with attached fittings

$$\text{Where } \Delta P_t = \left(\frac{F_{Lp}}{F_p}\right)^2 (P_1 - F_f P_v)$$

$$F_p = \left[1.0 + \frac{\sum K}{N_2}\left(\frac{C_v}{d^2}\right)^2\right]^{(-)\,1/2}$$

$$F_{Lp} = \left[\frac{K_i}{N_2}\left(\frac{C_v}{d^2}\right)^2 + \frac{1}{F_L^2}\right]^{(-)\,1/2}$$

Ki = k1 + K B1
Ki = Resistance coefficient of upstream fittings
K B1 = Inlet Bernoulli coefficient

$$K_1 = 0.5\left(1 - \frac{d^2}{D^2}\right)^2 \qquad K_{B1} = 1 - \left(\frac{d}{D}\right)^4$$

APPENDIX A
EQUATIONS USED IN THE Cv-PAK

Compressible fluids, volume units - Program VCV

$$Cv = \frac{q}{7320\ Fp\ P1\ Y \sqrt{\dfrac{x}{M\ T1\ Z}}}$$

q = Flow, standard cubic feet per hour
Fp= Piping geometry correction factor
Y = Expansion factor
x = Pressure drop ratio
M = Molecular weight
T1= Fluid inlet temperature, degrees Rankine
Z = Compressibility

$$Y = 1 - \left[\frac{x}{3\ Fk\ Xt}\right]$$

Critical when x >= (Fk Xt)
Y = 0.667 @ critical flow

Fk = K/1.4
K = cp/cv
x = $\Delta P/P1$
Xt = Pressure drop ratio required to produce critical flow when Fk = 1.0

$$Fp = \left[1.0 + \frac{\sum K}{N2}\left(\frac{Cv}{d^2}\right)^2\right]^{(-)\ 1/2}$$

$$Xtp = \left[\frac{Xt}{Fp^2}\quad 1.0 + \frac{Xt\ \ Ki}{1000}\left(\frac{Cv}{d^2}\right)^2\right]^{(-)\ 1}$$

APPENDIX A

EQUATIONS USED IN THE Cv-PAK

Compressible fluids, weight units - Program WCV

$$Cv = \frac{W}{63.3 \; Fp \; Y \quad x \quad P1 \, \gamma 1}$$

W = Flow, pounds per hour
γ = Specific weight, lb./ft3
Y = Expansion factor
P1= Pressure @ inlet, psia

$$Y = 1 - \left[\frac{x}{3 \; Fk \; Xt} \right]$$

Critical when x >= (Fk Xt)
Y = 0.667 @ critical

Fk = K/1.4
K = cp/cv
x = P/P1
Xt = Pressure drop ratio required to produce critical flow when Fk = 1.0

$$Fp = \left[1.0 + \frac{\sum K}{N2} \left(\frac{Cv}{d^2} \right)^2 \right]^{(-)\,1/2}$$

$$Xtp = \left[\frac{Xt}{Fp^2} \quad 1.0 + \frac{Xt \quad Ki}{1000} \left(\frac{Cv}{d^2} \right)^2 \right]^{(-)\,1}$$

APPENDIX A
EQUATIONS USED IN THE Cv-PAK

Aerodynamic noise prediction - Baumann method

$$SL = 145.5 + N + 10 \log (Cv\ FLp\ P1\ P2) - TL + G \qquad (1)$$

SL = Sound level, dBA @ 1.0 meter downstream of valve and 1.0 meter from pipe
N = Acoustical efficiency factor ($10 \log \eta$)
TL = Pipe wall transmission loss, dBA
G = Adjustment, dB

$$TL = 84.6 + 10 \log \left[\frac{t^3 (39 + D/2)}{D^3} \right] \qquad (2)$$

If $n(o) > 1$, add $10 \log n(0)$ to equation #2

IF reduced flow capacity exists ; $\overset{2}{Cv}\ FL < 4d$

Add to results of equation (2):

$$20 \log \left[\frac{4d^2}{Cv\ FL} \right]$$

For single seated globe valves, parabolic plug, flowed to open

$$10 \log \left[\frac{4d^2}{Cv\ FL} \right]$$

For all other valve types

Factor N at subsonic flow:

$$N = 26 \log \left[\frac{P1 - P2}{FL^2\ P1 - P1 + P2} \right] + 10 \log (FL^2) - 38.7$$

Aerodynamic noise- continued

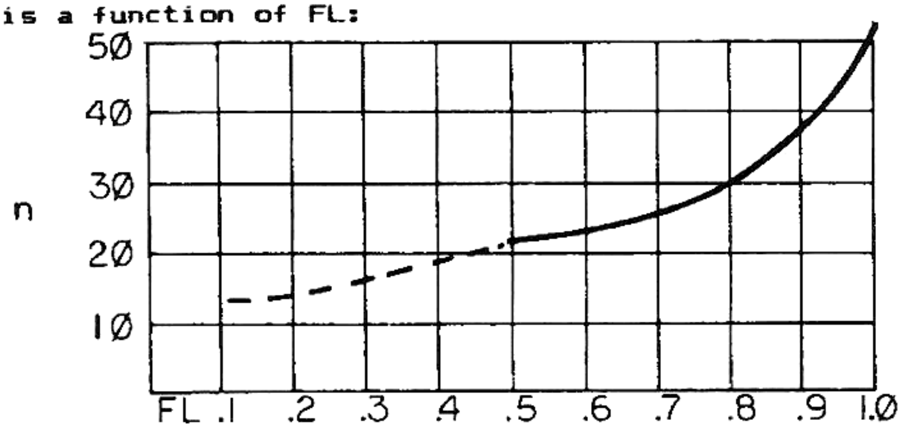
Factor N at sonic velocity up to break at (P1/P2)=2.8:

$$N = n \log \left[\frac{P1/P2}{P1/P2_{(sonic)}} \right] + 10 \log FL^2 - 38.7$$

Where

$$P1/P2_{(sonic)} = \left[\frac{P1}{P1 - (FL^2 \quad 0.5\ P1)} \right]$$

And n is a function of FL:



Factor N at supersonic flow (P1/P2) > 2.8:

$$N = 10 \log FL^2 + 10 \log (P1/2.8\ P2) - 30.0$$

APPENDIX A
EQUATIONS USED IN THE Cv-PAK

Laminer flow - Program LAM

Pseudo-sizing coefficient:

$$Cvc = \frac{q}{N1 \sqrt{\frac{P1-P2}{Gf}}}$$

Velocity of approach factor- can be disregarded

$$Rev = \frac{17,300\ Fd\ Q}{\nu \sqrt{FLp \sqrt{Cv}}} \left[\frac{1}{890} \frac{(FLp\ Cv)^2}{D^4} \right]^{1/4}$$

D = Nominal line size
Fd= Valve style modifier
ν = Kinematic viscosity of liquid - centistokes

Laminer flow Cv:

$$Cv = \frac{q}{Fr \sqrt{\frac{P1-P2}{Gf}}}$$

Fr = Reynolds number correction factor

Two phase flow - Program 2PH

$$Cvr = (Cvl + Cvg)\ (1.0 + Fm)$$

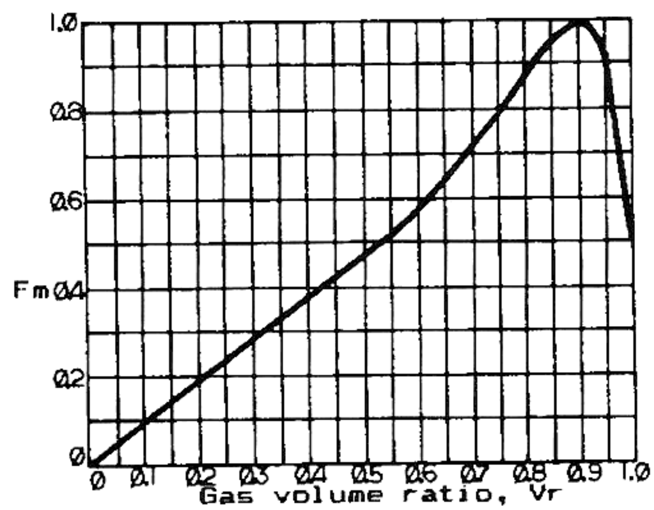
Where:
Cvr = Cv required for mixture flow
Cvl = Cv required for liquid phase
Cvg = Cv required for gas phase
Fm = Cv correction factor as a function of gas volume ratio

Gas volume ratio, Vr:

For liquid/gas mixtures:

$$Vr = \frac{Vg}{Vl + Vg} = \frac{Qg}{\left[\frac{284\ Ql\ P1}{T1}\right] + Qg}$$

Vg = Gas flow, ft^3/s
Vl = Liquid flow, ft^3/s
Qg = Gas flow, scfh
Ql = Liquid flow, gpm
T1 = Inlet temp., Rankine
Pi = Inlet press., psia



For liquid/vapor mixtures:

$$Vr = \frac{vg}{vg + vl\left(\frac{1-x}{x}\right)}$$

vg = Specific volume of gas phase, ft^3/lb
vl = Specific volume of liquid phase
x = Quality, lb. vapor/lb. mixture

APPENDIX A
EQUATIONS USED IN THE Cv-PAK

Outlet velocity, compressible fluids - program MACH

Outlet mach number:

$$M = \frac{Q\ (acfh)}{4380\ d^2 \sqrt{\frac{K\ T2}{M}}}$$

M = Mach no. @ outlet, out. vel/ sonic vel.
d = Outlet diameter, inches
T2= Outlet temperature, Rankine
M = Molecular weight

To convert volume units to actual cubic feet:

$$CFH = (SCFH) \times \left(\frac{14.7}{P2}\right) \times \left(\frac{T2}{520}\right) \times \left(\frac{Z2}{1}\right)$$

P2 = Pressure @ outlet, psia
Z2 = Compressibility @ outlet

To convert weight units to actual cubic feet:

$$\frac{lb/hr}{lb/ft^3} = ft^3/hr$$

$$lb/ft^3 = \frac{M\ P2}{10.73\ T2\ Z2}$$

APPENDIX E
REFERENCE MATERIAL

STEEL PIPE DATA

NOM. SIZE	NOM. O.D.		Sch 20	STD	Sch 30	Sch 40	XS	Sch 60	Sch 80	Sch 100	Sch 120	Sch 140	Sch 160	XXS
1	1.315	t		.133		STD	.179		XS				.250	.358
		d		1.049			.957						.815	.599
1.25	1.660	t		.140		STD	.191		XS				.250	.382
		d		1.380			1.278						1.160	.896
1.5	1.900	t		.145		STD	.200		XS				.281	.400
		d		1.610			1.500						1.338	1.100
2	2.375	t		.154		STD	.218		XS				.344	.436
		d		2.067			1.939						1.687	1.503
2.5	2.875	t		.203		STD	.276		XS				.375	.552
		d		2.469			2.323						2.125	1.771
3	3.500	t		.216		STD	.300		XS				.438	.600
		d		3.068			2.900						2.624	2.300
3.5	4.000	t		.226		STD	.318		XS					.636
		d		3.548			3.364							2.728
4	4.500	t		.237		STD	.337		XS		.438		.531	.674
		d		4.026			3.826				3.624		3.438	3.152
5	5.563	t		.258		STD	.375		XS		.500		.625	.750
		d		5.047			4.813				4.563		4.313	4.063
6	6.625	t		.280		STD	.432		XS		.562		.719	.864
		d		6.065			5.761				5.501		5.187	4.897
8	8.625	t	.250	.322	.277	STD	.500	.406	XS	.594	.719	.812	.906	.875
		d	8.125	7.981	8.071		7.625	7.813		7.437	7.187	7.001	6.813	6.875
10	10.750	t	.250	.365	.307	STD	.500	XS	.594	.719	.844	1.000	1.125	Sch
		d	10.250	10.020	10.136		9.750		9.562	9.312	9.062	8.750	8.500	140
12	12.750	t	.250	.375	.330	.406	.500	.562	.688	.844	1.000	1.125	1.312	Sch
		d	12.250	12.000	12.090	11.938	11.750	11.626	11.374	11.062	10.750	10.500	10.126	120
14	14.000	t	.312	.375	STD	.438	.500	.594	.750	.938	1.094	1.250	1.406	
		d	13.376	13.250		13.124	13.000	12.812	12.500	12.124	11.812	11.500	11.188	
16	16.000	t	.312	.375	STD	XS	.500	.656	.844	1.031	1.219	1.438	1.594	
		d	15.376	15.250			15.000	14.688	14.312	13.938	13.562	13.124	12.812	
18	18.000	t	.312	.375	.438	.562	.500	.750	.938	1.156	1.375	1.562	1.781	
		d	17.376	17.250	17.124	16.876	17.000	16.500	16.124	15.688	15.250	14.876	14.438	
20	20.000	t	STD	.375	XS	.594	.500	.812	1.031	1.281	1.500	1.750	1.969	
		d		19.250		18.814	19.000	18.376	17.938	17.438	17.000	16.500	16.062	
22	22.000	t	STD	.375	XS		.500	.857	1.125	1.375	1.625	1.875	2.125	
		d		21.250			21.000	20.250	19.750	19.250	18.750	18.250	17.750	
24	24.000	t	STD	.375	.562	.688	.500	.969	1.219	1.531	1.812	2.062	2.344	
		d		23.250	22.876	22.624	23.000	22.062	21.562	20.938	20.376	19.876	19.312	
26	26.000	t	XS	.375			.500							
		d		25.250			25.000							
28	28.000	t	XS	.375	.625		.500							
		d		27.250	26.750		27.000							
30	30.000	t	XS	.375	.626		.500							
		d		29.250	28.750		29.000							
36	36.000	t	XS	.375	.625	.750	.500							
		d		35.250	34.750	34.500	35.000							
42	42.000	t		.375	.625	.750	.500							
		d		41.250	40.750	40.500	41.000							

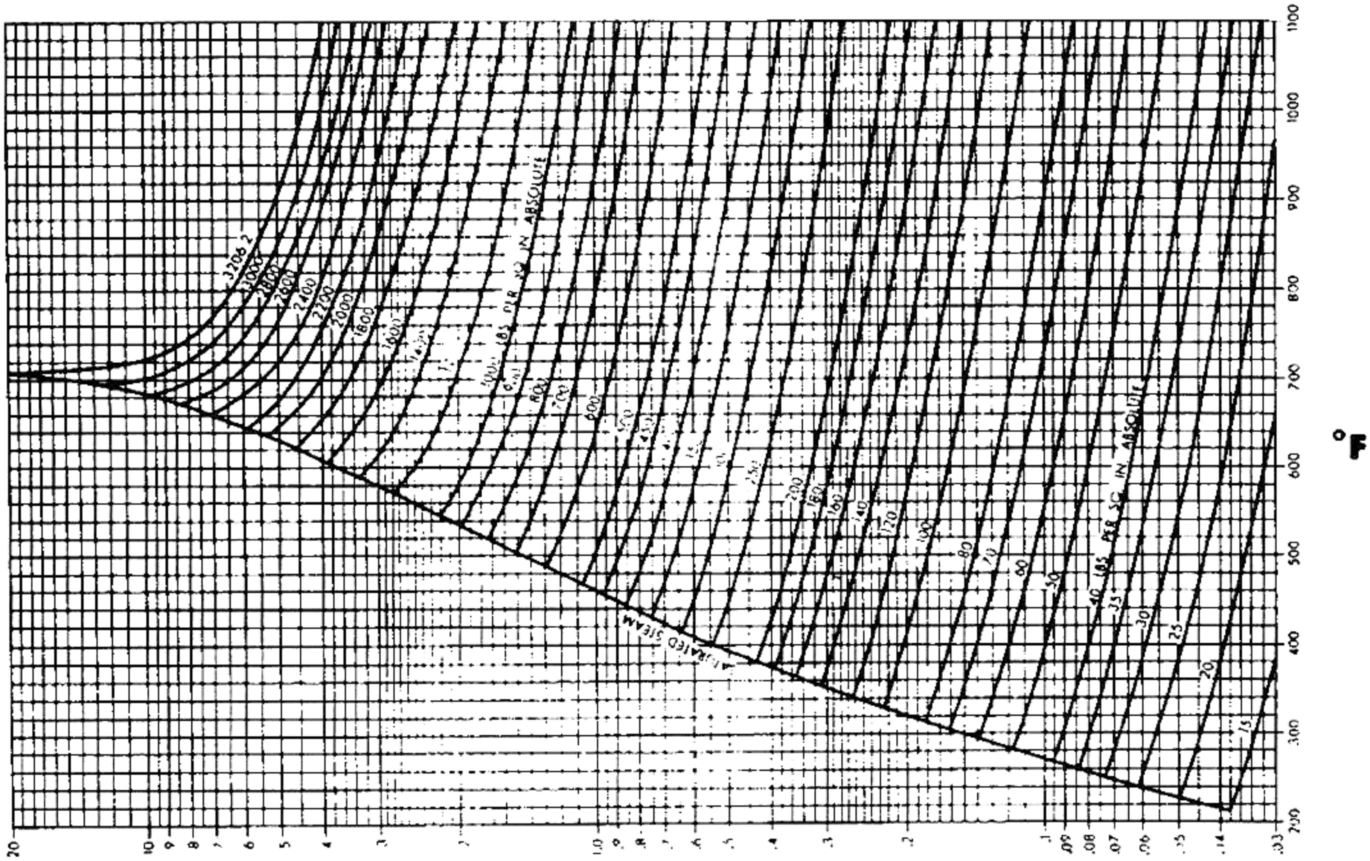
VALVE TYPE	No
Full bore ball valve	1
Single seat angle valve, flow to close	1
Eccentric rotary plug valve, flow to close	1
Segmented ball valve	1
Butterfly valve (non-fluted) 60° travel	2
Single seat globe valve, flow to open	2
Angle valve, flow to open	2
Eccentric rotary plug valve, flow to open	2
Double seated globe valve (parabolic)	4

GAS	G	GAS	G
Acetylene	-0.5	Hydrogen	-9.(
Air	0	Hydrogen Chloride	-1.(
Ammonia	1.5	Isobutane	-6.(
Argon	1.0	Methane	2.(
Butane	-6.0	Natural Gas	0.5
Carbon Dioxide	-3.0	Nitrogen	[illegible]
Carbon Monoxide	0	Oxygen	-0.5
Chlorine	-2.5	Pentane	-7.5
Ethane	-2.0	Propane	-4.5
Ethylene	-1.5	Propylene	4.5
Helium	-9.0	Sulphur Dioxide	5.(

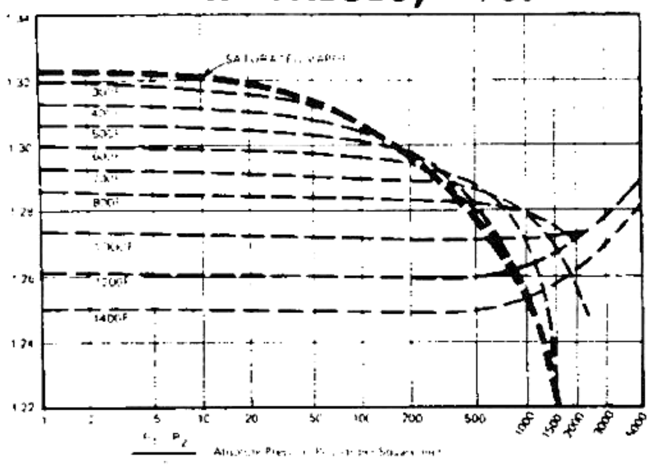
APPENDIX B

REFERENCE MATERIAL

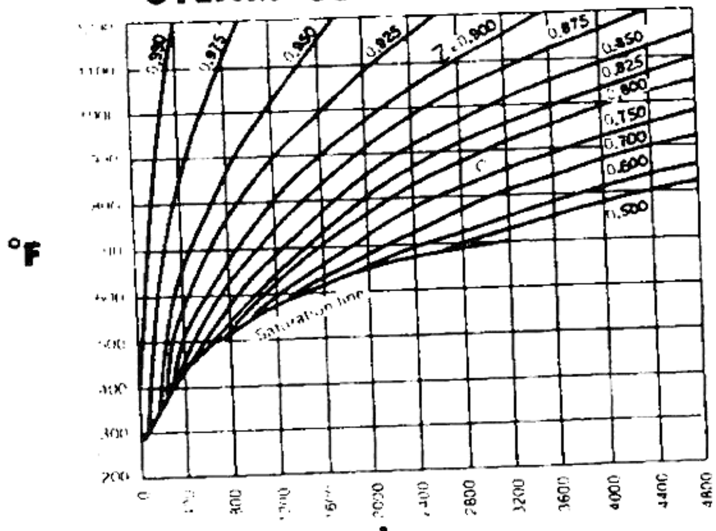
STEAM DENSITY, lb/ft³



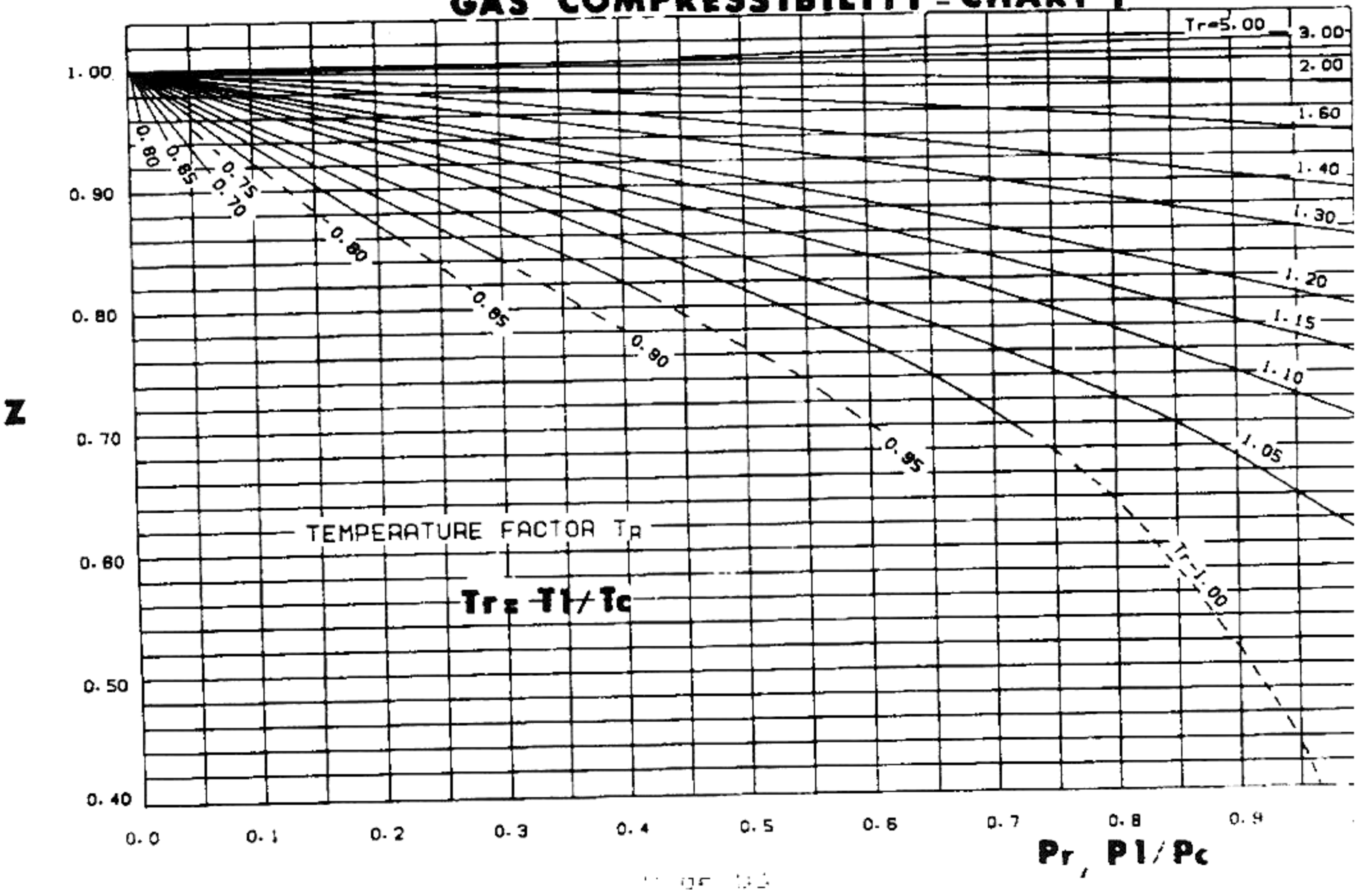
STEAM K VALUES, cP/cv



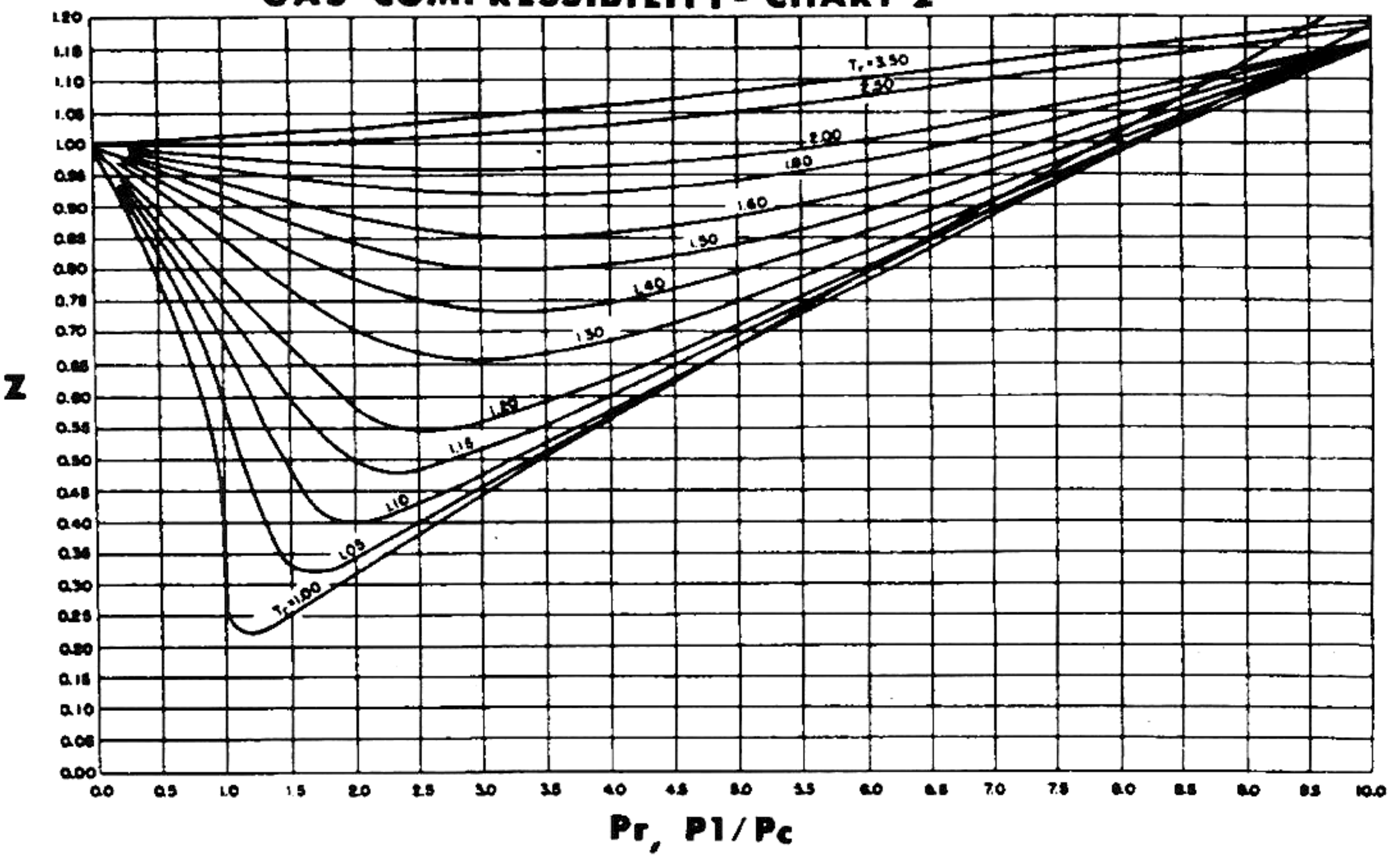
STEAM COMPRESSIBILITY



GAS COMPRESSIBILITY - CHART 1



GAS COMPRESSIBILITY- CHART 2



Critical Pressures and Temperatures for Various Gases

Gas	P critical psia/KPa	T critical °R/°K
Air	547 (3772)	240 (133)
Oxygen	731 (5040)	278 (154)
Nitrogen	492 (3392)	227 (126)
Hydrogen	306*(2110)*	41* (22)*
Carbon Dioxide	1073 (7398)	548 (304)
Helium	152* (1048)*	8* (4)*
Ammonia	1640 (11,308)	730 (405)
Methane	674 (4647)	343 (190)
Acetylene	912 (6288)	556 (309)
Argon	706 (4868)	272 (151)
Ethylene	7748 (5157)	509 (282)
Hydrogen Chloride	1200 (8274)	585 (325)
Nitric Oxide	956 (6592)	323 (179)
Sulfur Dioxide	1142 (7874)	775 (430)

Gas	Molecular formula	Molecular weight M	Cubic Weight γn		Spec. gravity (ratio of dens.)	Critical pressure		Critical temperature		Ratio of specific heats	
			lb/ft³	kg/m³	G_g	p_c/psia	p_c/bar	t_c/°F	t_c/°C	k*	
Acetylene	C_2H_2	26.04	.069	1.11	0.91	905	62.4	96	35.7	1.23	
Air	-	28.98	.076	1.225	1.00	547	37.7	-221	-140.7	1.40	
Ammonia	NH_3	17.03	.046	0.73	0.60	1638	113.0	271	132.4	1.32	
Argon	Ar	39.94	.106	1.69	1.38	705	48.6	-189	-122.4	1.67	
Benzene	C_6H_6	78.11	.206	3.30	2.70	703	48.5	551	288.5	1.10	(194°F)
Butane (n-)	C_4H_{10}	58.12	.162	2.59	2.09	529	36.5	309	153.2	-	
Butane (i-)	C_4H_{10}	58.12	.157	2.51	2.05	529	36.5	275	135.1	1.11	(59°F)
Butylene	C_4H_8	56.11	.148	2.37	1.94	570	39.5	296	146.6	-	
Carbon dioxide	CO_2	44.01	.117	1.87	1.53	1073	74.0	88	31.0	1.31	
Carbon monoxide	CO	28.01	.074	1.18	0.97	508	35.0	-220	-140.2	1.40	
Chlorine	Cl_2	70.91	.190	3.05	2.49	1116	77.0	292	144	1.34	
Chlorine dioxide	ClO_2	67.46	.184	2.94	2.40	-	-	-	-	-	
Cyanogen	C_2N_2	52.04	.139	2.23	1.78	882	60.8	262	128.3	1.26	
Dichlordi-flour methane (Freon 12)	CF_2Cl_2	120.92	.301	4.82	3.93	581	40.1	232	111.5	1.14	
Ethane	C_2H_6	30.07	.081	1.29	1.05	708	48.8	90	32.2	1.22	
Ethylene	C_2H_4	28.05	.074	1.19	0.98	742	51.2	49.5	9.7	1.25	
Fluorine	F_2	38.00	.101	1.61	1.31	808	55.7	-200	−128.7	-	
Formaldehyde	CH_2O	30.03	.082	1.32	-	-	-	-	-	-	
Helium	He	4.00	.011	0.17	0.14	33	2.3	-450	-267.9	1.66	
Hydrogen	H_2	2.02	.005	0.08	0.07	188	13.0	-400	-239.9	1.41	
Hydrogen bromide	HBr	80.92	.215	3.45	2.82	1241	85.6	194	90	1.36	
Hydrogen chloride	HCl	36.47	.097	1.55	1.27	1219	84.1	123	51.4	1.41	
Hydrogen iodide	HI	127.93	.343	5.49	4.48	1205	83.1	304	150.8	1.40	
Hydrogen sulfide	H_2S	34.08	.091	1.46	1.19	1306	90.1	213	100.5	1.33	
Methane	CH_4	16.04	.042	0.68	0.55	671	46.3	-117	82.5	1.30	
Methyl chloride	CH_3Cl	50.49	.137	2.19	1.78	969	66.8	290	143.1	1.28	
Methyl ether	C_2H_6O	46.07	.124	1.98	1.62	773	53.3	260	126.9	1.11	(68°F)
Methyl mercaptan	CH_4S	48.10	.066	1.06	0.87	1048	72.3	386	196.8	-	
Neon	Ne	20.18	.053	0.85	0.70	394	27.2	-380	-228.7	1.67	
Nitric oxide	NO	30.01	.079	1.27	1.04	956	65.9	-135	-94	1.40	
Nitrogen	N_2	28.02	.074	1.18	0.97	492	33.9	-232	-147.1	1.40	
Nitrous oxide	N_2O	44.02	.117	1.88	1.53	1054	72.7	98	36.6	1.28	
Oxygen	O_2	32.00	.084	1.35	1.11	731	50.4	-182	-118.8	1.40	
Ozone	O_3	48.00	.127	2.03	1.66	1356	93.5	23	-5	1.29	
Propane (n-)	C_3H_8	44.09	.119	1.90	1.56	618	42.6	206	96.8	1.14	
Propylene	C_3H_6	42.08	.113	1.81	1.48	666	45.9	198	92.0	-	
Sulfur dioxide	SO_2	64.06	.173	2.77	2.26	1143	78.8	316	157.3	1.29	
Steam	H_2O	18.02	(~.048)	(~0.76)	(~0.622)	3196	220.4	705	374	~1.3	(at normal conditions

* k is at temperature 32°F (0°C) unless otherwise specified.

LIQUID

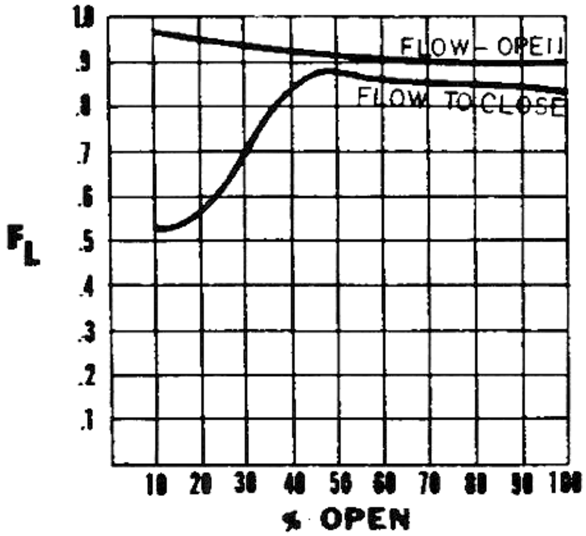
Liquid	Formula	Molecular weight M	Specific gravity G_f	Critical pressure p_c/psia	p_c/bar	Critical temperature t_c/°F	t_c/°C
Acetaldehyde	CH_3CHO	44.05	0.783	-	-	370	188
Acetic acid	CH_3COOH	60.05	1.049	840	57.9	612	322
Acetic anhydride	$(CH_3CO)_2O$	102.09	1.082	676	46.6	565	296
Acetone	$(CH_3)_2CO$	58.08	0.792	690	47.6	457	236
Amyl alcohol (i-)	$C_5H_{11}OH$	88.15	0.812	-	-	588	309
Amyl acetate (i-)	$CH_3COOC_5H_{11}$	130.18	0.873	-	-	618	326
Aniline	$C_6H_5NH_2$	93.12	1.022	770	53.1	798	426
Benzene	C_6H_6	78.11	0.879	705	48.6	552	289
Bromine	BR_2	159.83	3.120	1493	103	590	310
Butyl alcohol (i-)	C_4H_9OH	74.12	0.804	709	48.9	522	272
Carbon disulfide	CS_2	76.13	1.263	1073	74	523	273
Carbon tetrachloride	CCl_4	153.84	1.594	661	45.6	542	283
Chlorobenzene	C_6H_5Cl	112.56	1.107	655	45.2	678	359
Chloroform	$CHCl_3$	119.39	1.489	793	54.7	500	260
Cyclohexane	C_6H_{12}	84.16	0.779	584	40.3	536	280
Ethyl acetate	$CH_3COOC_2H_5$	88.10	0.900	555	38.3	482	250
Ethyl alcohol	C_2H_5OH	46.07	0.790	927	63.9	470	243
Ethyl ether	$(C_2H_5)_2O$	74.12	0.714	529	36.5	382	194
Ethylene glycol	$(CH_2OH)_2$	62.07	1.115	-	-	-	-
Ethylene trichloride	C_2HCl_3	131.40	1.464	728	50.2	520	271
Glycerine	$C_3H_5(OH)_3$	92.09	1.260	-	-	-	-
Heptane (n-)	C_7H_{16}	100.20	0.684	394	27.2	512	267
Hexane (n-)	C_6H_{14}	86.17	0.659	435	30.0	455	235
Mercury	Hg	200.61	13.546	15312	1056	2660	1460
Methyl alcohol	CH_3OH	32.04	0.792	1156	79.7	464	240
Methyl sulfide	$(CH_3)_2S$	62.13	0.845	802	55.3	446	230
Nitric acid	HNO_3	63.02	1.512	-	-	-	-
Octane (n-)	C_8H_{18}	114.22	0.702	363	25.0	565	296
Pentane (n-)	C_5H_{12}	72.15	0.626	484	33.4	387	197
Propionic acid	C_2H_5COOH	74.08	0.993	779	53.7	464	240
Propylalcohol (n)	C_3H_7OH	60.09	0.804	735	50.7	507	264
Propylamine	$C_3H_7NH_2$	59.11	0.719	687	47.4	435	224
Pyridine	C_5H_5N	79.10	0.983	882	60.8	652	344
Sulfurchloride	S_2Cl_2	135.03	1.68	-	-	-	-
Sulfuric acid	H_2SO_4	98.08	1.834	-	-	-	-
Toluene	$C_6H_5CH_3$	92.13	0.866	612	42.2	610	321
Water	H_2O	18.02	0.998	3196	220.4	705	374

Specific gravity at 68°F.

PROPERTIES OF WATER AT VARIOUS TEMPERATURES

(Referred to Water at 68 F Weighing 62 318 Lb/Cu Ft

Temp °F	Specific Volume cu ft/lb	Specific Gravity	Vapor Pressure PSIA	Temp °F	Specific Volume cu ft/lb	Specific Gravity	Vapor Pressure PSIA
32	0 01602	1.0016	0.0835	210	0.01670	0.9609	14.123
33	0.01603	1.0017	0.0922	220	0.01677	0.9569	17.186
34	0.01602	1.0017	0.0960	230	0.01684	0.9529	20.780
35	0.01602	1.0017	0.1000	240	0.01692	0.9484	24.969
36	0.01602	1.0017	0.1040	250	0.01700	0.9439	29.825
37	0.01602	1.0018	0.1082	260	0.01709	0.9392	35.429
38	0.01602	1.0018	0.1126	270	0.01717	0.9346	41.853
39	0.01602	1.0018	0.1171	280	0.01726	0.9297	49.203
40	0.01602	1.0018	0.1217	290	0.01735	0.9249	57.556
41	0.01602	1.0018	0.1265	300	0.01745	0.9196	67.013
42	0.01602	1.0018	0.1315	310	0.01755	0.9143	77.68
43	0.01602	1.0017	0.1367	320	0.01765	0.9092	89.60
44	0.01602	1.0017	0.1420	330	0.01776	0.9036	103.04
45	0.01602	1.0017	0.1475	340	0.01787	0.8920	118.01
46	0.01602	1.0017	0.1532	350	0.01799	0.8920	134.63
47	0.01603	1.0016	0.1591	360	0.01811	0.8361	153.04
48	0.01603	1.0016	0.1653	370	0.01823	0.8302	173.37
49	0.01603	1.0016	0.1716	380	0.01836	0.8741	195.77
50	0.01603	1.0015	0.1781	390	0.01850	0.8673	220.37
51	0.01603	1.0014	0.1849	400	0.01864	0.8609	247.31
52	0.01603	1.0014	0.1918	410	0.01878	0.8545	276.75
53	0.01603	1.0013	0.1990	420	0.01894	0.8473	308.83
54	0.01603	1.0013	0.2064	430	0.01910	0.8402	343.72
55	0.01603	1.0012	0.2141	440	0.01926	0.8332	381.59
56	0.01603	1.0011	0.2220	450	0.0194	0.826	422.6
57	0.01603	1.0010	0.2302	460	0.0196	0.818	466.9
58	0.01604	1.0010	0.2386	470	0.0195	0.810	514.7
59	0.01604	1.0009	0.2473	480	0.0200	0.802	566.1
60	0.01604	1.0008	0.2563	490	0.0202	0.794	621.4
62	0.01604	1.0006	0.2751	500	0.0204	0.786	680.3
64	0.01605	1.0004	0.2951	510	0.0207	0.775	744.3
66	0.01605	1.0002	0.3164	520	0.0209	0.767	812.4
68	0.01605	1.0000	0.3390	530	0.0212	0.757	885.0
70	0.01606	0.9998	0.3631	540	0.0215	0.746	962.5
75	0.01607	0.9991	0.4298	550	0.0218	0.737	1045.2
80	0.01608	0.9984	0.5069	560	0.0221	0.725	1133.1
85	0.01609	0.9976	0.5959	570	0.0224	0.716	1226.5
90	0.01610	0.9968	0.6952	580	0.0228	0.704	1325.8
95	0.01612	0.9958	0.8153	590	0.0232	0.692	1431.2
100	0.01613	0.9949	0.9492	600	0.0236	0.680	1542.9
110	0.01617	0.9927	1.275	610	0.0241	0.666	1661.2
120	0.01620	0.9903	1.692	620	0.0247	0.650	1786.6
130	0.01625	0.9878	2.223	630	0.0253	0.634	1919.3
140	0.01629	0.9850	2.889	640	0.0260	0.618	2059.7
150	0.01634	0.9321	3.713	650	0.0268	0.599	2203.2
160	0.01639	0.9790	4.741	660	0.0278	0.578	2365.4
170	0.01645	0.9755	5.992	670	0.0290	0.554	2531.8
180	0.01651	0.9720	7.510	680	0.0305	0.526	2703.1
190	0.01657	0.9684	9.337	690	0.0328	0.489	2895.1
200	0.01663	0.9619	11.526	705 4	0.0503	0.319	3205.2



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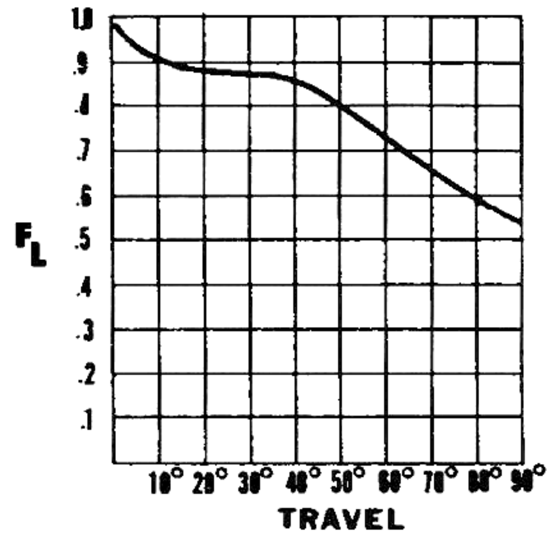

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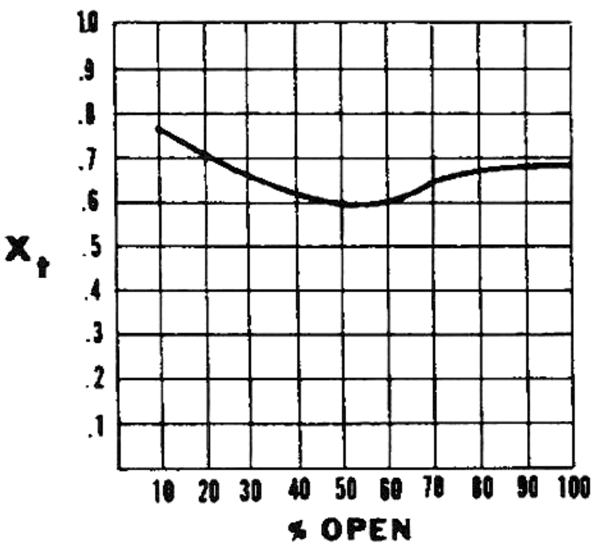

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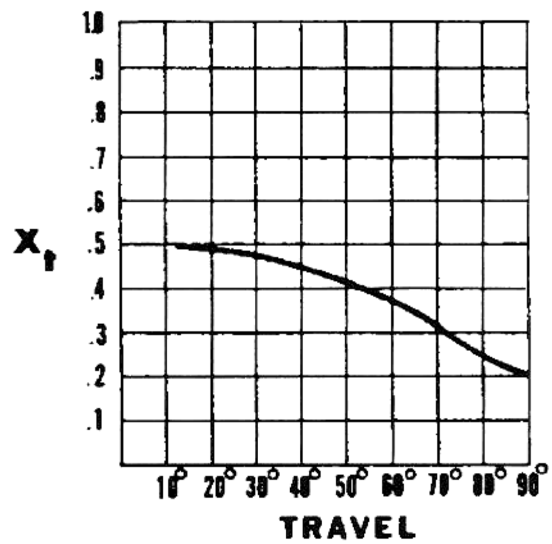

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