

Mechanical Engineering Review
Problems and Solutions



CHOTKEH

Mechanical Engineering Review

Problems and Solutions

Mechanical Engineering Review Software Package.
Version (6.0)

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TABLE OF CONTENTS

<u>SUBJECT</u>	<u>SECTION</u>
COMBUSTION	1
DUCTS	2
ELECTRICITY	3
ENGINEERING ECONOMICS	4
FANS	5
GEARS	6
HEAT TRANSFER	7
HVAC	8
HYDRAULIC MACHINES	9
POWER CYCLE	10
SPRINGS	11

COMBUSTION EXAMPLES

1. If the gravimetric analysis of a compound shows 19.4% carbon, 77.4% oxygen, and 3.2% hydrogen, determine:
The simplest molecular formula.

Solution (REFERENCE: HP48 CALCULATOR):

To calculate the molecular number of every element, take the following steps:

Step 1 Divide the percentage of each element by its atomic weight:

For C: Key in 19.4 SPC 12 press ÷ 1.62

For O: Key in 77.4 SPC 16 press ÷ 4.84

For H: Key in 3.2 SPC 1 press ÷ 3.2

Step 2 Pick the lowest number of the results , i.e. 1.62 and divide each element's result by that:

For C: Key in 1.62 SPC 1.62 press ÷ C = 1

For O: Key in 4.84 SPC 1.62 press ÷ O = 3

For H: Key in 3.2 SPC 1.62 press ÷ H = 2

Formula = CH_2O_3 , Answer.

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2. If a heater burns 200 cf of methane and heats up the water from 60 oF to 200 oF, determine:
The weight of the heated water. Assume the heating value of methane equals to 24,000 BTU/lbm and the efficiency of the system as 50%.

Solution (REFERENCE: CHOTKEH MANUAL):

This is a Combustion (CMBS), boilers/heaters (HEATR), problem.

To calculate the weight of the heated water, in English Units, refer to equation (06) ENG
(CMBS/HEATR/WATR)

For $m_f = 200 \times 0.0416 = 8.32$ lbm (0.0416 is methane density from CHOTKEH's Gas Properties Table, page 1-5), $HV = 24000$ BTU/lbm, $\eta = .5$, $t_{out} = 200$ oF, and $t_{in} = 60$ oF

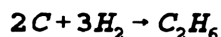
$m_w = 713.14$ lbm, Answer.

COMBUSTION EXAMPLES

3. Determine the weight of carbon and hydrogen required to produce 33 g of ethane (C₂H₆).

Solution (REFERENCE: CHOTKEH MANUAL):

Step 1 Write the ideal chemical reaction:



Step 2 To find the weight of the elements, C and H, in a binary compound reaction, refer to equation (05) **BI.EQ** (CMBS)

Step 3 Calculate weight of carbon (W1):

For W2= key in ' 33-W1 **ENTER**, press menu key under W2, **NA1=2** (number of atoms of carbon), **NA2=6** (number of atoms of hydrogen), **AW1=12** (atomic weight of carbon), and **AW2=1** (atomic weight of hydrogen)

Press $\leftarrow$ W1

$$W1(C) = 26.4 \text{ g.}$$

Step 4 Stay with the same equation and calculate weight of hydrogen (W2)

Press $\leftarrow$ W2

$$W2(H) = 6.6 \text{ g.}$$

C = 26.4 g and H = 6.6 g, <u>Answer.</u>
--

NOTE: Ensure to solve W1 first and W2 afterward.

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4. Determine the theoretical weight of oxygen required for perfect combustion of 250 g carbon.

Solution (REFERENCE: CHOTKEH MANUAL):

Step 1 Write the ideal combustion reaction: $C + O_2 \rightarrow CO_2$

Step 2 To find the weight of oxygen, O, in a binary compound reaction, refer to equation (05) **BI.EQ** (CMBS)

For W1=250 g, NA1=1, NA2=2, AW1=12, AW2=16

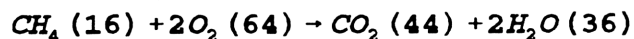
W2 (O) = 666.7 g, <u>Answer.</u>

COMBUSTION EXAMPLES

5. Determine the volume of dry CO₂ generated from a perfect combustion of 30 pound of methane (CH₄). Assume flue gas temperature as 90 oF at 30 inHg.

Solution (REFERENCE: CHOTKEH MANUAL):

Step 1 Write the ideal chemical reaction:



Step 2 To find the volume of CO₂, with the given mass, refer to ideal gas equation (24) MASS (CMBS/I.GAS)

For $p=30$ inHg=**2121.79** psf (unit conversion), $m=$ key in $'44/16*30=82.5$ lbm (weight of generated CO₂), $R=35.1$ ft-lbf/lbm-oR (from CHOTKEH Gas Table, Page 1-5), and $T=90+460=550$ oR

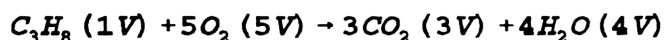
$$V = 750.6 \text{ cf, Answer.}$$

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6. Determine the weight of air required to burn 10,000 cf of propane (C₃H₈). Assume perfect combustion and 33% excess air at 85 oF and 14.7 psia.

Solution (REFERENCE: CHOTKEH MANUAL):

Step 1 Write the ideal chemical reaction:



Step 2 To find the mass of air, calculate the mass of Oxygen first. Refer to ideal gas equation (24) MASS (CMBS/I.GAS)

For $p=14.7*144=2116.8$ psf (unit conversion), $V=$ key in $'10000*5*1.33$ (from formula + 33% excess air)=**66500** cf, $R=48.3$ ft-lbf/lbm-oR (from CHOTKEH's Gas Property Table, page 1-5), and $T=85+460=545$ oR

$$m\text{O}_2 = 5348 \text{ lbm.}$$

Considering 4.32 as air/oxygen weight ratio.

$$m\text{Air} = 23102 \text{ lbm, Answer.}$$

COMBUSTION EXAMPLES

7. For one (1) pound of a solid fuel having the following composition analysis:
Carbon: 85%, Hydrogen: 13.7%, Nitrogen: 0.4%, and Sulfur: 0.9%, determine:
The amount of air required for perfect combustion.

Solution (REFERENCE: CHOTKEH MANUAL):

This is a Combustion (CMBS), mass of air (AIR/MASS), problem.

To find the mass of air, for a solid fuel, refer to equation (02) **SOLID** (CMBS/AIR/MASS)

For $m_f = 1$ lb, $W.C = .85$, $W.H_2 = .137$, $W.O_2 = 0$, $W.S_2 = .009$, and $X_{AIR} = 0$ (Assum. no excess air)

$m_{Air} = 14.47 \text{ lbm/lb of fuel, Answer.}$

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8. Following are the information about 1000 pound of coal burned.

<u>Combustion ash</u>	<u>Coal ultimate analysis</u>	<u>Dry flue gas</u>
Ash removed: 180 lb	Carbon: 54.0%	12 lb/lb of fuel, including fly ash.
Carbon content: 20%	Hydrogen: 4.5%	
Fly ash to calculate	Oxygen: 7.0%	
	Nitrogen: 1.0%	
	Sulfur: 4.0%	
	Ash: 17.0%	
	Moisture: 12.5%	

Based on above data, determine:

The mass of supply air per pound of fuel.

Solution (REFERENCE: CHOTKEH MANUAL):

This is a Combustion (CMBS), mass of air, problem.

Considering that the amount of excess air is not specified, to solve the problem: (1) find the percentage of burned carbon, (2) calculate the theoretical amount of air needed for combustion (no excess air), (3) find the theoretical weight of flue gas (excluding excess air), and finally (4) calculate the amount of excess air and add it up to the amount of calculated air, step (2) above.

COMBUSTION EXAMPLES

Step 1 Calculate the percent of carbon burnt (% in coal minus % in ash)

$$C = \text{Key in } '.54 - 180 \times .2 / 1000 \text{ (\% of carbon in removed ash)} = .504 \text{ or } 50.4\%$$

Step 2 Calculate the theoretical mass of air/lbm of fuel.

Refer to equation (02) **SOLID** (CMBS/AIR/MASS)

For $m_f = 1$, $W.C = .504$, $W.H_2 = .045$, $W.O_2 = .07$, $W.S_2 = .04$, and $X_{AIR} = 0$

$$m_a = 7.186 \text{ lbm of air/lbm of fuel.}$$

Step 3 Calculate the theoretical weight of flue gas which consists of the following:

Burned material:	$.504(C) + .045(H_2) + .04(S_2)$	0.589
Free O ₂ and intact N ₂ in coal:	$.07 + .01$	0.08
Combustion air (step 2)		7.186
Fly ash in flue: .17 (ash in coal) - 180*.8/1000		0.026
Theoretical weight of flue gas (wet)		7.881
Less weight of generated water: $.045 (H_2) \times 9$		0.405
Theoretical weight of flue gas (dry)		7.476 lb/lb.

Step 4 Calculate the excess air and total air:

Excess air = Actual flue (given) - Theoretical (above) = 12 - 7.476	4.525
Theoretical combustion air (step 2)	7.186
	11.71 lb/lb

$$m_{Air} = 11.71 \text{ lbm of air/lb of coal, Answer.}$$

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9. A flue gas from a solid fuel has the following volumetric analysis:

CO₂: 11%, CO: 1%, N₂: 82%, O₂: 6%

If the barometric pressure is 30 inHg and the temperature of intake air measured as 68 °F, determine:

COMBUSTION EXAMPLES

a. Percentage of supplied excess air.

b. Volume of air used per lbm of fuel. Assume the fuel contains 93% C and 7% H₂

Solution (REFERENCE: CHOTKEH MANUAL):

This is a Combustion (CMBS), Excess air, mass of air (AIR/MASS), problem.

a. To find the excess air refer to equation (04) **EXAIR** (CMBS/AIR)

For $V.O_2 = .06$, $V.CO = .01$, and $V.N_2 = .82$

$$XAIR = .34 = 34\%, \text{ Answer for (a).}$$

b. To find the volume of air find the mass first. Refer to equation (02) **SOLID** (CMBS/AIR/MASS)

For $m_f = 1$, $W.C = .93$, $W.H_2 = .07$, $W.O_2 = 0$, $W.S_2 = 0$, and $XAIR = .34$ $m_a = 17.49 \text{ lbm/lb fuel.}$

With the calculated mass of the air, to find the volume, refer to ideal gas equation (24) **MASS** (CMBS/I.GAS)

For $p = 30 \text{ inHg} = 2121.79 \text{ psf}$ (unit conversion), $m = 17.49 \text{ lbm}$, $R = 53.3 \text{ ft-lbf/lbm-oR}$ (From CHOTKEH's Gas Table, page 1-5), and $T = 68 + 460 = 528 \text{ oR}$

$$V = 232 \text{ cf of air/ lbm of fuel, Answer for (b).}$$

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10. The analysis of coal and the stack flue gas are shown below:

<u>Coal ultimate analysis</u>		<u>Flue gas</u>	
Carbon:	82.0%	CO ₂ :	11.0%
Hydrogen:	4.5%	CO:	0.5%
Oxygen:	2.0%	O ₂ :	6.5%
		N ₂ :	82.0%

Based on the above, determine:

The amount of air required for perfect combustion.

Solution (REFERENCE: CHOTKEH MANUAL):

This is a Combustion (CMBS), excess air and mass of air (AIR/MASS), problem.

COMBUSTION EXAMPLES

To solve this problem, the amount of excess air must be calculated first. Refer to equation (04) **EXAIR** (CMBS/AIR).

For $V.O_2 = .065$, $V.CO = .005$, and $V.N_2 = .82$

$$\underline{XAIR = 0.406}$$

To calculate the amount of air, refer to equation (02) **SOLID** (CMBS/AIR/MASS)

For $m_f = 1$ lbm, $W.C = .82$, $W.H_2 = .035$, $W.O_2 = .02$, $W.S_2 = 0$, and $XAIR = .406$

$$m_{air} = 15.25 \text{ lbm/lb of coal, Answer.}$$

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11. For a coal having the following gravimetric composition analysis:

Carbon: 82%, Hydrogen: 5.5%, Oxygen: 7.7%, and Nitrogen: 1.7%, determine:

- a. The theoretical temperature of the product of combustion. Assume perfect combustion, no excess air. For air: $c_{pa} = .24$ BTU/lbm-oF, for flue: the average $c_{pg} = .255$ BTU/lbm-oF, and the combustion intake air temperature equals to 68 oF.
- b. The actual temperature of the product of combustion. Assume perfect combustion, 38% excess air, and that the 75% of the generated heat is absorbed by the boiler.

Solution (REFERENCE: CHOTKEH MANUAL):

This is a Combustion (CMBS) problem.

To solve this problem, (1) calculate the coal's HV, (2) the amount of air used for the combustion, and finally (3) from the heat balance equation, determine the product's (flue) temperature.

Step 1 Calculate the Heating Value (HV) of the coal.

For coal HV in English units, refer to equation (12) **ENG** (CMBS/HTVAL/COAL)

For $W.C = .82$, $W.H_2 = .055$, $W.O_2 = .077$, and $W.S_2 = 0$ $HV.C = 14322$ BTU/lbm of fuel.

Step 2 Calculate the amount of air for solid fuel.

Refer to equation (02) **SOLID** (CMBS/AIR/MASS).

For question (a), with no excess air:

For $m_f = 1$ lbm, $W.C = .82$, $W.H_2 = .055$, $W.O_2 = .077$, $W.S_2 = 0$, and $XAIR = 0$

$$\underline{m_a(a) = 10.94 \text{ lbm air/lb of fuel.}}$$

COMBUSTION EXAMPLES

question (b):

For the same values, but **XAIR = .38**

$$\underline{ma(b) = 15.1 \text{ lbm air / lb of fuel.}}$$

Step 3 Calculate the product's temperature.

For English Units, refer to heat balance equation (10) **ENG** (CMBS/HTBAL)

question (a):

For **mf = 1 lbm**, **HV = 14322 BTU/lbm**, **$\eta = 0$** , **ma = ma(a) = 10.94 lbm**, **c_{pa} = .24**

BTU/lbm-oF, **t_{sup} = 68 oF**, **t_{amb} = 68 oF**, **mg = 1 + 10.94 = 11.94 lbm (air + fuel)**, **c_{pg} = .255**

BTU/lbm-oF, **mH₂O = .055*18/2 = .495 lbm**

$$t_g = 4614 \text{ oF, Answer for (a).}$$

question (b):

The same equation with the same data but, **$\eta = .75$** (generated heat absorbed by the boiler),

ma = ma(b) = 15.1 lbm, and **mg = 1 + 15.1 = 16.1 lbm (air + fuel)**.

$$T_g = 823 \text{ oF, Answer for (b).}$$

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Problem 12 - 14

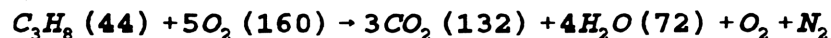
A flow of 350 SCFM of propane is mixed with an oxidizer containing 63% O₂ and 37% N₂, which provides 43% excess oxygen by weight. If the maximum velocity of fuel/oxidizer is 350 fpm with 78 oF temperature at 14.7 psia and the velocity of exhaust is 780 fpm with 450 oF at 9 psia, solve the following problems (12 thru 14):

12. Determine the size of the intake duct.

Solution (REFERENCE: CHOTKEH MANUAL):

To find the size of the intake duct, the volumetric flow of the gas mixture must be calculated.

Step 1 Write the ideal burning chemical reaction for propane (C₃H₈):



COMBUSTION EXAMPLES

Step 2 Calculate the actual weight of the gas mixture (propane + oxygen)

Weight of 350 CFM propane at the Standard condition (60 oF, 14.7 psia) :

For calculating the mass, refer to ideal gas equation (24) **MASS** (CMBS/I.GAS)

For $p = 14.7 \times 144 = 2116.8$ psf, $V = 350$ cfm, $R = 35$ ft-lbf/lbm-oR (from CHOTKEH Gas Table, page 1-5), and $T = 60 + 460 = 520$ oR $\underline{m(C_3H_8) = 40.71 \text{ lbm/min}}$

Weight of the Oxygen.

Considering the chemical reaction and the amount of excess air:

$$m(O_2) = m(C_3H_8) * 160/44 * (1 + X_{AIR}):$$

Key in '40.71*160/44*(1+.43) **EVAL** $\underline{m(O_2) = 211.69 \text{ lbm/min}}$

Step 3 Calculate the volume of the gas mixture (propane + oxidizer)

Volume of the Propane at the given condition (78 oF, 14.7 psia) :

Use the same (I.GAS) equation.

For $p = 14.7 \times 144 = 2116.8$ psf, $m = 40.71$ lbm/min, $R = 35$ ft-lbf/lbm-oR, and $T = 78 + 460 = 538$ oR $\underline{V(C_3H_8) = 362.14 \text{ cfm}}$

Volume of Oxygen.

Use the same (I.GAS) equation.

For $p = 14.7 \times 144 = 2116.8$ psf, $m = 211.69$ lbm/min, $R = 48.3$ ft-lbf/lbm-oR (from CHOTKEH Gas Table, page 1-5), and $T = 78 + 460 = 538$ oR $\underline{V(O_2) = 2598.66 \text{ cfm}}$

Volume of Nitrogen.

considering $N_2/O_2 = 37/63$ (given), key in '2598.66*37/63 **EVAL** $\underline{V(N_2) = 1526.2 \text{ cfm}}$

Step 4 Calculate the area of the duct.

From **area = cfm/fpm**, key in '(362.14 + 2598.66 + 1526.2)/350 **EVAL**

area = 12.82 sf, Answer.

13. Determine the diameter of stack.

Solution (REFERENCE: CHOTKEH MANUAL):

To find the size of the stack, the volume of the flue must be calculated.

Use the reaction equation, find the weight of every component in the flue, then by using the current gas equation (I.GAS), calculate the volume.

COMBUSTION EXAMPLES

V(CO₂): For $p = 9 \times 144 = 1296$ psf, $m(\text{CO}_2) = \text{Key in '40.71} \times 132/44 \text{ EVAL} = 122.13 \text{ lbm}$,
 $R = 35.1 \text{ ft-lbf/lbm-oR}$ (from CHOTKEH Gas Table, page 1-5), and
 $T = 450 + 460 = 910 \text{ oR}$ $V(\text{CO}_2) = 3010 \text{ cf.}$

V(H₂O): For $p = 9 \times 144 = 1296$ psf, $m(\text{H}_2\text{O}) = \text{Key in '40.71} \times 72/44 \text{ EVAL} = 66.62 \text{ lbm}$,
 $R = 85.8 \text{ ft-lbf/lbm-oR}$ (from CHOTKEH Gas Table, page 1-5), and
 $T = 450 + 460 = 910 \text{ oR}$ $V(\text{H}_2\text{O}) = 4013.55 \text{ cf.}$

V(O₂): For $p = 9 \times 144 = 1296$ psf, $m(\text{O}_2) = \text{Key in '211.69} \times .43/1.43 \text{ EVAL} = 63.66 \text{ lbm}$
(excess oxygen), $R = 48.3 \text{ ft-lbf/lbm-oR}$ (from CHOTKEH Gas Table, page 1-5), and
 $T = 450 + 460 = 910 \text{ oR}$ $V(\text{O}_2) = 2159 \text{ cfm.}$

V(N₂): To find $V(\text{N}_2)$, not knowing the weight of N_2 , use the following ideal gas equation:
 $p_1 \times V_1 \times T_2 = p_2 \times V_2 \times T_1$:
For $p_1 = 14.7 \times 144 = 2116.8$ psia (problem 10), $V_1 = 1526.2 \text{ cfm}$ (from problem 10),
 $T_2 = 450 + 460 = 910 \text{ oR}$, $p_2 = 9 \times 144 = 1296$ psf, and $T_1 = 78 + 460 = 538 \text{ oR}$ (problem 10):
Key in $'2116.8 \times 1526.2 \times 910 / (1296 \times 538) \text{ EVAL}$
 $V(\text{N}_2) = 4216.43 \text{ cfm.}$

Area: Calculate the area of the duct.

From $\text{area} = \text{cfm/fpm}$, key in $'(3010 + 4013.55 + 2159 + 4216.43)/780 \text{ EVAL}$

area = 17.18 sf, Answer.

14. Determine the exhaust Dew Point.

Solution (REFERENCE: HP48 CALCULATOR AND STEAM TABLE):

The exhaust dew point is the flue temperature at which the water vapor, in the flue, will condensate.
To find this temperature, the vapor's partial pressure must be calculated first, then by knowing the pressure, from the steam table, the corresponding saturated temperature to be identified.

Step 1 Find the partial pressure:

From $P(\text{H}_2\text{O})/P(\text{total}) = V(\text{H}_2\text{O})/V(\text{total})$:

$P(\text{H}_2\text{O}) = \text{key in '4013.55/13398.98} \times 9 \text{ EVAL} = 2.696 \text{ psia.}$

From saturated steam: pressure table, for $P = 2.696$ (by interpolation)

COMBUSTION EXAMPLES

Dew point (saturated temperature) = 136.8 oF, Answer.

NOTE: Using CHOTKEH'S steam table, SAT.P: For P=2.696 psia

Dew point = 137.3 oF

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15. For a flue stack, 90 ft high, if the ambient temperature and pressure are 29 inHg and 62 oF respectively, determine:

The stack effect, in inH₂O. Assume the average flue temperature measured as 510 oF.

Solution (REFERENCE: CHOTKEH MANUAL):

This is a Combustion (CMBS), stack (STAK), problem.

To calculate the stack effect, in English Units, refer to equation (34) **ENG** (CMBS/STAK/EFFECT)

For **p**=29 inHg=14.24 psia (Unit conversion)=**2050.56** psf, **H**=90 ft, **T_a**=62+460=**522** oR,

T_g=510+460=**970** oR, and **R**=**53.3** ft-lbf/lbm-oR (From CHOTKEH Gas Table, page 1-5)

$$\text{effect} = 3.0625 \text{ psf} = 0.02127 \text{ psi}$$

Use the Unit conversion. For 0.02127 psi

effect = .59 inH₂O, Answer.

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Problems 16 - 18

27 meter high stack is surrounded by 15 oC ambient air at 100 kPa absolute pressure. If the average flue temperature is measured as 240 oC, solve the following problems:

16. Determine: The stack effect, in Pa and mmHg.

Solution (REFERENCE: CHOTKEH MANUAL):

This is a Combustion (CMBS), stack (STAK), problem.

To calculate the stack effect, in SI Units, refer to equation (35) **SI** (CMBS/STAK/STAK)

For **p**=100000 Pa, **H**=27 m, **R**=287 J/kg.K (CHOTKEH's Gas property Table, page 1-5), and

T_a=15+273=**288** K, **T_g**=240+273=**513** K.

COMBUSTION EXAMPLES

$\text{efect} = 140.6 \text{ Pa} = 1.055 \text{ mmHg (Unit Conversion), Answer.}$

16. **Determine: The density of the flue gas.**

Solution (REFERENCE: CHOTKEH MANUAL):

To find the flue's density, refer to ideal gas mass equation (24) **MASS** (CMBS/I.GAS)

For $p=100000 \text{ Pa}$, $V=1 \text{ m}^3$, $R=286.8 \text{ J/kg.K}$, and $T=T_g=513 \text{ K}$

$\text{Density} = m = 0.68 \text{ kg/m}^3, \text{ Answer.}$

17. **Determine: The stack head.**

Solution (REFERENCE: CHOTKEH MANUAL):

To find the stack's head, refer to equation (36) **HEAD** (CMBS/STAK)

For $H=27 \text{ m}$, $T_g=513 \text{ K}$, and $T_a=288 \text{ K}$

$\text{head} = 21.1 \text{ m, Answer.}$

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Problems 19 - 22

An electric power plant with coal fired steam boiler has the following characteristics:

Maximum power capacity: 22,000 kW

Electric generator efficiency: 94%

Steam turbine efficiency: 85%

Coal consumption rate: 8,700 kg/hr

Refused removal: 235 kg/hr (including 35% carbon and no sulfur)

If the ultimate fuel analysis measured as: carbon 76%, oxygen 8%, sulfur 2.5%, silicon 6%, nitrogen 2%, and hydrogen 5.5%, solve the following problems:

COMBUSTION EXAMPLES

19. Determine the rate of produced sulfur dioxide (SO₂), in kg/hr:

Solution (REFERENCE: HP48 CALCULATOR):

From S (MW=32) + O₂ (MW=32) = SO₂ (MW=64) and considering that all sulfur is burnt, each 32 kg of S produces 64 kg SO₂, therefore for 2.5% sulfur content, to find the rate:

key in ' 8700*.025*64/32 EVAL

Rate (SO₂) = 435 kg/hr, Answer.

20. Determine the emission rate of the solid particulate, in kg/hr:

Solution (REFERENCE: HP48 CALCULATOR):

Considering that:

the solid particulate is in the form of (SiO₂);

each 60.1 kg of SiO₂ contains 28.1 kg of Si;

35% of refuse is carbon (the balance is SiO₂); and

the fuel silicon content is 6%, to find the rate:

key in ' 8700*.06*60.1/28.1 - 235*(1-.35) EVAL

Rate (solid particulate) = 963.7 kg/hr, Answer.

21. If the environmental regulations requires that the rate of the emission of solids particulate not to exceed 60 g/GJ/hr, determine the efficiency of dust collection system.

Solution (REFERENCE: CHOTKEH MANUAL):

Following steps must be taken to solve the problem:

Step 1 Calculate the heat value of the fuel:

For heat value of coal, in SI units, refer to equation (13) SI (CMBS/HTVAL/COAL)

For W.C= key in ' .76 - .35*235/8700 EVAL = 0.7505, W.H₂ = 0.055, W.O₂ = 0.08, and

W.S₂ = 0.025

HV.C = 3.12EE7 J/kg

COMBUSTION EXAMPLES

Step 2 Calculate total hourly input heat:

key in '8700*3.12EE7 EVAL

qin = 271.4 GJ/hr

Step 3 Calculate the allowable emission rate:

key in ' 271.4*.06 EVAL

Rate (allowed) = 16.28 kg/hr

Step 4 Determine the efficiency:

Use the total emission rate, from problem 20 (963.7 kg/hr)

Key in ' (963.7 - 16.28)/963.7 EVAL = .983

efficiency = 98.3%, Answer.

22. If the river water used to cool the generating system, determine the flow rate of the cooling water in liter per second. Assume the maximum allowable water temperature rise as 1.5 oC

Solution (REFERENCE: CHOTKEH MANUAL):

To find the flow rate, in SI units, refer to power plant condensate equation (28) SI
(CMBS/PLANT/COND/FLOW)

For $q_{in} = 271.4 \text{ EE9 J/hr}$ (problem 21), $kW = 22000$, $\eta_{GEN} = .94 * .85 = .799$, and $\Delta t = 1.5^\circ C$

lps = 7,621, Answer.

* * * * *

Problems 23 - 25

Two (2) kgmole of methane (CH₄) burnt, in dry air, to CO₂ and H₂O. If the combustion products cooled and dried, solve the following problems:

23. Determine the volume of dried flue gas at 20 oC and 750 mmHg. Assume 12% excess air.

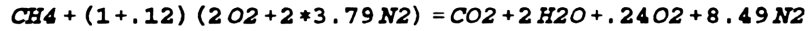
Solution (REFERENCE: CHOTKEH MANUAL):

To find the volume:

Step 1 Determine the number of kgmole of dried flue gas: Write the combustion equation.

COMBUSTION EXAMPLES

Considering that for each mole of O₂ there are 3.79 moles of N₂ in the air and taking 12% excess air:



Base on the above, the number of moles equal to:

$$1 (\text{CO}_2) + .24 (\text{O}_2) + 8.49 (\text{N}_2) = 9.73 \text{ mole of gas/mole of CH}_4.$$

Step 2 Calculate the volume. With the calculated number of moles in SI units, refer to ideal gas equation (26) SI (CMBS/I.GAS/MOLE)

For $p = 750 \text{ mmHg} = 99992 \text{ Pa}$ (unit conversion), $n = 2 * 9.73 = 19.46 \text{ kgmole}$, and

$$T = 20 + 273 = 293 \text{ K}$$

$$V = 474 \text{ m}^3, \text{ Answer.}$$

24. Determine the partial pressure of CO₂ in the flue gas.

Solution (REFERENCE: HP48 CALCULATOR):

From $p(\text{CO}_2) = p(\text{total}) \frac{\text{mole}(\text{CO}_2)}{\text{mole}(\text{total})}$, key in ' 750*1/9.73 EVAL

$$p(\text{CO}_2) = 77.1 \text{ mmHg} = 10279 \text{ Pa}, \text{ Answer.}$$

25. Determine the weight of produced water.

Solution (REFERENCE: HP48 CALCULATOR):

Considering that each mole of CH₄ produces two (2) moles of water:

Key in ' 2*2*18 EVAL

$$m(\text{H}_2\text{O}) = 72 \text{ kg}, \text{ Answer.}$$

DUCTS EXAMPLES

1. For a 18" x 12" duct, determine:
1.1 The diameter of equivalent round duct for equal friction.
1.2 The new dimension of equivalent rectangular duct, for an aspect ratio of 2.

Solution (REFERENCE: CHOTKEH MANUAL):

- 1.1 To find the diameter, refer to equal friction loss equation (07) **D** (DUCT/EQL.F)
For **a=12"** and **b=18"**

$d = 16"$, Answer for (1.1).

- 1.2 To find the new dimensions, use round to rectangular equations:

Side a: Refer to equation (08) **A** (DUCT/EQL.F) MENU key.

For **d=16"** and **R=2**

$$a = 10.5"$$

Side b: Refer to equation (09) **B** (DUCT/EQL.F) MENU key.

For the same data

$$b = 21"$$

New dimensions = 10.5" x 21" Answer for (1.2).

* * * * *

2. 18" diameter galvanized duct carries 5000 cfm of air. It has three (3) elbows at $r/d=1$ and one (1) 2" pipe crossing the duct with 90 degree angle. If the length of the duct equals to 600 ft, determine:
The total pressure loss through the duct. Assume equivalent minor length of each elbow as 17d and loss coefficient for crossing pipe equals to 0.2.

Solution (REFERENCE: CHOTKEH MANUAL):

To solve this problem, (1) find the friction through the duct and (2) calculate the minor loss (for pipe crossing the duct) and add them up.

Step 1 Duct's friction loss:

Determine the equivalent length of the elbows.

Key in ' 3*17*18/12 **EVAL** = 76.5 ft.

Calculate the friction loss. For the given **FQ** and **D**, in English Units, refer to equation (10) **FQ&D** (DUCT/F.LOS/ENG)

For **Le=600+76.5(le)=676.5** ft, **cfm=5000**, and **d=18"**. $P_f(\text{duct}) = 3.57 \text{ inH}_2\text{O}$

Step 2 Minor loss:

To find the minor loss, the velocity must be calculated first. For English units, refer to equation (03) **VELO** (DUCT/FLOW/ENG)

For **cfm=5000** and **d=18"**.

$$v = 2829 \text{ fpm.}$$

To calculate the minor loss, in English Units, refer to equation (16) **ENG** (DUCT/M.LOS)

For **cm=.2** (given) and **fpm=2829** fpm.

$$P_m(\text{pipe}) = .1 \text{ inH}_2\text{O}$$

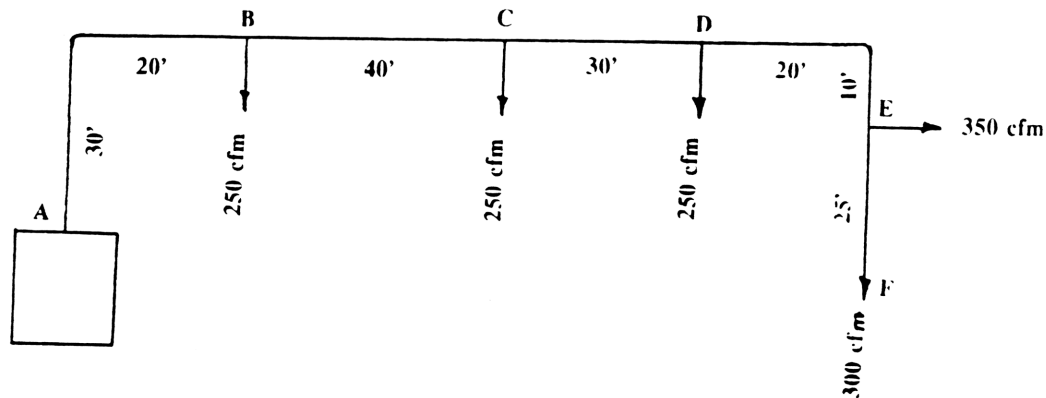
DUCTS EXAMPLES

Total friction loss:

$$P \text{ (total)} = 3.57 + .1 = 3.67 \text{ inH}_2\text{O, Answer.}$$

* * * * *

3. 1400 cfm of conditioned air must be distributed, through a rectangular duct, as shown in the figure below. If 0.23 inH₂O static pressure is required at each outlet, determine:
- 3.1. The size of the duct at each section. Use the equal friction method, assume aspect ratio $R=1.6$ and r/d for the elbows equal to 1.5.
 - 3.2. The fan's total head.



Solution (REFERENCE: CHOTKEH MANUAL):

- 3.1 To size the ducts, assume velocity in the duct as **1500 fpm**.

Section A-B:

Step 1 Calculate the duct's diameter. For English Units, refer to flow equation (01) **DIAM** (DUCT/FLOW/ENG).

For **cfm=1400** and **fpm=1500**.

$$\underline{d(A-B) = 13.08''}$$

Step 2 Find the equivalent rectangular sides for equal friction. Refer to equal friction loss equations (08) **A** (DUCT/EQL.F) and (09) **B** (DUCT/EQL.F).

For **d=13.08"** and **R=1.6**

$$\underline{a = 9.5'', b = 15.2'', \text{ SECTION A-B}}$$

Section B-C:

Since sizing is based on the equal friction, calculate the friction loss (**Pf**) for 1 ft of A-B section and use it to find the diameter of other sections. For the given velocity (**V**) and flow quantity (**FQ**), in English Units, refer to friction loss equation (12) **V&FQ** (DUCT/F.LOS/ENG)

DUCTS EXAMPLES

For **fpm=1500**, **Le=1 ft**, and **cfm=1400**

$$\underline{Pf = 2.454\text{E-}3 \text{ inH}_2\text{O/ft.}}$$

Step 1 Calculate the duct diameter. Use the friction loss equation (10) **FQ&D** (DUCT/F.LOS/ENG)
For **Pf=2.454E-3 inH₂O/ft**, **Le=1 ft**, **cfm=1400-250=1150**. $\underline{d(BC) = 12.15"}$

Step 2 Find the equivalent rectangular sides for equal friction. Refer to equal friction loss equations (08) **A** (DUCT/EQL.F) and (09) **B** (DUCT/EQL.F).
For **d=12.15"** and **R=1.6**

$$\underline{a = 8.85", b = 14.16", \text{SECTION B-C}}$$

Section C-D:

Follow the steps 1 and 2 of B-C section.

Step 1 Calculate the duct diameter. Use the friction loss equation (10) **FQ&D** (DUCT/F.LOS/ENG).
For the same data, but **cfm=1150-250=900** $\underline{d(CD) = 11.09"}$

Step 2 Find the equivalent rectangular sides for equal friction. Refer to equal friction loss equations (08) **A** (DUCT/EQL.F) and (09) **B** (DUCT/EQL.F).
For **d=11.09"** and **R=1.6**

$$\underline{a = 8.08", b = 12.93", \text{SECTION C-D}}$$

Section D-E:

Follow the steps 1 and 2 of B-C section.

Step 1 Calculate the duct diameter. Use the friction loss equation (10) **FQ&D** (DUCT/F.LOS/ENG).

$$\text{For the same data, but } \underline{\text{cfm}=900-250=650} \quad \underline{d(DE) = 9.81"}$$

Step 2 Find the equivalent rectangular sides for equal friction. Refer to equal friction loss equations (08) **A** (DUCT/EQL.F) and (09) **B** (DUCT/EQL.F).
For **d=9.81"** and **R=1.6**

$$\underline{a = 7.14" \text{ and } b = 11.43", \text{SECTION D-E.}}$$

Section E-F:

Follow the steps 1 and 2 of B-C section.

Step 1 Calculate the duct's diameter. Use the friction loss equation (10) **FQ&D** (DUCT/F.LOS).
For the same data, but **cfm=650-350=300**. $\underline{d(EF) = 7.35"}$

Step 2 Find the equivalent rectangular sides for equal friction. Refer to equal friction loss equations (08) **A** (DUCT/EQL.F) and (09) **B** (DUCT/EQL.F).
For **d=7.35"** and **R=1.6**

$$\underline{a = 5.35", b = 8.56", \text{SECTION E-F}}$$

NOTE: To make the calculations faster, you may, at step 1, find all sections' diameter, then, through step 2, calculate all corresponding rectangular dimensions.

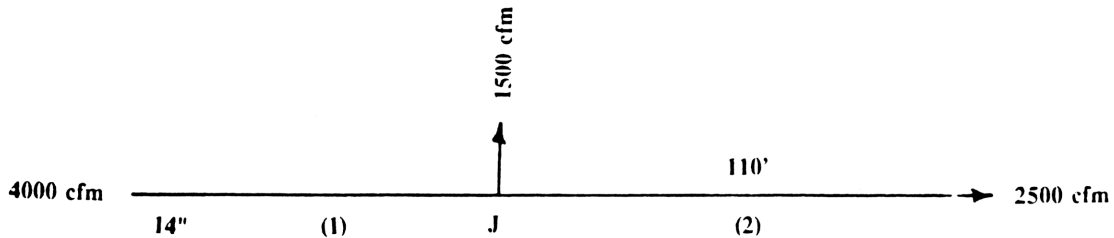
DUCTS EXAMPLES

- b. Find the fan's total head: For $r/d=1.5$ the equivalent length of the elbow is equal to $12*D$
 From $P(\text{fan}) = P_f * L_e(\text{duct}) + P(\text{at outlet})$
 For: $P_f = 2.454 \text{ EE-3 inH}_2\text{O/ft. (calculated)}$
 $L_e = (A-B): 30 + 12*13.08/12 + 20 + (B-C): 40 + (C-D): 30 + (D-E): 20 + 12*9.81/12 + 10,$
 $(D-E): 25$
 Key in '30+13.08+20+40+30+20+9.81+10+25 EVAL
 $L_e = 197.89 \text{ ft,}$
 $P(\text{outlet}) = 0.23 \text{ inH}_2\text{O (given)}$
 Key in '2.454EE-3*197.89+.23

$P(\text{fan}) = .72 \text{ inH}_2\text{O, Answer for (b).}$

* * * * *

4. In a ducting system shown in the following figure, determine:
 The diameter of duct at section (2). Use the static regain method and assume that the static regain coefficient, $RC=0.67$.



Solution (REFERENCE: CHOTKEH MANUAL):

The static regain method is based on the principal that the static regain, by reducing the velocity, should offset the friction loss at the succeeding section. Or in this case the diameter at section (2) must be such that the static regain at point J, must be equal to friction loss at section (2).

Step 1 Identify the static regain. Since the diameter of the duct (**D**) is the requirement: with the given FQ in English Units, refer to equation (19) **FQ&D (DUCT/REGAIN/ENG)**, which is:

$$P_{sr} = \frac{C_{sr}}{477.14} \left(\frac{cfm_1^2}{d_1^4} - \frac{cfm_2^2}{d_2^4} \right)$$

DUCTS EXAMPLES

Step 2 Identify the friction loss. Since the diameter of the duct (**D**) is the requirement: with the given **FQ** in English Units, refer to equation (10) **FQ&D** (DUCT/F.LOS/ENG), which is:

$$P_f = \frac{1.2326EE-3 * L_e * cfm^{1.82}}{d^{4.86}}$$

Step 3 From **Psr=Pf** enter the following values and solve for **d2**

csr = Regain coefficient = .67 (given)

cfm1 = Main duct flow quantity = 4000 cfm (given)

d1 = Main duct diameter = 14" (given)

cfm2 = Section (2) flow quantity = 2500 cfm (given)

d2 = Section (2) duct diameter = to be found

Le = Equivalent length of Section B duct (must be compensated for the fittings in the section) = 110 ft

cfm = **cfm2** = 2500

d = **d2**, to be found.

For HP48GX Press $\rightarrow$ SOLVE ENTER Type:

.67*(4000^2/14^4-2500^2/D2^4)/477.14=1.2326EE-3*110*2500^1.82/D2^4.86

ENTER Press SOLVE

For HP48SX Press $\leftarrow$ SOLVE Type:

'.67*(4000^2/14^4-2500^2/D2^4)/477.14=1.2326EE-3*110*2500^1.82/D2^4.86

Press STEQ SOLVR $\leftarrow$ D2

d2 = D2 = 14.93", Answer.

NOTE: If there are any fittings in the subject section, where the equivalent length of the fitting is a function of the ducts diameter, you may:

1. Either estimate the diameter, then calculate the corresponding length of the fitting and add it to the duct's length. In this case when the duct's diameter is calculated, then re-estimate **Le** and repeat the calculation, until the calculated answers become very close.

2. Or when typing the equation, write the corresponding expression for **Le**. For example (in problem number 4) if the section (2) contains an elbow, which its equivalent length is 17*D (D is in ft), then **Le**=110+17*D2/12. In this situation:

For HP48GX: Press $\rightarrow$ SOLVE ENTER Type:

.67*(4000^2/14^4-2500^2/D2^4)/477.14=1.2326EE-3*(110+17*D2/12)*2500^1.82/D2^4.86 ENTER

Press SOLVE

For HP48SX: Press $\leftarrow$ SOLVE Type:

'.67*(4000^2/14^4-2500^2/D2^4)/477.14=1.2326EE-3*(110+17*D2/12)*2500^1.82/D2^4.86

Press STEQ SOLVR $\leftarrow$ D2

d2 = D2 = 15.35", Answer.

DUCTS EXAMPLES

5. For a 500 mm duct, determine:
The equal friction dimensions of rectangular duct. Assume aspect ratio as 3.5

Solution (REFERENCE: CHOTKEH MANUAL):

To find the side dimensions, use round to rectangular equations:

Side a: Refer to equation (08) A (DUCT/EQL.F)

For $d=500$ mm and $R=3.5$

$a = 256 \text{ mm, Answer.}$

Side b: Refer to equation (09) B (DUCT/EQL.F) MENU key.

For the same data

$b = 896 \text{ mm, Answer.}$

* * * * *

6. If 1000 lps of air flows in a 350 mm diameter and 75 m long duct, determine:
6.1 The velocity of the air
6.2 The friction loss through the duct.

Solution (REFERENCE: CHOTKEH MANUAL):

- 6.1 To find the velocity, in SI Units, refer to flow equation (06) **VELO** (DUCT/FLOW/SI)
For $lps=1000$ and $d=350$ mm

$mps = 10.4, \text{ Answer for 6.1.}$

- 6.2 To calculate the friction loss, with the given flow quantity (**FQ**) and (**D**), in SI Units, refer to equation (13) **FQ&D** (DUCT/F.LOS/SI)
For $Le=75$ m, $lps=1000$, and $d=350$ mm

$Pf = 248 \text{ Pa, Answer for 6.2}$

* * * * *

7. In 50 m long rectangular duct air is flowing at the rate of 1500 lps and the velocity of 8 mps.
If the pressure drop along the duct not to exceed 95 Pa, determine:
The dimensions of the duct.

Solution (REFERENCE: CHOTKEH MANUAL):

Step 1 Calculate the equivalent diameter of the duct. With the given **FQ**, in SI Units, refer to friction loss equation (13) **FQ&D** (DUCT/F.LOS/SI)

For $Pf=95$ Pa, $Le=50$ m, and $lps=1500$

$$\underline{d = 457 \text{ mm}}$$

DUCTS EXAMPLES

Step 2 To find the dimensions, use round to rectangular equations:

Side a: Refer to equation (08) **A** (DUCT/EQL.F)

For $d=457$ mm and $R=2.5$

$a = 271 \text{ mm, Answer.}$

Side b: Refer to equation (09) **B** (DUCT/EQL.F) MENU key.

For the same data

$b = 678 \text{ mm, Answer.}$

* * * * *

8. A duct has 450 mm and 350 mm in diameter before and after a take off. If the air flow at these sections are 750 lps and 220 lps respectively, determine:
The static regain in the duct. Assume static regain coefficient as 0.8.

Solution (REFERENCE: CHOTKEH MANUAL):

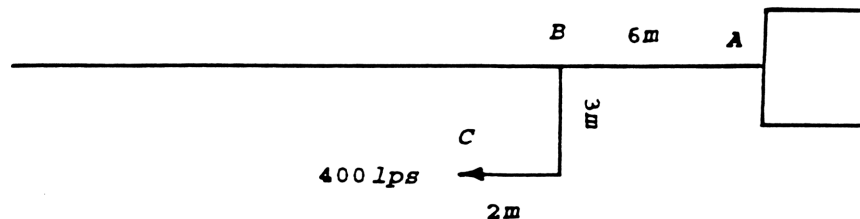
To calculate the static regain, with the given **FQ** and **D**, in SI Units, refer to static regain equation (21) **FQ&D** (DUCT/REGAIN/SI)

For $csr = .8$, $lps1 = 750$, $d1 = 450$ mm, $lps2 = 220$, and $d2 = 350$ mm

$P_{sr} = 8.18 \text{ Pa, Answer.}$

* * * * *

9. A duct system, shown below, has the following characteristics:
- Total friction loss in the main run: 40 Pa.
 - Design pressure drop in main run, using equal friction method: 2.5 Pa/m.
- Based on the above, determine:
The diameter of duct at B-C section in order equalize the losses through increased velocity at this section.



DUCTS EXAMPLES

Solution (REFERENCE: CHOTKEH MANUAL):

To solve this problem, the available static pressure at point B must be calculated and be used as the friction loss between points B and C. And finally the diameter to be calculated.

Step 1 Determine the static pressure at point B:

$$Ps(B) = 40 \text{ (given)} - 6 \text{ (length of AB)} * 2.5 = 25 \text{ Pa}$$

Step 2 Calculate the equivalent length of B-C. Assume equivalent length of take off as 5 m and the elbow as 4 m.

Key in ' 5+3+4+2 **EVAL**

$$Le \text{ (B-C)} = 14 \text{ m.}$$

Step 3 Find the diameter. With the calculated friction loss and given **FQ**, in SI Units, refer to friction loss equation (13) **FQ&D** (DUCT/F.LOS/SI)

For **Pf=Ps=25 Pa**, **Le=14 m**, and **lps=400**

$d = 282 \text{ mm, Answer.}$

NOTE: By using equation (15) **V&FQ**, you may calculate the velocity in the duct, which is **6.5 mps**. By knowing the velocity, determine the minor losses at the take-off and elbow (which was assumed before). Then calculate the equivalent length and finally the more accurate diameter of the B-C duct.

ELECTRICITY EXAMPLES

1. For 450 ft copper wire with diameter equal to 0.07 inch, determine: the wire's resistance. Assume the electrical resistivity equals to 12.5 ohm-Cmil/ft.

Solution (REFERENCE: CHOTKEH MANUAL)

This is an Electricity (ELEC), Resistance problem.

Refer to equation (58), **R_{pLA}** (ELEC/RESI).

For $\rho=12.5$ ohm-Cmil/ft, $L=450$ ft, and $A_{cmil} = \text{key in } '.07^2 * 1EE6 \text{ EVAL} = 4900 \text{ Acmil}$:

$$R = 1.15 \text{ ohm, Answer.}$$

* * * * *

2. A 440 volt, three (3) wire, three (3) phase, and 60 Hz source, supplies power to a 130 kw inductive load through a three (3) 300 KCM conductor cable. If the distance is 600 ft and the load's power factor is 0.85, determine:
The voltage drop across in each conductor.

Solution (REFERENCE: CHOTKEH MANUAL):

This is an Electricity (ELEC), Voltage drop, problem.

To solve the problem: (1) find the line current (2) calculate the voltage drop.

Step 1 To calculate the line current, for three (3) phase line, refer to equation

(70) **I_{3 ϕ}** (ELEC/VDRP).

For $kw=130$ kw, $V=440$ volt, and $PF=.85$:

$$I = 200.7 \text{ amps.}$$

Step 2 To calculate the voltage drop, for Kcml size conductor, refer to equation

(79) **KCM** (ELEC/VDRP), prev. MENU key.

For $L=600$ ft, $I=200.7$ amp, $Kcml=300$ Kcml, and $PF=.85$:

$$VD = 7.83 \text{ volts, Answer}$$

* * * * *

3. A battery driven truck applies a 400 pound pull at the speed of 5 mph. If the efficiency of the system is 70%, determine: The current drawn from the 110 volt battery.

ELECTRICITY EXAMPLES

Solution (REFERENCE, HP48 CALCULATOR):

To solve this problem write the power equations for both source and load side.

Power available at source side = $V \cdot I$ watts.

Power required at load side = $\frac{w \times v}{\eta}$ ft-lbf/sec = $\frac{w \times v \times 1.356}{\eta}$ watts. (1 ft-lbf = 1.356

watts. This conversion can not be done by calculator.)

Based on above: $V \cdot I = \frac{w \times v \times 1.356}{\eta}$

For $w=400$ lb, $v=5$ mph= 7.33 fps (Use unit conversion), $V=110$ volt, and $\eta = 0.7$

Key in ' $110 \cdot I = 400 \cdot 7.33 \cdot 1.356 / .7$ ENTER

For HP48SX: Press left arrow, SOLVE, STEQ, SOLVR

For HP48GX: Press left arrow, SOLVE, ROOT, left arrow, EQ, SOLVR

Press left arrow, I:

$I = 51.63$ amps, Answer.

* * * *

4. A section of an industrial plant draws 120 kw at a power factor of 0.8 lagging. Another section draws 50 kw at unity power factor. If the source of supply is three (3) phase, 440 volt, and 60 Hz, determine: The total line current drawn by the plant.

Solution (REFERENCE: CHOTKEH MANUAL):

This is an Electricity (ELEC), Power Factor, problem.

To find the current, the overall power factor of the system must be calculated first. Refer to equation (52), SYPF (ELEC/PFAC).

For $KWR=50$ kw, $KWI=120$ kw, and $PFI=.8$: $\underline{PF1 = .884}$

Now by knowing the overall power factor, to find the current, for three phase load, refer to equation

(50), W-3 ϕ (ELEC/PFAC), prev. MENU key.

For $PF=PF1=.884$, $KW=50+120=170$ kw, and $V=440$ volt:

$I = 252.34$ amps, Answer.

* * * * *

5. If a plant draws 360 amps from a single phase 120 volt 60 Hz line at 0.80 power factor lagging, determine: The value of a capacitor to be added to the system to improve the power factor to unity.

ELECTRICITY EXAMPLES

Solution (REFERENCE: CHOTKEH MANUAL):

This is an Electricity (ELEC), Power Factor, problem.

To find the capacitor's value, the Kvar of the capacitor must be calculated. To find the Kvar, the load's kw should be calculated first. For single phase system, refer to equation (49), **W-1 ϕ** (ELEC/PFAC).

For **PF=.8**, **V=120** volt, and **I=360** amp: kw = 34.56

To find the Kvar of the capacitor, refer to equation (53), **KVAR** (ELEC/PFAC), MENU key.

For **KWR=0** kw, **KWI=34.56** kw, **PF1=.8**, and **PF2=1**: Kvar = 25.92

To find the capacitor's value, refer to equation (54), **CVAL** (ELEC/PFAC), MENU key.

For **Kvar=25.92** kw, **f=60** cps, and **V=120** volt:

$$f = .004775 \text{ farads or } 4775 \text{ microfarad, } \underline{\text{Answer.}}$$

* * * * *

6. For a 3 horsepower induction motor with 77% efficiency and .89 full load power factor, determine:
The full load current at 110 volt supply.

Solution (REFERENCE: CHOTKEH MANUAL):

This is an Electricity (ELEC), Motor/Power, problem.

Refer to equation (31) **HP1 ϕ** (ELEC/MOTR/POWR).

For **hp=3** hp, **V=110** volt, **PF=.89**, and **$\eta_M=0.77$** :

$$I = 29.68 \text{ amps., } \underline{\text{Answer}}$$

* * * * *

7. For a three (3) phase, four (4) pole, 60 Hz, 440 volt, and 75 horsepower induction motor with 81% full load efficiency, a full load 0.89 power factor, determine:
- The full load line current;
 - The motor's rotational speed. Assume 3% slip; and
 - The torque.

ELECTRICITY EXAMPLES

Solution (REFERENCE: CHOTKEH MANUAL):

This is an Electricity (ELEC), Motor, problem.

- a. To find the line current, refer to equation (33) **HP3 ϕ** (ELEC/MOTR/POWR).

For **hp=75** hp, **V=440** volt, **PF=.89**, and **$\eta_M=0.81$** :

$$I = 101.8 \text{ amps.}, \text{ Answer for (a)}$$

- b. To find the motor's rotational speed, refer to equation (37), **SPED** (ELEC/MOTR).
For **f=60** cps, **S=.03**, and **p=4**:

$$n = 1746 \text{ rpm.}, \text{ Answer for (b)}$$

- c. To find the motor's torque, refer to equation (38), **TORQ** (ELEC/MOTR), MENU key.
For **hp=75** and **n=1746** rpm:

$$T = 2707 \text{ in-lbf or } 226 \text{ ft-lbf}, \text{ Answer for (c)}$$

* * * * *

8. A single phase 120 kw load is located 1500 ft from a 660 volt source of supply. The power is transmitted through two (2) copper conductor feeder. If the resistance of conductor is .051/1000 ft, determine the voltage drop between the supply and load.

Solution (REFERENCE: HP48 CALCULATOR):

Step 1 Calculate the line's resistance.

From **R=2** conductors * **1500** ft * **.051** ohm/1000 ft = **.153** ohm.

Step 2 Write two (2) equations which represent the **Voltage drop** and the **load power**:

If **VD** = voltage drop, **V** = source voltage, and **P** = power in watts:

(1) **VD=I*R** (2) **P=I*(V-VD)**. Divide equation (1) by equation (2):

cancel "like-terms (I)"

$$\frac{VD}{P} = \frac{R}{V-VD} \quad \text{For } P=120000 \text{ watts, } R=.153 \text{ ohm, and } V=660 \text{ volts:}$$

Key in ' **VD/120000=.153/(660-VD)** ENTER

For HP48SX: Press left arrow, SOLVE, STEQ, SOLVR

For HP48GX: Press left arrow, SOLVE, ROOT, left arrow, EQ, SOLVR

Press left arrow, VD:

$$VD = 29.1 \text{ volts}, \text{ Answer.}$$

ELECTRICITY EXAMPLES

9. For an elevator with the net lifting weight of 2000 pound and the speed of 100 fpm, determine the motor's horsepower. Assume 75% overall system efficiency.

Solution (REFERENCE: CHOTKEH MANUAL):

This is an Electricity (ELEC), Motor/Elevator, problem.

To find the horsepower, refer to equation (29), **HP** (ELEC/MOTR/ELEV).

For $w=2000$ pound, $v=100$ fpm, and $\eta = .75$:

$hp = 8.08 \text{ hp, Answer.}$

* * * * *

10. For a pump with an efficiency of 65% and the capacity of 1800 gpm at 140 foot head, Determine: The electric power of the motor in hp and KW.

Solution (REFERENCE: CHOTKEH MANUAL):

This is an Electric (ELEC), Motor/Pump, problem.

For the flow given in gpm, refer to equation (34) **HP_Q** (ELEC/MOTR/PUMP)

For $h=140$ ft, $Q=1800$ gpm, $SG=1$ (assumed pumping water), and $\eta=0.65$:

$hp = 97.9$, use the unit conversion, $kw = 73$, <u>Answer.</u>

* * * * *

11. For a three (3) phase, four (4) pole, 60 Hz, 440 volt induction motor, determine: Motor's rotational speed. Assume 4% slip.

Solution (REFERENCE: CHOTKEH MANUAL):

This is an Electricity (ELEC), Motor, problem.

To find the motor's rotational speed, refer to equation (37), **SPED** (ELEC/MOTR).

For $f=60$ cps, $S=.04$, and $p=4$:

$n = 1728 \text{ rpm., Answer}$

ELECTRICITY EXAMPLES

12. For a three (3) phase, 24 pole, and 440 volt alternator rotating at 600 rpm, determine:
The frequency of alternating current.

Solution (REFERENCE: CHOTKEH MANUAL):

This is an Electricity (ELEC), Motor, problem.

To find the frequency, refer to equation (37), **SPED** (ELEC/MOTR).

For **n=600** rpm, **S=0**, and **p=24**:

$f = 120 \text{ Hz (cps), } \underline{\text{Answer.}}$

ENGINEERING ECONOMICS EXAMPLES

1. Interest is paid at 12% per year compounded quarterly. Determine the effective interest rate for the compounding period.

Solution:

Refer to equation (27) **EFFEC** (ENEC/INTER)

For $i = 0.12$ and $m = 12/3 = 4$:

$IEF = 0.1255$ or 12.55% , <u>Answer</u>
--

* * * * *

2. A deposit of \$1,050 is made in a bank account which pays an 8% interest. How much will be on deposit at the end of 12 years?

Solution:

Refer to equation (13) **FP** (ENEC/FACTR)

For $i = 0.08$, $n = 12$ and $P = 1050$:

$F = \$2,644$, <u>Answer</u>

* * * * *

3. Fifteen years ago, \$1,000 was deposited in a bank account and today it is worth \$2,368.74. The bank pays interest semi-annually. What interest rate, compounded semi-annually, was paid on this account?

Solution:

Step 1 Find the semi-annually compounded effective interest rate:

Refer to equation (13) **FP** (ENEC/FACTR)

For $F = 2368.74$, $n = 15$ and $P = 1000$:

$IEF = i = 0.0592$

Step 2 Refer to equation (27) **IEF** (ENEC/INTR)

For $IEF = 0.0592$ and $M = 12/6 = 2$:

$i = 0.0583$ or 5.83% , <u>Answer</u>

* * * * *

4. A car was bought for \$18,000 including \$5000 down payment. If the balance to be paid in 12 equal annual payments of \$1600, determine the annual interest rate.

Solution:

To find the interest rate with the annual payment and present value are known, refer to equation (12)

AP (ENEC/FACTR)

For $A = 1600$, $n = 12$ and $P = 18000 - 5000 = 13000$:

$i = 0.0658$ or 6.58% , <u>Answer</u>

ENGINEERING ECONOMICS EXAMPLES

5. How long will it take, to the nearest year, for money to triple at a 9% interest?

Solution:

Refer to equation (13) **FP** (ENEC/FACTR)

For $F = 3$, $i = 0.09$ and $P = 1$:

$n = 12.7 \text{ or } 13 \text{ years, Answer}$

* * * * *

6. A rental property pays \$5,000/year with \$250 increase per year starting the second year. Based on 10 year period and 8% annual interest rate, compute the unified average annuity, considering the gradient.

Solution:

To calculate the equivalent annual increase from unified gradient, refer to equation (11) **AG** (ENEC/FACTR)

For $i = 0.08$, $n = 10$ and $G = 250$:

$$A = \$967.83$$

Add the original annual rental.

Average rental = \$5967.83/year, Answer

* * * * *

7. It is planned for deposits of \$200 to be made at the end of each month for 17 years at 12%/yr compounded monthly interest. How much will be available in 8 years?

Solution:

Step 1 Since the payment is made on a monthly basis, the interest is compounded automatically.

Step 2 Refer to equation (10) **AF** (ENEC/FACTR)

For $A = 200$, $i = 0.12/12 = 0.01/\text{month}$, and $n = 8 \times 12 = 96$ months:

$F = \$31,985.46$, Answer

* * * * *

8. A car costs \$24,986. A down payment of \$4,986 is made and the balance is borrowed from a bank at 9% interest for 5 years. With monthly installments required, how much are the payments?

Solution:

Refer to equation (30) **INSTL** (ENEC/MORT)

For $i = 0.09/12 = 0.0075/\text{month}$, $n = 5 \times 12 = 60$ months, and

$\text{LOAN} = 24986 - 4986 = 20000$:

$\text{INSTL} = \$415.17$, Answer

ENGINEERING ECONOMICS EXAMPLES

9. A deposit of \$2000 is made in a saving account which pays 8% interest compounded annually. Determine the amount of saving after 12 years.

Solution:

Refer to equation (13) **FP** (ENEC/FACTR)

For $i=0.08$, $n=12$ and $P=2000$

$F = \$5036.34$, <u>Answer</u>

* * * * *

10. In problem 9 above, how much will be the deposit if the interest rate is compounded quarterly.

Solution:

Refer to equation (13) **FP** (ENEC/FACTR)

For $i=0.08/4=.02$, $n=4*12=48$ and $P=2000$

$F = \$5174.14$, <u>Answer</u>

* * * * *

11. In problem 9 above, how much will be the deposit if the interest rate is compounded continuously.

Solution:

To find the amount of deposit, under this condition, the continuous compounded rate must be calculated first. Refer to equation (26) **YIELD** (ENEC/INTER)

For $i=0.08$ and $y=1$ year

$$\underline{iCO = .08329}$$

Refer to equation (13) **FP** (ENEC/FACTR)

For $i=0.08329$, $n=12$ and $P=2000$

$F = \$5223.56$, <u>Answer</u>

* * * * *

12. Maintenance on a machine is forecasted to be \$500 in the first year and an increase by \$50 each year, for 9 years. What present sum of money would be needed now to pay the maintenance for the 10-year period? Interest is 8% per year.

Solution:

Step 1 Find the unified average annual payment for the unified gradient:

Refer to equation (11) **AG** (ENEC/FACTR)

For $i=0.08$, $n=10$ and $G=\$50$

$$\underline{A = \$193.57}$$

Step 2 Refer to equation (12) **AP** (ENEC/FACTR) (previous MENU key)

For $A=500+193.57=693.57$, $i=0.08$ and $n=10$

$P = \$4,653.91$, <u>Answer</u>

ENGINEERING ECONOMICS EXAMPLES

13. In June 1990, a firm purchased a used computer for \$2,000. Repairs were needed in 1991 for a \$100, in 1993 for \$165, and \$200 in 1994. The computer was sold in 1996 for \$650. The firm used the computer for payroll services and received \$500 per year for each year it owned the computer. Calculate the future value of the money the firm had after sale of the computer. Interest rate is 10%.

Solution:

Assume negative values for expenses and positive values for incomes. Clear the screen.

Step 1 Calculate the future value of initial investment.

Refer to equation (13) **FP** (ENEC/FACTR)

For $i=0.1$, $n=6$ and $P=-2000$

$F=-3,543.12$

Step 2 Calculate the future values of expenses in 1991, 93, and 94. Stay with the same equation, do not clear the screen.

For 1991, $i=0.1$, $n=1996-1991=5$ and $P=-100$

$F=-161.05$

This answer is in level one and the prior answer was in level 2

For 1993, $i=0.1$, $n=1996-1993=3$ and $P=-165$

$F=-219.62$

For 1994, $i=0.1$, $n=1996-1994=2$ and $P=-200$

$F=-242.00$

Step 3 Calculate the future value of annual incomes.

Refer to equation (10) **AF** (ENEC/FACTR) (Previous MENU key)

For $A=500$, $i=0.1$ and $n=6$

$F=3,857.80$

Step 4 Enter 650 for the future sales value

$F=650$

Step 5 Press (+ +) to add all of them (six figures)

$F=342.02$, <u>Answer</u>

* * * * *

14. A person wants to buy a car which costs \$16,500. The total value of the car can be financed at a special interest rate of 6% for four years or a dealer rebate of \$1,500 and interest at 12% can be accepted. Payments are to be made quarterly.
- Which payment approach should be taken?
 - How much of the principal will be paid after 8 payments?
 - After 3 years, the loan is to be retired; how much should be paid to the bank?
 - How much interest will be paid to the bank over the life of the loan?

ENGINEERING ECONOMICS EXAMPLES

Solution:

- a. Calculate the periodical payments (installment) for both alternatives.
Refer to equation (30) **INSTL** (ENEC/MORT)
For $i=0.06/4=0.015/\text{quarter}$, $n=4 \times 4=16$ quarters and $\text{LOAN}=16,500$
Installment (1) = INSTL = \$1167.62

For $i=0.12/4=0.030/\text{quarter}$, $n=4 \times 4=16$ quarters and
 $\text{LOAN}=16,500-1500=15000$
Installment (2) = INSTL = \$1194.16

Alternative (1), Answer for (a)

- b. Refer to equation (36) **TOTAL** (ENEC/MORT/PRINC).
For $\text{LOAN}=16500$, $\text{INSTL}=1167.62$, $i=0.015$, $x=8$, and $n=16$

$P_t = \$7,759.28$, Answer for (b)

- c. Refer to equation (32) **BALAN** (ENEC/MORT).
For $\text{INSTL}=1167.62$, $i=0.015$, $x=3 \times 4=12$ and $n=16$

$\text{BAL}_x = \$4,500.46$, Answer for (c)

- d. Refer to equation (34) **TOTAL** (ENEC/MORT/INTER).
For $\text{INSTL}=1167.62$, $x=4 \times 4=16$, $\text{LOAN}=16500$, $i=0.015$ and $n=16$

$I_t = \$2,181.92$, Answer for (d)

* * * * *

15. What should an investor pay for a \$2,000, 10-year bond paying 6%, if the investor requires an 8% rate of return on the investment? Interest is paid semi annually.

Solution:

To find the present worth of the bond, refer to equation (05) **PW** (ENEC/BOND).
For $\text{BSV}=2000$, $R=0.08/2=0.04$, $N=10 \times 2=20$, $i=0.06$ and $\text{BFV}=2000$

$\text{PW} = \$1,728.19$, Answer

* * * * *

16. What would the investors rate of return be if the bond described in example 10 is sold after 6 years for \$1,850.00? Interest is paid annually.

Solution:

Refer to equation (06) **ROR** (ENEC/BOND).
For $\text{BSV}=1850$, $\text{PW}=1728.19$, $n=N=6$, $i=0.06$ and $\text{BFV}=2000$

$\text{ROR} = 0.078$ or 7.8% , Answer

ENGINEERING ECONOMICS EXAMPLES

17. An investor is offered a bond for \$7,000 with a face-value of \$10,000 at an interest rate of 5% with a maturity in 15 years. What is the rate of return on the investment?

Solution:

Refer to equation (06) **ROR** (ENEC/BOND).

For $BSV = 10000$, $PW = 7000$, $n = 15$, $i = 0.05$ and $BFV = 10000$

$$ROR = 0.082 \text{ or } 8.2\% , \text{ Answer}$$

* * * * *

18. A new asset is purchased for \$1,200, with an estimated salvage value of \$200 and a useful life of 7 years. What will be:
- The annual depreciation cost for the 5th year, using Straight Line method.
 - The annual depreciation cost for the 5th year, using Sinking Fund method, interest rate at 5%.
 - The book value at the end of 5th year, using Straight Line method.
 - The book value at the end of 5th year, using Sinking Fund method.

Solution:

- a. Refer to equation (20) **DX** (ENEC/DEPRI/SL)

For $P = 1200$, $L = 200$ and $n = 7$

$$Dx = \$142.86 , \text{ Answer for (a).}$$

- b. Refer to equation (18) **DX** (ENEC/DEPRI/SF)

For same data, $i = 0.05$ and $x = 5$

$$Dx = \$149.29 , \text{ Answer for (b).}$$

- c. Refer to equation (21) **BVX** (ENEC/DEPRI/SL)

For the same data

$$BVx = \$485.71 , \text{ Answer for (c).}$$

- d. Refer to equation (19) **BVX** (ENEC/DEPRI/SF)

For same data

$$BVx = \$521.34 , \text{ Answer for (d).}$$

* * * * *

19. For an asset purchased for \$25,000 with an estimated useful life of 7 years and \$3,000 salvage value, use the Straight Line method and determine:
- The depreciation cost in the 4th year.
 - The book value at the end of 4th year.

ENGINEERING ECONOMICS EXAMPLES

Solution:

- a. Refer to equation (20) **DX** (ENEC/DEPRI/SL)
For $P=25000$, $L=3000$ and $n=7$

$Dx = \$3142.86$, <u>Answer</u> for (a).

- b. Refer to equation (21) **BVX** (ENEC/DEPRI/SL) MENU key.
For the same data and $x=4$

$BVx = \$12428.57$, <u>Answer</u> for (b).

* * * * *

20. Solve problem 19, using the Sinking Fund method. Assume 8% interest rate.

Solution:

- a. Refer to equation (18) **DX** (ENEC/DEPRI/SF)
For $P=25000$, $L=3000$, $i=.08$, $n=7$ and $x=4$

$Dx = \$3105.94$, <u>Answer</u> for (a).

- b. Refer to equation (19) **BVX** (ENEC/DEPRI/SF) MENU key.
For the same data

$BVx = \$13889.76$, <u>Answer</u> for (b).

* * * * *

21. Solve problem 19, using the Double Declining Balance method.

Solution:

- a. Refer to equation (15) **DX** (ENEC/DEPRI/DDB)
For $P=25000$, $L=3000$, $n=7$ and $x=4$

$Dx = \$2603.08$, <u>Answer</u> for (a).

- b. Refer to equation (16) **BVX** (ENEC/DEPRI/DDB) MENU key.
For the same data

$BVx = \$6507.71$, <u>Answer</u> for (b).
--

ENGINEERING ECONOMICS EXAMPLES

22. Solve problem 19, using the Sum Of the Years' Digits method.

Solution:

- a. Refer to equation (23) **DX** (ENEC/DEPRI/SOYD)

For $P=25000$, $L=3000$, $n=7$ and $x=4$

$$D_x = \$3142.86, \text{ Answer for (a).}$$

- b. Refer to equation (24) **BVX** (ENEC/DEPRI/SOYD)

For the same data

$$BV_x = \$7714.29, \text{ Answer for (b).}$$

* * * * *

23. A city must convey sewage through or over a rock ridge to its treatment plant. Plan A calls for a 5,000 foot gravity sewer in rock tunnel, which costs \$300/foot. Plan B requires the construction of a pumping station for \$750,000, with a salvage value of \$150,000, and a 5,000 foot forced main at a cost of \$125/foot. The cost to maintain the gravity or forced main are the same, the pumping station has an annual operating and maintenance cost of \$35,000. Capital costs in each case will be financed by 30 yr, 5% bonds retired by equal annual payments combining interest and principle. Compute the annual cost for each plan, state which is more economical, and show the difference in annual cost.

Solution:

Refer to equation (01) **SF** (ENEC/ANNU), assumed Sinking Fund Depreciation method.

ALT A:

For $P=5000 \times 300 = 1500000$, $L=0$, $i=0.05$, $n=30$ and $AE=0$

$$A = \$97,577.15$$

ALT B:

For $P=750000 + 5000 \times 125 = 1375000$, $L=150000$, $i=0.05$, $n=30$ and $AE=35000$

$$A = \$122,188.00$$

Alternative A, Answer

* * * * *

24. Two alternative locations for a new aqueduct are being considered. Interest is 5%. Determine which alternative location results in the lowest annual cost. Location 1 requires a rock tunnel 1,000 foot long which costs \$100/ft to dig. The tunnel is considered permanent, with annual costs of \$1,000/yr and an additional \$5,000 every ten years for an inspection and repairs. A flume costing \$45,000, with an estimated life of 20 years is also required. Maintenance of the flume will cost \$2,000/yr. Location 2 requires a pipe line costing \$35,000 with a 50 year life and an annual maintenance cost of \$1,200, a permanent earth canal costing \$40,000, with annual costs of \$1,000 and a concrete lining with a first cost of \$20,000, a life of 25 years and maintenance costs of \$300/yr.

ENGINEERING ECONOMICS EXAMPLES

Solution:

Location 1:

Annual cost contains the following:

- | | | |
|----------------------|--|---------------------------------|
| 1-1 | Interest on initial cost of tunnel: $\$1000 \times 100 \times 0.05 = \underline{\$ 5,000}$ | <u>1-1 = \$5,000</u> |
| 1-2 | Total annual cost = <u>\$1,000</u> | <u>1-2 = \$1,000</u> |
| 1-3 | Inspection and Repair:
To find the equivalent annual cost of inspection, refer to equation (10) AF
(ENEC/FACTR)
For $i=0.05$, $n=10$ and $F=5000$ | <u>1-3 = \$397.52</u> |
| 1-4 | Flume:
Refer to equation (01) SF (ENEC/ANNU)
For $P=45000$, $L=0$, $i=0.05$, $n=20$, and $AE=2000$ | <u>1-4 = \$5,610.92</u> |
| Add 1-1 through 1-4: | | <u>Location 1 = \$12,008.44</u> |

Location 2:

Annual cost contains the following:

- | | | |
|----------------|--|--------------------------------|
| 2-1 | Pipe line- same equation as 1-4
For $P=35000$, $L=0$, $i=0.05$, $n=50$ and $AE=1200$ | <u>2-1 = \$3,117.19</u> |
| 2-2 | Annual interest on initial cost of earth canal:
$\$40000 \times 0.05 = \2000 | <u>2-2 = \$2,000</u> |
| 2-3 | Annual cost on earth canal: \$1000 | <u>2-3 = \$1,000</u> |
| 2-4 | Concrete lining:
Refer to equation (01) SF (ENEC/ANNU)
For $P=20000$, $L=0$, $i=0.05$, $n=25$, and $AE=300$ | <u>2-4 = \$1719.05</u> |
| Add 2-1 - 2-4: | | <u>Location 2 = \$7,836.24</u> |

Location 2 is preferable, Answer

* * * * *

25. An underground gas main, placed in a corrosive environment was installed for \$12,000/mile. The main is projected to develop leaks over time because of the corrosive environment. Leaks are not expected for the first 12 years. It is estimated that a mile of gas main will lose \$75/mile worth of gas in the 13th year, and the loss will increase at \$50/mile/year thereafter. The minimum acceptable rate of return is 10%. Determine if the main should be retired in 20 or 25 years.

Solution:

For comparison purposes, move the project to twelve years later. Calculate the future worth of the present cost, at year twelve (12):

Refer to equation (13) **FP** (ENEC/FACTR)

For $i=0.1$, $n=12$, and $P=12000$ F = \$37,661.14

NOTE: This amount is the Present Value for year 12 at which $t=0$ for the following calculations.

20 year life annual cost:

To calculate the unified equivalent annual cost, including unified gradient, refer to equation (02) **SF+G** (ENEC/ANNU)

ENGINEERING ECONOMICS EXAMPLES

For $P=37661.14$, $L=0$, $i=0.1$, $n=20-12=8$, $AE=75$, and $G=50$

$$A(20)=\$7,284.58$$

25 year life annual cost:

Using the same equation and same data, but $n=25-12=13$

$$A(25)=\$5,611.82$$

Since $A(25) < A(20)$

Retire in 25 years, <u>Answer</u>

* * * * *

26. An equipment with an initial cost of \$3,000 has an annual maintenance cost of \$300. If the interest rate is 7.5%, determine:
The present worth of the equipment over 11 years.

Solution:

This is a before tax present worth with uniform annual expenses. Refer to equation (37) **UNIF** (ENEC/PW/B.TAX)

For $P=3000$, $AR=0$ (no revenue), $AE=300$, $i=.075$, $n=11$, and $L=0$ (assumed)

$PW = -5,194.63$, <u>Answer.</u>

* * * * *

27. In problem 26, if the maintenance cost increases \$50 annually, determine:
The present worth of the equipment over 11 years.

Solution:

This is a before tax present worth with uniform gradient annual expenses. Refer to equation (38) **GRADI** (ENEC/PW/B.TAX)

For $P=3000$, $AR=0$ (no revenue), $AE=300$, $i=.075$, $n=11$, $G=50$, and $L=0$ (assumed)

$PW = -6,761.73$, <u>Answer.</u>

* * * * *

28. A corporation has invested \$120,000 in a business, which generates \$36,000 revenue per year. The annual expense is estimated for \$8,000 and the salvage value of \$6,000 at the end of year 10. If the corporation to pay 51% on income tax and the interest rate is 8.5%, determine:
The after tax present worth with no consideration to depreciation.

Solution:

This is an after tax present worth with uniform annual expenses. Refer to equation (39) **UNIF** (ENEC/PW/A.TAX)

For $P=120000$, $AR=36000$, $AE=8000$, $TAX.R=.51$, $i=.085$, $n=10$ and $L=6000$

ENGINEERING ECONOMICS EXAMPLES

$$\text{PW} = -27,324.59, \text{ Answer.}$$

* * * * *

29. In problem 28, if the annual expenses to be increased by \$500 annually, determine:
The after tax present worth with no consideration to depreciation.

Solution:

This is an after tax present worth with uniform gradient annual expenses. Refer to equation (40)

GRADI (ENEC/PW/A.TAX)

For $P=120000$, $AR=36000$, $AE=8000$, $i=.085$, $n=10$, $G=500$, $TAX.R=.51$, and $L=6000$

$$\text{PW} = -33,488.49, \text{ Answer.}$$

* * * * *

30. In problem 28, if the investment is depreciated by Straight Line method, determine:
a. The present worth of the after tax depreciation recovery.
b. The overall present worth of the investment, including depreciation recovery.

Solution:

- a. Refer to depreciation recovery equation (22) **RECOV** (ENEC/DEPRI/SL)
For $TAX.R=.51$, $P=120000$, $L=6000$, $n=10$, and $i=.085$

$$\text{ATDR} = 38,147.68, \text{ Answer for (a).}$$

- b. The PW (overall) = PW (problem 28) + PW (problem 30) or:
 $\text{PW (overall)} = -27324.59 + 38147.68$

$$\text{PW (overall)} = 10,823.09, \text{ Answer for (b).}$$

* * * * *

31. In problem 28, if the investment is depreciated by Double Declining Balance method, determine:
a. The present worth of the after tax depreciation recovery.
b. The overall present worth of the investment, including depreciation recovery.

Solution:

- a. Refer to depreciation recovery equation (17) **RECOV** (ENEC/DEPRI/DDB)
For $TAX.R=.51$, $P=120000$, $n=10$, and $i=.085$

$$\text{ATDR} = 40,907.80, \text{ Answer for (a).}$$

ENGINEERING ECONOMICS EXAMPLES

- b. The PW (overall) = PW (problem 28) + PW (problem 31) or:
PW (overall) = -27324.59 + 40907.80

$$\text{PW (overall)} = 13,583.21, \text{ Answer for (b).}$$

* * * * *

32. In problem 28, if the investment is depreciated by Sum of the Years' Digits, determine:
a. The present worth of the after tax depreciation recovery.
b. The overall present worth of the investment, including depreciation recovery.

Solution:

- a. Refer to depreciation recovery equation (25) **RECOV** (ENEC/DEPRI/SOYD)
For TAX.R = .51, n = 10, i = .085, P = 120000, and L = 6000.

$$\text{ATDR} = 42,764.33, \text{ Answer for (a).}$$

- b. The PW (overall) = PW (problem 28) + PW (problem 32) or:
PW (overall) = -27324.59 + 42764.33

$$\text{PW (overall)} = 15,439.74, \text{ Answer for (b).}$$

* * * * *

33. Wood and steel structures are being considered for a foot bridge.
The wooden structure requires a \$10,000 first cost, annual painting and general maintenance is estimated to cost \$1,800. A major overhaul will be required every 5 years which costs \$3,500. The steel bridge will cost \$25,000 with annual up keep estimated to cost \$1,000. Only one overhaul will be required in the 15th year and cost \$6,000. The bridge will have a salvage value of \$5,000 at the end of is 25 years.
An expense of \$4,000 will be required to remove the wooden structure. Using the present worth comparison, determine the best alternative. Interest is 10%.

Solution:

1-Wooden foot bridge, present worth: (2 components)

- 1-1 Initial plus annual uniform cost: Use before tax equations.
Refer to equation (37) **UNIF** (ENEC/PW/B.TAX)
For P = 10000, AR = 0, AE = 1800, i = 0.10, n = 25, and L = -4000 (cost of removal)
PW 1-1 = -26,707.86

- 1-2 Periodical overhaul cost:
In this part, calculations are based on 5 year period.
Refer to equation (28) **EQUIV** (ENEC/INTER) to find the 5-year period equivalent interest rate.
For m = 1/5 or 12/60 = 0.2, i = 0.10 iEQ = 0.61051

ENGINEERING ECONOMICS EXAMPLES

To find the present worth, refer to equation (37) **UNIF** (ENEC/PW/B.TAX)

For $P=0$, $AR=0$, $AE=3500$, $i=0.61051$, $n=25/5=5$ and $L=0$ PW 1-2 = -5,203.79

Add 1-1 and 1-2

$$\text{PW (wood)} = -31,911.65$$

2-Steel foot bridge, present worth:(2 components)

Annual cost contains the following:

2-1 Initial plus annual uniform cost:

Refer to equation (37) **UNIF** (ENEC/PW/B.TAX)

For $P=25000$, $AR=0$, $AE=1000$, $i=0.10$, $n=25$ and $L=5000$ PW 2-1 = -33,615.56

2-2 Periodical overhaul cost:

Refer to equation (13) **FP** (ENEC/FCR)

For $F=-6000$, $i=0.10$, and $n=15$, PW 2-2 = -1436.35

Add 2-1 and 2-2

$$\text{PW (steel)} = -35,051.91$$

Wooden foot bridge, <u>Answer</u>

* * * * *

34. Two types of buildings are being considered for a new project. The following table provides the estimates prepared for each type of building. Determine which building is the economic choice when interest is at 9%.

Description	Building A	Building B
Investment Cost-\$	60,000	200,000
Estimated Life-Years	15	25
Net Salvage Value	0	50,000
Annual Disbursements	11,000	5,000

Solution:

For comparison, the least common multiple is 75 years, which is 4 replacements for BLDNG A and 2 replacements for BLDNG B.

Step 1 Calculate the 15 and 25-year period equivalent interest rates.

Refer to equation (28) **EQUIV** (ENEC/INTER)

For $i=0.09$ and $m=1/15=0.066667$

$$\text{iEQ}(15) = 2.6425$$

For $i=0.09$ and $m=1/25=0.04$

$$\text{iEQ}(25) = 7.6231$$

Step 2 Calculate the before tax present worth for each period.

With the uniform annual cost, refer to equation (37) **UNIF** (ENEC/PW/B.TAX)

a. For $P=60000$, $AR=0$, $AE=11000$, $i=0.09$, $n=15$ and $L=0$ PW(15) = -148667.57

ENGINEERING ECONOMICS EXAMPLES

- b. For $P=200000$, $AR=0$, $AE=5000$, $i=0.09$, $n=25$ and $L=50000$ $PW(25)=-243314.51$

Step 3 Calculate the 75-year present worth.

Use the same equation

- a. For $P=148667.57$, $AR=0$, $AE=148667.57$, $i=IEQ=2.6425$, $n=4$ and $L=0$
 $PW(A)=-204,608.17$
- b. For $P=243314.51$, $AR=0$, $AE=243314.51$, $i=IEQ=7.6231$, $n=2$, and $L=0$
 $PW(B)=-274,803.31$

Building A preferred, Answer

* * * * *

35. If an investment has an initial cost of \$40,000 and annual expenses of \$20,000, determine:
The capitalized cost for perpetual services. Assume interest rate as 7.5%

Solution:

Refer to capitalized cost, with no replacement, equation (07) **N.REP** (ENEC/CAPIT)

For $P=40000$, $AE=20000$, and $i=.075$

$CC = 306,666.7$, Answer.

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36. In problem 35 if additional \$10,000 re-investment is required every three (3) years, determine:
The capitalized cost for perpetual services.

Solution:

Refer to capitalized cost, with other replacement, equation (08) **OTHER** (ENEC/CAPIT/W.REP)

For $P=40000$, $PC=10000$, $i=.075$, $n=3$, and $AE=20000$

$CC = 347,938.35$, Answer.

* * * * *

37. In problem 35 if in-kind re-investment is required every three (7) years, determine:
The capitalized cost for perpetual services. Assume salvage value as \$7,000.

Solution:

Refer to capitalized cost, with in-kind replacement, equation (09) **KIND** (ENEC/CAPIT/W.REP)

For $P=40000$, $L=7000$, $i=.075$, $n=7$, and $AE=20000$

$CC = 356,738.81$, Answer.

ENGINEERING ECONOMICS EXAMPLES

38. The cost of computer "A" is \$3500 with annual expense of \$200 and 4 year useful life with no salvage value. The cost of computer "B" is \$5000 with annual expense of \$300 and 6 year useful life with \$600 salvage value. Determine the capitalized cost of perpetual services for both "A" and "B". And based on financial analysis, which one is the better choice. Assume 9% annual interest rate.

Solution:

To find the capitalized cost, with in-kind replacement, refer to equation (08) **KIND** (ENEC/CAPIT/W.REP)

- | | | |
|----|--|--|
| a. | For $P=3500$, $L=0$, $i=0.09$, $n=4$, and $AE=200$ | <u>$CC(A) = \\$14,226.00$</u> |
| b. | For $P=5000$, $L=600$, $i=0.09$, $n=6$, and $AE=300$ | <u>$CC(B) = \\$14,831.63$</u> |

Computer A is preferable, Answer

NOTE: For perpetual service, the computer must be replaced at the end of its useful life.

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39. Two structures for an industrial building are under consideration. Using a minimum attractive rate of return of 5%. Which structure should be built based on a capitalized cost comparison. The following data is provided for each structure.

Solution:

GIVEN	STRUCTURE X	STRUCTURE Y
First Cost	\$6,000	\$20,000
Estimated Life, year	10	25
Estimated Salvage Value	0	\$5,000
Annual Expenses	\$1,100	\$500

Structure X:

For capitalized cost, with in-kind replacement for perpetual service, refer to equation (08) **KIND** (ENEC/CAPIT/W.REP)

For $P=6000$, $L=0$, $i=0.05$, $n=10$, and $AE=1100$	<u>$CC(X) = \\$37,540.55$</u>
--	--

Structure Y:

For $P=20000$, $L=5000$, $i=0.05$, $n=25$, and $AE=500$	<u>$CC(Y) = \\$36,285.74$</u>
---	--

Structure Y, Answer

ENGINEERING ECONOMICS EXAMPLES

40. A machine has a first cost of \$20,000. The annual maintenance costs associated with the machine will be \$1,000. The yearly income generated by the machine is expected to be \$8,000, 7,500, 5,000, 9,000 and 500 over the five year useful life of the machine.

Part A; Determine the rate of return for this investment and whether the investment should be made if the minimum acceptable rate of return is 10%.

Part B; Should the machine be operated for the fifth year, explain your answer.

Solution:

For both Parts A & B, in order to determine if the operation generates a minimum 10% ROR, calculate the Expected Annual Average Revenue, AAR (for a 10% ROR).

Then calculate the Actual AAR, and compare them.

Part A: (5 years)

Step 1 To find the expected AAR (assuming $ROR = .1$), with zero salvage value, refer to equation (42) $SAL = 0$ (ENEC/ROR)

For $ROR = 0.1$, $n = 5$, and $P = 20000$

$$\underline{AAR = 5,275.95}$$

To this amount, add 1,000 maintenance cost

$$\underline{\text{Expected AAR} = 6,275.95}$$

Step 2 To find the Actual Average Annual Revenue, for variable annual generated incomes, refer to equation (04) AEQ (ENEC/ANNU)

For $i = ROR = 0.1$, $n = 5$, $A_1 = 8000$, $A_2 = 7500$, $A_3 = 5000$, $A_4 = 9000$, and $A_5 = 500$

$$\underline{\text{Actual AAR} = Aeq = 6,248.10}$$

Since the actual AAR is less than expected AAR,

Expected ROR is not generated, Answer for A

Part B: (4 years, not operated the 5th year)

Step 1 Follow the same procedures: Same data, but $n = 4$

$$\underline{AAR = 6,309.42}$$

To this amount, add 1,000 maintenance cost

$$\underline{\text{Expected AAR} = 7,309.42}$$

Step 2 Same data, except $A_5 = 0$ and $n = 4$

$$\underline{\text{Actual AAR} = \$7,374.06}$$

Since the Actual AAR is greater than the Expected AAR,

Not to be operated the fifth year, Answer for B

* * * * *

41. A corporation has purchased a new machine at a cost of \$200,000 installed. It is expected that the machine will reduce the annual operation and maintenance cost by \$40,000 per year for 10 years. The machine is expected to have a \$35,000 salvage value after ten years of operation. Calculate the before tax and after tax expected rate of return associated with this investment based on straight line depreciation. The corporations income tax rate is 48%.

ENGINEERING ECONOMICS EXAMPLES

Solution:

Before tax:

To find the AAR, with expected salvage value, refer to equation (41) $SAL > 0$ (ENEC/ROR).

For $n=10$, $AAR=40000$, $L=35000$, and $P=200000$

$ROR=0.1616$ or 16.2% , <u>Answer</u> , before tax

After tax:

To calculate the tax, calculate the Depreciation (straight line)

Straight line depreciation: $(200000-35000)/10=16500$

Taxable income: $40000-16500=23500$

Income Tax: $23500 \times 0.48=11280$

AAR after tax: $AAR=40000-11280=28720$

Refer to same equation and data, except for $AAR=28720$

$ROR=0.0891$ or 8.91% , <u>Answer</u> , after tax
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42. The following estimated data is provided for two investments, A and B, for which revenues as well as costs are known. If the minimum attractive rate of return is 15%, assuming the Alternative A has been justified, determine if Alternative B is justified.

DESCRIPTION	A	B
Investment	2,000	15,000
Annual Revenue	10,000	17,000
Annual Expense	8,200	12,700
Economic Life	10	10
Net Salvage	0	0

Solution:

Solve this by the incremental Rate of Return System. For zero salvage value, refer to equation (42)

$SAL=0$ (ENEC/ROR).

For $n=10$, $AAR=(17000-12700)(B) - (10000-8200)(A)=2500$, and

$P=15000(B) - 2000(A) = 13000$

$$ROR=14.08\%$$

Since this is less than the expected 15%,

Alternative B is not justified, <u>Answer</u>

ENGINEERING ECONOMICS EXAMPLES

43. An automobile is purchased for \$10,000 and has the following trade-in salvage values and annual expenses for operation and maintenance. Determine when the automobile should be replaced. Interest is at 10%.

YEAR	TRADE-IN	AE
1	6,500	2,500
2	4,500	2,750
3	2,000	3,375
4	750	5,550
5	500	6,750

Solution:

Step 1 Calculate the equalized annual expenses for each of the five years of use.

Refer to equation (04) **AEQ** (ENEC/ANNU)

One (1) year:

$$\underline{AE(1)=2500}$$

Two (2) years: For $i=0.1$, $n=2$, $A1=2500$, $A2=2750$, $A3=0$, $A4=0$, and $A5=0$

$$\underline{AE(2)=2619.05}$$

Three (3) years: All data is same except: $n=3$ and $A3=3375$

$$\underline{AE(3)=2847.43}$$

Four (4) years: All data is same except: $n=4$ and $A4=5550$

$$\underline{AE(4)=3429.76}$$

Five (5) years: All data is same except: $n=5$ and $A5=6750$

$$\underline{AE(5)=3973.60}$$

Step 2 Calculate the equivalent annual cost for the same years.

Refer to equation (01) **SF** (ENEC/ANNU)

One (1) year: For $P=10000$, $L=6500$, $i=0.1$, $n=1$, and $AE=AE(1)=2500$

$$\underline{A(1)=7000.00}$$

Two (2) years: For $P=10,000$, $L=4,500$, $i=0.1$, $n=2$, and $AE=AE(2)=2619.05$

$$\underline{A(2)=6238.10}$$

Three (3) years: For $P=10000$, $L=2000$, $i=0.1$, $n=3$, and $AE=AE(3)=2847.43$

$$\underline{A(3)=6264.35}$$

Four (4) years: For $P=10000$, $L=750$, $i=0.1$, $n=4$, and $AE=AE(4)=3429.76$

$$\underline{A(4)=6422.86}$$

Five (5) years: For $P=10000$, $L=500$, $i=0.1$, $n=5$, and $AE=AE(5)=3973.60$

$$\underline{A(5)=6529.68}$$

Step 3 By comparing the equivalent annual costs, since after the second year the unified equivalent annual cost will start to increase:

Replace after 2 years, <u>Answer</u>

ENGINEERING ECONOMICS EXAMPLES

44. A switchboard containing 150 pair cables can be made of either enameled wire or tinned wire. There will be 550 soldered connections. Cost to solder a connection is \$0.02 for enameled wire and \$0.015 for tinned wire. A 150 pair cable costs \$0.65 per foot for enameled wire and \$0.85 per foot for tinned wire. For what length of cable will the installation be the same.

Solution:

Cost of enameled wire: $550 \times 0.02 + L \times 0.65$

Cost of tinned wire: $550 \times 0.015 + L \times 0.85$

To find the length (L) for the same cost:

Key in ' $550 \times 0.02 + L \times 0.65 = 550 \times 0.015 + L \times 0.85$

For HP48SX: Press left arrow key, SOLVE, STEQ, SOLVR

For HP48GX: Press left arrow key, SOLVE, ROOT, left arrow key, EQ, SOLVR

Press left arrow key, L

$L = 13.75 \text{ ft.}, \text{ Answer}$

* * * * *

45. Two motors, each rated at 80 kw, are offered to a prospective buyer. Motor A will cost \$900 and have a guaranteed full load efficiency of 90%. Motor B will cost \$500 and have a guaranteed full load efficiency of 88%. Electric service costs \$1.25 per month per kw of monthly demand and \$0.03 per kwhr of use. For how many hours of full load operation per year would the motors just break even as to the economy. Interest is 10% and both motors are expected to last for 10 years.

Solution:

Step 1 Find the unified equivalent annual fixed cost:

Refer to equation (01) SF (ENEC/ANNU)

MOTOR A: For $P=900, L=0, i=0.1, n=10$ and $AE=\text{key in } '80 \times 12 \times 1.25 / 0.9$

EVAL = 1333.33

A(A)=1,479.80

MOTOR B: For $P=500, L=0, i=0.1, n=10$ and $AE=\text{key in } '80 \times 12 \times 1.25 / 0.88$

EVAL = 1363.64

A(B)=1,445.01

Step 2 Find the total annual cost:

MOTOR A: $1479.80 + 80 \times H \times 0.03 / 0.90$ (H = Number of hours)

MOTOR B: $1445.01 + 80 \times H \times 0.03 / 0.88$

Step 3 To find the break-even hours (H):

Key in ' $1479.80 + 80 \times H \times 0.03 / 0.90 = 1445.01 + 80 \times H \times 0.03 / 0.88$

For HP48SX: Press left arrow key, SOLVE, STEQ, SOLVR

For HP48GX: Press left arrow key, SOLVE, ROOT, left arrow key, EQ, SOLVR

Press left arrow key, H

$H = 574 \text{ hours}, \text{ Answer}$

FANS EXAMPLES

1. Determine:

(a) the temperature and (b) the pressure of atmospheric air at 33,000 feet altitude.

Solution (REFERENCE CHOTKEH MANUAL):

- a. For English Units, at LIBRARY press FANS ALTIT ENG TEMP $0 \leq \text{ALT} < 35000$
For ALT=33000 ft

$t = -59$ oF, <u>Answer</u> for (a)

- b. For English Units, at LIBRARY press FANS ALTIT ENG PRESS NXT NXT
 $32500 < \text{ALT} < 60000$. For ALT=33000 ft

$P = 3.8$ psi, <u>Answer</u> for (b)

* * * * *

2. Determine:

The altitude at which the atmospheric temperature equals to 32 oF.

Solution (REFERENCE CHOTKEH MANUAL)::

- a. For English Units, at LIBRARY press FANS ALTIT ENG TEMP $0 \leq \text{ALT} < 35000$
For t=32 oF

ALT = 7485 ft, <u>Answer</u> .

* * * * *

3. For a fan with the following characteristics at standard condition:

Air flow quantity: 25,000 cfm

Flow velocity: 1760 fpm

Static pressure: 2.5 inH2O

Brake horsepower: 14.3 hp.

Determine:

- Fan's total pressure.
- Fan's air horsepower.
- Fan's mechanical efficiency.

FANS EXAMPLES

Solution (REFERENCE CHOTKEH MANUAL)::

- a. To find the total pressure, at standard condition in English Units, refer to total pressure equation (31) **STAN** (FANS/PRESS/ENG/TOTAL)
For **P_s.ST=2.5 inH₂O**, and **fpm=1760**.

Pt.ST = 2.69 inH₂O , <u>Answer</u> for (a).

- b. For air horsepower at standard condition, in English Units, refer to equation (13) **STAN** (FANS/HP/ENG/AIR)
For **Pt.ST=2.69 inH₂O**, and **Q.ST=25000 cfm**.

ahp = 10.6 hp , <u>Answer</u> for (b).

- c. From **eff=ahp/bhp**, key in ' 10.6/14.3 EVAL

eff = .74 = 74% , <u>Answer</u> for (c).

* * * * *

4. For a fan supplying 4000 cfm air against the 2.5 inH₂O system's total pressure, draw:
The system's characteristic, **Pt(Q)**, curve. Make it for 0 - 8000 cfm range.

Solution (REFERENCE CHOTKEH MANUAL)::

Refer to system characteristics curve equation (48) **CURVE** (FANS)

Calculate the pressure for different **cfm** and enter the results in the following table.

For **P1=2.5 inH₂O**, **Q2=1000 cfm**, and **Q1=4000 cfm**

P2 = .16 inH₂O

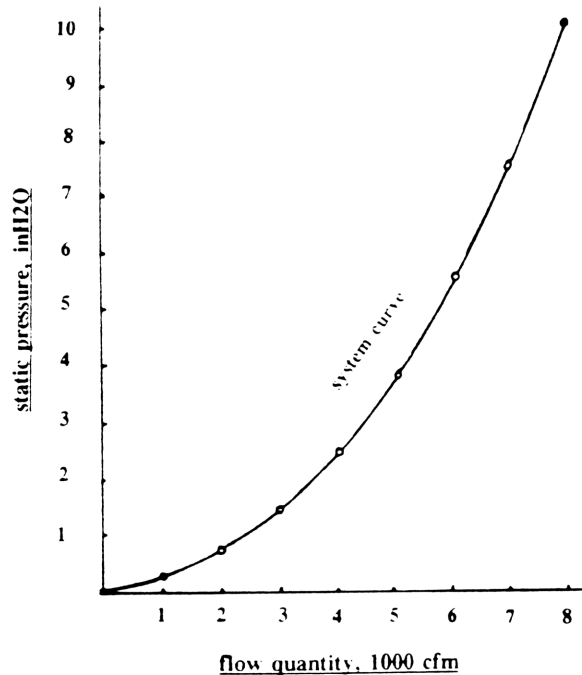
For the same values, but **Q2=2000 cfm**

P2 = .63 inH₂O

Continue for **Q2=3000, 4000,**, then draw the curve.

Q2 (cfm)	1000	2000	3000	4000	5000	6000	7000	8000
P2 (inH ₂ O)	.16	.63	1.4	2.5	3.9	5.6	7.7	10

FANS EXAMPLES



5. For a fan running under the following characteristics at standard conditions:

Air flow quantity: 13,500 cfm

Static pressure: 3.5 inH₂O.

Fan's rotation: 850 rpm.

Brake horsepower: 8.9 hp.

Determine:

- a. The new brake horsepower if the rotational speed is changed to 1350 rpm.
- b. The new rpm for 4.2 inH₂O static pressure.

Solution (REFERENCE CHOTKEH MANUAL)::

- a. For new brake horsepower, due to change in rpm, refer to fan's law equation (25) **RPM**
(FANS/LAW/ ΔHP)
For $hp_1 = 8.9$ hp, $n_1 = 850$ rpm, and $n_2 = 1350$ rpm.

$$hp_2 = 35.7 \text{ hp, Answer for (a).}$$

- b. For new rpm, due to change in pressure, refer to fan's law equation (27) **RPM**
(FANS/LAW/ ΔP)
For $P_1 = 3.5$ inH₂O, $P_2 = 4.2$ inH₂O, and $n_1 = 850$ rpm.

$$n_2 = 931 \text{ rpm, Answer for (b).}$$

FANS EXAMPLES

6. For problem 5, under "b" condition, determine:
- The new brake horsepower of the fan.
 - The flow quantity of the fan.

Solution (REFERENCE CHOTKEH MANUAL)::

- a. For new brake horsepower, due to change in **rpm**, refer to fan's law equation (25) **RPM** (FANS/LAW/ ΔHP)
For **hp1=8.9 hp**, **n1=850 rpm**, and **n2=931 rpm**.

hp2 = 11.7 hp, Answer for (a).

- b. For new flow quantity, due to change in **rpm**, refer to fan's law equation (29) **RPM** (FANS/LAW/ ΔQ)
For **Q1=13500 cfm**, **n1=850 rpm**, and **n2=931 rpm**.

Q2 = 14786 cfm, Answer for (b).
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7. For a fan running under the following characteristics and standard conditions:

Air flow quantity: 30,000 cfm

Static pressure: 2.2 inH₂O.

velocity pressure: neglect.

If the temperature of air is raised to 135 oF with all other conditions remained the same, determine:

- The density factor.
- The new static pressure.
- The brake horsepower, under the standard condition, assume 72% fan's efficiency.
- The brake horsepower, under the new condition, same efficiency.

Solution (REFERENCE CHOTKEH MANUAL)::

- a. To find the density factor, in English Units, refer to density equation (06) **ρ_{FAC}** (FANS/DENSI/ENG)
For **t.AC=135 oF** and **P.AC=14.7 psia** (no change in pressure).

Kd = 1.12, Answer for (a).

FANS EXAMPLES

- b. From $P_s(\text{actual}) = P_s(\text{standard})/K_d$, key in ' 2.2/1.12 EVAL

$$P_s(\text{actual}) = 1.96 \text{ inH}_2\text{O}, \text{ Answer for (b).}$$

- c. For brake horsepower at standard condition, in English Units, refer to equation (16) STAN (FANS/HP/ENG/BRAK)

For $P_t.ST = 2.2 \text{ inH}_2\text{O}$ (neglect velocity pressure), $Q.ST = 30,000 \text{ cfm}$, and $\eta_m = .72$.

$$bhp = 14.42 \text{ hp}, \text{ Answer for (c).}$$

- d. For brake horsepower at actual condition and the given standard data, in English Units, refer to equation (18) STD.D (FANS/HP/ENG/BRAK/ACTU)

For $P_t.ST = 2.2 \text{ inH}_2\text{O}$, $Q.ST = 30,000 \text{ cfm}$, $P.AC = 14.7 \text{ psia}$, $t.AC = 135 \text{ oF}$, and $\eta = .72$.

$$bhp = 12.85 \text{ hp}, \text{ Answer for (d).}$$

NOTE: Dividing the standard $bhp = 14.42$ by $K_d = 1.12$, gives the same answer.

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8. For a fan with the following characteristics and working conditions:

Working altitude: 8,000 ft.

Actual air flow quantity: 30,000 cfm

Actual system's static pressure: 2.2 inH₂O.

System's air velocity: 2200 fpm.

Determine:

- a. The density factor.
- b. The equivalent standard static pressure.
- c. The actual brake horsepower (at 8,000 ft altitude), assume 72% fan's efficiency.
- d. The equivalent standard brake horsepower, same efficiency.

Solution (REFERENCE CHOTKEH MANUAL)::

To solve this problem the temperature and pressure at 8,000 ft altitude must be determined first:

1. Actual temperature:

For English Units, refer Altitude equations (02) TEMP (FANS/ALTIT/ENG)

For $ALT = 8000 \text{ ft}$

$$t = 30.2 \text{ oF}$$

FANS EXAMPLES

2. Actual pressure:

For English Units, refer Altitude equations (01) **PRESS** (FANS/ALTIT/ENG)

For **ALT=8000** ft

$$\underline{P = 10.9 \text{ psi}}$$

- a. To find the density factor, in English Units, refer to density equation (06) **ρ FAC** (FANS/DENSI/ENG)

For **t.AC=30.2** oF and **P.AC=10.9** psi.

$$\boxed{\mathbf{Kd = 1.2475, \text{ Answer for (a).}}}$$

- b. From **Ps(actual)=Ps(standard)/Kd**, key in ' 2.2*1.2475 **EVAL**

$$\boxed{\mathbf{Ps(standard) = 2.74 \text{ inH}_2\text{O, Answer for (b).}}}$$

- c. To find the actual brake horsepower take the following steps:

Step 1 Calculate the total pressure:

For total pressure at actual conditions, in English Units, refer to equation (32)

ACTU (FANS/PRESS/ENG/TOTAL)

For **Ps.AC=2.2** inH₂O and **fpm=2200**, **P.AC=10.9** psia, and **t.AC=30.2** oF

$$\underline{\mathbf{Pt.AC = 2.44 \text{ inH}_2\text{O}}}$$

Step 2 Calculate the actual brake horsepower:

For brake horsepower at actual conditions with the given actual data, in English

Units, refer to horsepower equation (17) **ACT.D** (FANS/HP/ENG/BRAK/ACTU)

For **Pt.AC=2.44** inH₂O, **Q.AC=30,000** cfm, and **$\eta = .72$** .

$$\boxed{\mathbf{bhp = 16 \text{ hp, Answer for (c).}}}$$

- d. For standard condition brake horsepower, in English Units, refer to equation (16) **STAN** (FANS/HP/ENG/BRAK)

For **Pt.ST=2.44*1.2475=3.044** inH₂O, **Q.ST=30,000** cfm, and **$\eta = .72$** .

$$\boxed{\mathbf{bhp = 19.95 \text{ hp, Answer for (d).}}}$$

NOTE: Multiplying the actual **bhp=16** by **Kd=1.2475**, gives the same answer.

FANS EXAMPLES

9. A fan discharges 12,500 cfm of 87 oF air through a 3 ft by 2 ft duct with an actual static pressure of 1.3 inH₂O. If the barometric pressure and the brake horsepower are measured as 28.3 inHg and 4.9 hp, respectively, determine:
- The mechanical efficiency of the fan
 - The fan's static pressure efficiency.

Solution (REFERENCE CHOTKEH MANUAL)::

- a. To find the mechanical efficiency, take the following steps:

Step 1 Find the total system's pressure:

For total pressure at actual conditions, refer to equation (32) ACTU
(FANS/PRESS/TOTAL)

For Ps.AC=1.3 inH₂O, fpm= key in ' 12500/(3*2) EVAL =2083.3,

P.AC=28.3 inHg=13.9 psia (calculator's unit conversion), and t.AC=87 oF

Pt.AC = 1.55 inH₂O

Step 2 Calculate the mechanical efficiency:

With the given actual brake horsepower, in English Units, refer to efficiency equation (09)

ENG (FANS/EFFI/ η_M /BHP)

For Pt=1.55 inH₂O, cfm=12,500, and bhp=4.9 hp.

$$\eta_M = .622 = 62.2\% \text{ , Answer for (a).}$$

- b. To find the static pressure efficiency, refer to efficiency equation (12) η_s
(FANS/EFFI)

For Ps=1.3 inH₂O, Pt=1.55 inH₂O, and $\eta_M = .622$

$$\eta_s = .52 = 52\% \text{ , Answer for (b).}$$

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10. A 1/10 scale model fan has the following test characteristics, performed under the standard condition.

Flow quantity: 45 cfm

Total system's pressure: 0.6 inH₂O

Rotational speed: 350 rpm.

If the full size fan is to work on 6,000 ft altitude at 60% of the model's speed, determine:

The full size fan's air horsepower.

FANS EXAMPLES

Solution (REFERENCE CHOTKEH MANUAL)::

Step 1 Find the actual temperature and pressure at 6000 ft altitude.

1. Actual temperature:

For English Units, refer to Altitude equations (02) **TEMP** (FANS/ALTIT/ENG)

For **ALT=6,000** ft $t = 37.3$ oF

2. Actual pressure:

For English Units, refer to Altitude equations (01) **PRESS** (FANS/ALTIT/ENG)

For **ALT=6,000** ft $P = 11.78$ psi

Step 2 Find the models air horsepower, at 6,000 ft altitude condition. For air horsepower at actual conditions with the given fan's standard data, in English Units, refer to equation (15) **STD.D** (FANS/HP/ENG/AIR/ACTU)

For **Pt.ST=.6** inH2O, **Q.ST=45** cfm, **P.AC=11.78** psia, any **t.AC=37.3** oF
 $ahp = .00363$ hp

Step 3 Calculate the full scale's air horsepower.

Use the fan's similarity equations . For change in **ahp** due change in diameter (**D**) and rpm (**n**), refer to similarity equation (42) **D . N . ρ** (FANS/SIMIL/HP)

For **ahpA=.00363** hp, **DA=1**, **DB=10**, **nA=350** rpm, **nB=350*.6=210** rpm
and **ρA=ρB=1** (or any other equal number)

$ahpB = 78.4$ hp, <u>Answer.</u>

* * * * *

11. Solve problem "10", using the similarity equations and fan's standard data.

Solution (REFERENCE CHOTKEH MANUAL)::

For solving this problem, using the fan's standard data take the following steps.

Step 1 Find the actual temperature and pressure at 6000 ft altitude.

From problem 10:

$$t = 37.3 \text{ oF}$$

$$P = 11.78 \text{ psi}$$

FANS EXAMPLES

Step 2 Find the density of air for both standard and 6000 ft altitude condition.

1. Density at standard condition:

For English Units, refer to air density equations (05) **ρ_{AIR}** (FANS/DENSI/ENG)

For **P=14.7** psia and **t=70** oF

$$\rho_{ST} = .0749 \text{ pcf}$$

2. Density at 6,000 ft altitude:

Stay with the same equation

For **P=11.78** psia and **t=37.3** oF

$$\rho_{AC} = .06396 \text{ pcf}$$

Step 3 Find the model's air horsepower at standard condition. For English Units, refer to air horsepower equation (13) **STAN** (FANS/HP/ENG/AIR)

For **Pt.ST=.6** inH2O, **Q.ST=45** cfm

$$\text{ahp} = .00425 \text{ hp}$$

Step 4 Calculate the full scale's air horsepower.

Use the fan's similarity equations. For change in **ahp** due change in diameter (**D**), rpm (**n**), and density (**ρ**), refer to similarity equation (42) **$D \cdot N \cdot \rho$** (FANS/SIMIL/HP)

For **ahpA=.00425** hp, **DA=1**, **DB=10**, **nA=350** rpm, **nB=350*.6=210** rpm

, **$\rho A = \rho_{ST} = .0749$** , and **$\rho B = \rho_{AC} = .06396$**

$$\text{ahpB} = 78.4 \text{ hp, Answer.}$$

* * * * *

12. A 40" diameter fan, running at 650 rpm, delivers 11,000 cfm air at 1.8 inH2O static pressure. The density of delivered air is .075 pcf and the air horsepower is measured as 3.2 hp. If a geometrically similar fan with 50" diameter fan runs at 900 rpm with no change in the air density, determine the required air horsepower.

Solution (REFERENCE CHOTKEH MANUAL)::

For new air horsepower, due to change in **D**, **N**, and **ρ** , refer to similarity equation (42) **$D \cdot N \cdot \rho$**

For **ahpA=3.2** hp, **DA=40"**, **DB=50"**, **nA=650** rpm, **nB=900** rpm, and **$\rho A = \rho B = .075$**

$$\text{ahpB} = 25.9 \text{ hp, Answer.}$$

13. Based on the information of problem 12, determine:
- The new flow quantity.
 - The new static pressure.

FANS EXAMPLES

Solution (REFERENCE CHOTKEH MANUAL)::

- a. With the given change in **D** and **N**, refer to similarity flow equation (40) **D.N** (FANS/SIMIL/FLOW)
For **QA = 11000** cfm and the same values for others.

QB = 29,748 cfm, Answer for (a).

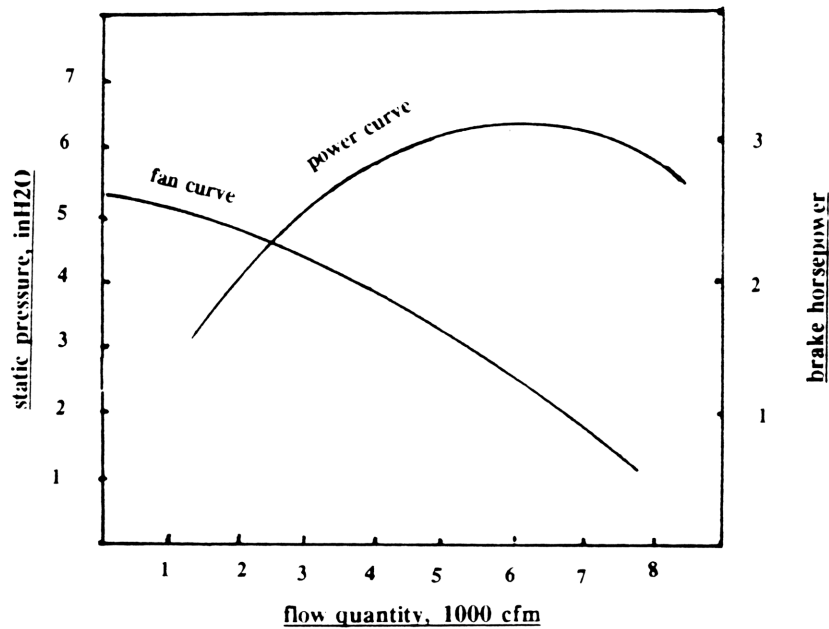
- b. Refer to similarity pressure equation (45) **PRESS** (FANS/SIMIL)
For **PA = 1.8** inH₂O and the same values for others.

PB = 5.39 inH₂O, Answer for (b).

* * * * *

Problems 14 - 15

A fan is operating at 1550 rpm with the characteristics shown below. It should supply the air to a ducting system which has the static pressure of 2 inH₂O when handles 4,000 cfm at standard condition.



Based on the above information, solve the following two (2) problems.

14. Determine:

The flow, the static pressure, and the brake horsepower of the system, when the fan and ducting are connected together.

FANS EXAMPLES

Solution (REFERENCE CHOTKEH MANUAL)::

This problem must be solved graphically. The operating condition is the characteristics of the point of intersection between the fan's and system's characteristics curves. Since the fan's curve is given, draw the system's curve, locate the operation point, and read the conditions from the chart.

Step 1 Draw the system's characteristics curve.

Refer to system characteristics curve equation (48) **CURVE (FANS)**

Calculate the pressure for different cfm and enter the results in the following table.

For $P_1 = 2$ inH₂O, $Q_2 = 1,000$ cfm, and $Q_1 = 4,000$ cfm

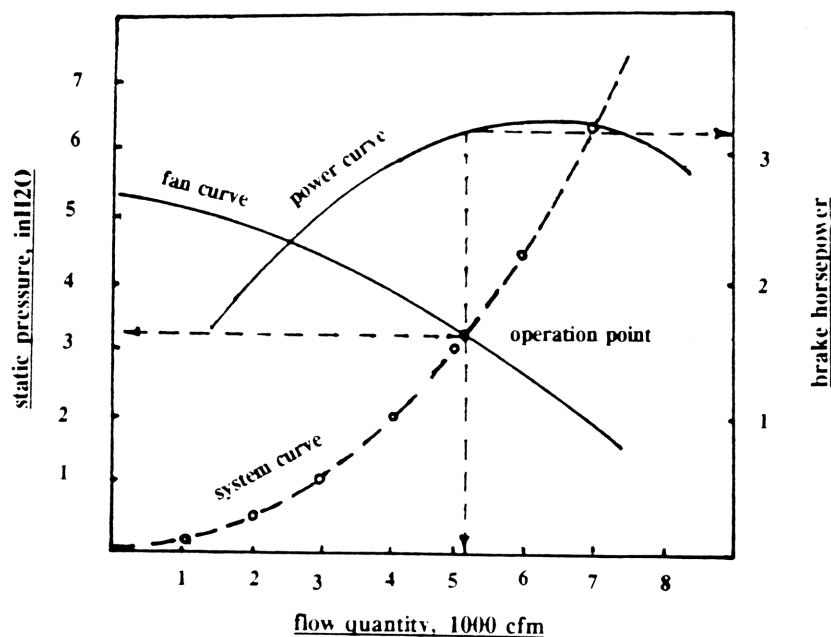
$$P_2 = .125 \text{ inH}_2\text{O}$$

For the same values, but $Q_2 = 2,000$ cfm

$$P_2 = .5 \text{ inH}_2\text{O}$$

Continue for $Q_2 = 3,000, 4,000, \dots$, then draw the curve on the chart.

Q2 (cfm)	1000	2000	3000	4000	5000	6000	7000	8000
P2 (inH ₂ O)	.125	.5	1.125	2	3.125	4.5	6.125	8



Step 2 Read the characteristics of the operating condition.

$Q = 5,170$ cfm, $P_s = 3.2$ inH₂O, $bhp = 3.15$ hp, Answer.

FANS EXAMPLES

15. If the system has to provide 6000 cfm of air at standard condition, determine:
- The new rotational speed of the fan.
 - The system's static pressure.
 - The required brake horsepower.

Solution (REFERENCE CHOTKEH MANUAL):

To solve this problem, use the fans' laws equations.

- a. For new **rpm**, due to change in **flow**, refer to fan's law equation (29) **RPM (FANS/LAW/ ΔQ)**
For **Q1=5,170 cfm**, **Q2=6,000 cfm**, and **n1=1,550 rpm**.

$$n2 = 1,799 \text{ rpm, Answer for (a).}$$

- b. For new pressure, due to change in **rpm**, refer to fan's law equation (27) **RPM (FANS/LAW/ ΔP)**
For **P1=3.2 inH2O**, **n1=1,550 rpm**, and **n2=1,799 rpm**.

$$P2 = 4.3 \text{ inH2O, Answer for (b).}$$

- c. For new brake horsepower, due to change in **rpm**, refer to fan's law equation (25) **RPM (FANS/LAW/ ΔHP)**
For **hp1=3.15 hp**, **n1=1,550 rpm**, and **n2=1,799 rpm**.

$$hp2 = 4.93 \text{ hp, Answer for (c).}$$

* * * * *

16. Determine:
- (a) the temperature and (b) the pressure of atmospheric air at 10,000 meters altitude.

Solution (REFERENCE CHOTKEH MANUAL):

- a. For SI Units, at LIBRARY press **FANS ALTIT SI TEMP** $0 \leq ALT < 10670$
For **ALT=10000 m**

$$t = -50.2 \text{ oC, Answer for (a)}$$

FANS EXAMPLES

- b. For SI Units, a LIBRARY press FANS ALTIT SI PRESS NXT NXT 9900 < ALT < 18500
For ALT = 10000 m

$$P = 26,456 \text{ Pa, Answer for (b)}$$

* * * * *

17. A fan runs with the speed of 700 rpm and delivers 3300 lps at 300 Pa static pressure. If the fan's speed increased to 800 rpm, determine:
- The fan's new flow rate.
 - The fan's new static pressure.

Solution (REFERENCE CHOTKEH MANUAL):

To solve this problem, use the fans' laws equations.

- a. For new flow, due to change in rpm, refer to fan's law equation (29) **RPM (FANS/LAW/ ΔQ)**
For $Q_1 = 3,300$ lps, $n_1 = 700$ rpm, and $n_2 = 800$ rpm.

$$Q_2 = 3,771 \text{ lps, Answer for (a).}$$

- b. For new pressure, due to change in rpm, refer to fan's law equation (27) **RPM (FANS/LAW/ ΔP)**
For $P_1 = 300$ Pa, $n_1 = 700$ rpm, and $n_2 = 800$ rpm.

$$P_2 = 392 \text{ Pa, Answer for (b).}$$

* * * * *

18. For a fan with the following characteristics and working condition:

Working altitude: 2,400 m.

Actual air flow quantity: 14,000 lps

Actual system's static pressure: 550 Pa.

System's air velocity: 11 mps.

Determine:

- The density factor.
- The equivalent standard static pressure.
- The actual brake horsepower (at 8,000 ft altitude), assume 72% fan's efficiency.
- The equivalent standard brake horsepower, same efficiency.

FANS EXAMPLES

Solution (REFERENCE CHOTKEH MANUAL)::

To solve this problem the temperature and pressure at 2,400 m altitude must be determined first:

1. Actual temperature:

For SI Units, refer Altitude equations (04) **TEMP** (FANS/ALTIT/SI)

For **ALT=2400** m $t = -0.8$ oC

2. Actual pressure:

For SI Units, refer Altitude equations (03) **PRESS** (FANS/ALTIT/SI)

For **ALT=2400** m $P = 75,595$ Pa

- a. To find the density factor, in SI Units, refer to density equation (08) **ρ_{FAC}** (FANS/DENSI/SI)
For **t.AC = -.8** oC and **P.AC = 75595** Pa.

$$Kd = 1.2456, \text{ Answer for (a).}$$

- b. From **Ps(actual)=Ps(standard)/Kd**, key in ' 550*1.2456 **EVAL**

$$Ps(\text{standard}) = 685 \text{ Pa, Answer for (b).}$$

- c. To find the actual brake horsepower take the following steps:

Step 1 Calculate the total pressure:

For total pressure at actual condition, in SI Units, refer to equation (36) **ACTU**
(FANS/PRESS/SI/TOTAL)

For **Ps.AC=550** Pa, **mps=11**, **P.AC=75595** Pa, and **t.AC = -.8** oC

$$Pt.AC = 617.3$$

Step 2 Calculate the actual brake horsepower:

For brake horsepower at actual condition and the given actual data, in SI Units, refer to equation (23) **ACT.D** (FANS/HP/SI/BRAK/ACTU)

For **Pt.AC=617.3** Pa, **Q.AC=14,000** lps, and **$\eta_m = .72$** .

$$bhp = 16.1 \text{ hp, Answer for (c).}$$

FANS EXAMPLES

- d. For brake horsepower at standard condition, in SI Units, refer to equation (22) STAN (FANS/HP/SI/BRK)

For $Pt.ST=617.3 \times 1.2456 = 768.91$ Pa, $Q.ST=14,000$ Pa, and $\eta_M = .72$.

$$bhp = 20 \text{ hp, Answer for (d).}$$

NOTE: Multiplying the actual $bhp=16.1$ by $Kd=1.2456$, gives the same answer.

* * * * *

19. If a fan delivers 5,000 lps at 360 Pa static pressure, draw the system's curve.

Solution (REFERENCE CHOTKEH MANUAL):

Refer to system characteristics curve equation (48) CURVE (FANS)

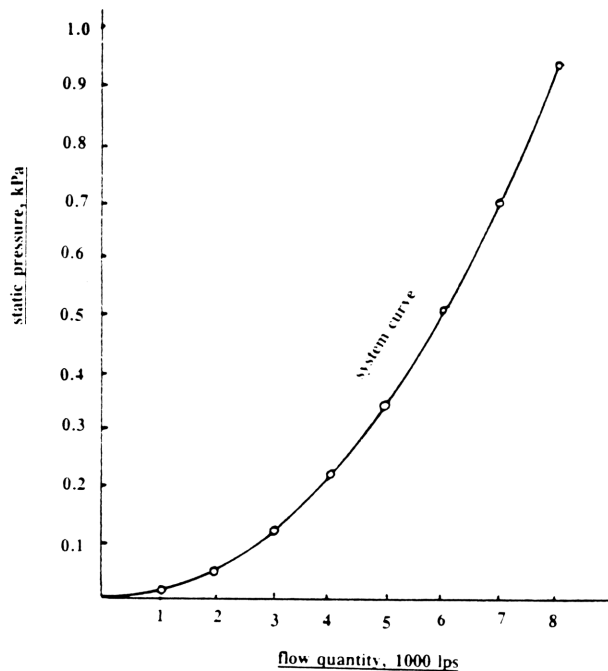
Calculate the pressure for different lps and enter the results in the following table.

For $P1=360$ Pa, $Q2=1,000$ lps, and $Q1=5,000$ lps $P2 = 14.4$ Pa

For the same values, but $Q2=2,000$ lps $P2 = 57.6$ Pa

Continue for $Q2=3,000, 4,000, \dots$, then draw the curve on the chart.

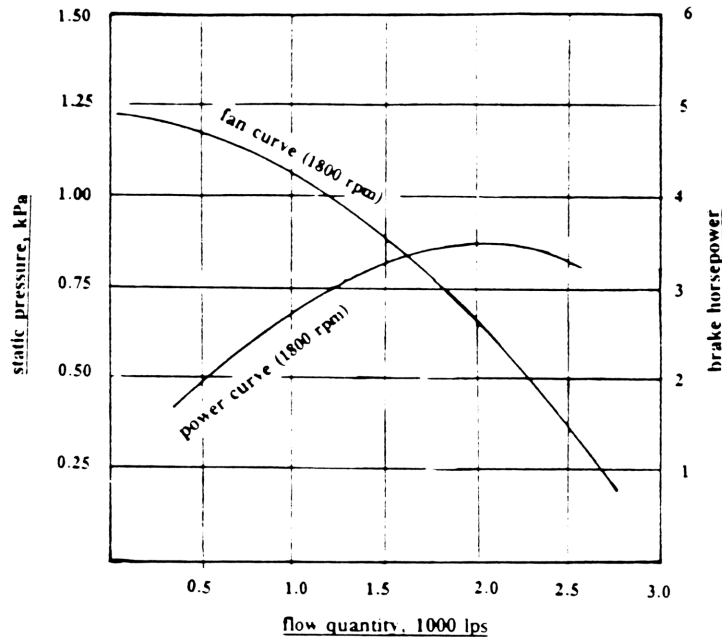
Q2 (lps)	1000	2000	3000	4000	5000	6000	7000	8000
P2 (Pa)	14.4	57.2	129.6	230.4	360	518.4	705.6	921.6



FANS EXAMPLES

Problems 20 - 27

The following figure represents the characteristics of a fan operating at 1800 rpm. If the fan delivers 1500 lps of air to a duct at 550 Pa static pressure resistance, solve the following problems:



20. Determine:
The system static pressure at 2,000 lps.

Solution (REFERENCE CHOTKEH MANUAL):

Refer to system characteristics curve equation (48) CURVE (FANS)

For $P_1 = 550$ Pa, $Q_2 = 2,000$ lps, and $Q_1 = 1,500$ lps

$$P_2 = 978 \text{ Pa, Answer.}$$

21. If the static pressure at one point of the duct measured as 625 Pa, determine:
The flow rate of the system.

Solution (REFERENCE CHOTKEH MANUAL):

Refer to system characteristics curve equation (48) CURVE (FANS)

For $P_2 = 625$ Pa, $P_1 = 550$ Pa, and $Q_1 = 1,500$ lps

$$Q_2 = 1,599 \text{ lps, Answer.}$$

FANS EXAMPLES

22. Draw the system resistance curve.

Solution (REFERENCE CHOTKEH MANUAL):

Refer to system characteristics curve equation (48) **CURVE (FANS)**

Calculate the pressure for different **lps** and enter the results in the following table.

For **P1=550 Pa**, **Q2=500 lps**, and **Q1=1,500 lps**

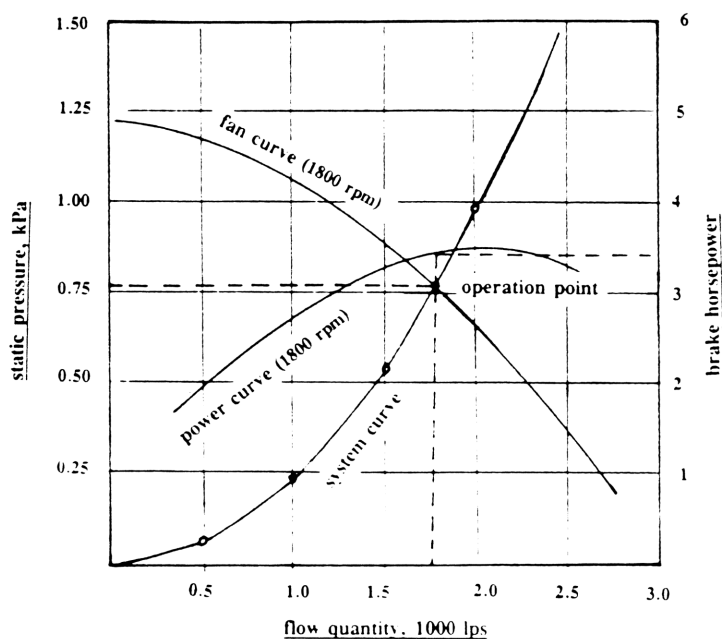
$$P2 = 61 \text{ Pa}$$

For the same values, but **Q2=1,000 lps**

$$P2 = 244 \text{ Pa}$$

Continue for **Q2=1,500, 2,000,**, then draw the curve on the chart.

Q2 (lps)	500	1000	1500	2000	2500	3000
P2 (Pa)	61	244	550	978	1528	2200



23. **Determine:**
The flow rate of the fan-duct system.

Solution (REFERENCE PERFORMANCE CURVE):

Fan operates at the point of intersection between the fan and system curves, point A. The corresponding flow rate is 1750 lps.

$Q \text{ (fan-duct system)} = 1750 \text{ lps, Answer.}$

FANS EXAMPLES

24. **Determine:**
The static pressure of the fan-duct system.

Solution (REFERENCE PERFORMANCE CURVE):

Based on the above, the corresponding static pressure is 780 Pa.

$$P \text{ (fan-duct system)} = 780 \text{ Pa, Answer.}$$

25. **Determine:**
The required brake horsepower of the fan-duct system.

Solution (REFERENCE PERFORMANCE CURVE):

Based on the above, the corresponding required horsepower is 3.4 hp.

$$\text{bhp (fan-duct system)} = 3.4 \text{ hp, Answer.}$$

26. **If system requires to have a flow rate of 2200 lps, by increasing the fan's speed, determine:**
The fan's new speed.

Solution (REFERENCE CHOTKEH MANUAL):

To find the new rpm, use the fan laws equations. For change in the flow rate, due to change in rpm, refer to equation (29) **RPM (FANS/LAW/ ΔQ)**

For **$Q_1 = 1750$** lps (existing flow rate at point A), **$Q_2 = 2200$** lps, and **$n_1 = 1800$** rpm.

$$n_2 = 2263 \text{ rpm, Answer.}$$

27. **Under the new condition, determine:**
The required horsepower.

Solution (REFERENCE CHOTKEH MANUAL):

To find the new hp, use the fan laws equations. For change in the horsepower, due to change in rpm, refer to equation (25) **RPM (FANS/LAW/ ΔHP)**

For **$hp_1 = 3.4$** hp (existing horsepower at point A), **$n_1 = 1800$** rpm, and **$n_2 = 2263$** rpm.

$$hp_2 = 6.8 \text{ hp, Answer.}$$

FANS EXAMPLES

28. Under the new condition, determine:
The system static pressure.

Solution (REFERENCE CHOTKEH MANUAL):

To find the new static pressure, use the fan laws equations. For change in the static pressure, due to change in rpm, refer to equation (27) **RPM (FANS/LAW/ ΔP)**

For **P1 = 780 Pa** (existing pressure at point A), **n1 = 1800 rpm**, and **n2 = 2263 rpm**.

$P_2 = 1233 \text{ Pa, } \underline{\text{Answer.}}$
--

GEARS EXAMPLES

1. A pair of 20° , full depth, spur gears have a transmission ratio of 3 to 1. A diametral pitch is 3 and the pinions pitch diameter is 6.5".

Base on the above, determine:

- (a) The number of teeth in each gear.
- (b) The addendum.
- (c) The outside Diameter.
- (d) The base circle diameter.

Solution:

- a. 1. Number of teeth in gear (N_g):

From $N_g = P \cdot D_g$ and for:

N_g = to be calculated (Number of teeth in gear)

$P = 3$ (given) (Diameter pitch (P) is the number of teeth per inch of pitch diameter, where the pitch diameter is an imaginary circle on which both gears rolling on each other with no slip)

$D_g = 3 \cdot 6.5 = 19.5$ (Gear's pitch diameter, which is pinion's pitch diameter times transmission ratio)

$$N_g = 58.5 = 60 \text{ teeth, Answer for (a1)}$$

2. Number of teeth in pinion (N_p):

From $N_p = P \cdot D_p$ and for: $P = 3$ and $D_p = 6.5$ "

$$N_p = 19.5 = 20 \text{ teeth, Answer for (a2)}$$

- b. Addendum is the radial distance between the pitch circle and gears outside diameter. From Mark's Mechanical handbook, for 20° spur gear: $a = 1/P = 1/3$

$$a = .333", \text{ Answer for (b)}$$

- c. The outside diameter may be found from the following equation

$$D_o = D(\text{pitch}) + 2a$$

For gear: Key in ' $19.5 + 2 \cdot .333$ EVAL = 20.166"

For pinion: Key in ' $6.5 + 2 \cdot .333$ EVAL = 7.166"

$$D_o (\text{gear}) = 20.166", D_o (\text{pinion}) = 7.166", \text{ Answer for (c)}$$

GEARS EXAMPLES

- d. The base circle diameter may be found from the following equation

$$D_b = D(\text{pitch}) * \cos \phi$$

For gear: Key in '19.5*COS(20) EVAL =18.32"

For pinion: Key in '6.5*COS(20) EVAL =6.11"

DB (gear) = 18.32", DB (pinion) = 6.11", Answer for (d)

* * * * *

2. For a pair of 20° full depth involute spur gear, if the number of teeth for pinion and gear are 18 and 54 respectively, determine:
- The Form Factor of the pinion (Y).
 - The Form Factor of the gear (Y).

Solution:

- a. At LIBRARY press NXT GEAR TABLE FORM 20° FULL $12 \leq N < 20$
For N=18 teeth

Y (pinion) = .308, Answer for (a)

- b. At LIBRARY press NXT GEAR TABLE FORM 20° FULL NXT $40 < N < 100$
For N=54 teeth

Y (gear) = .412, Answer for (b)

* * * * *

3. For a pair of carefully cut (second class) spur gears, if the diametral pitch is 4.5, determine:
The value of the action error.

Solution:

At LIBRARY press NXT GEAR TABLE ERROR CLASS 2ND $1 \leq P \leq 5$
For P=4.5

ERROR = .00112 in., Answer.

GEARS EXAMPLES

4. For a pair of **14.5°** involute spur gear, if the pinion made of steel, the gear is in cast iron, and the action error equals to .0013 in., determine:
The value of the Deformation Factor (C).

Solution:

At LIBRARY press NXT GEAR TABLE DEFOR ST.CI **14.5°**
For **EROR** = .0013 in.

C = 1430, Answer.

* * * * *

5. For a pair of steel spur gears with the Brinell Hardness of 223, determine:
The Surface Endurance Limit (Ses).

Solution:

- a. At LIBRARY press NXT GEAR TABLE ENDU ST.ST
For **BHN** = 223

Ses = 79,200 psi, Answer.

* * * * *

6. For a pair of **20°** spur gears, if the pinion is made of steel with 173 Brinell Harness Number and the gear is of bronze, determine:
The Stress Fatigue Factor (K).

Solution:

- a. At LIBRARY press NXT GEAR TABLE FATIG **20°** ST.BR
For **BHN** = 173

K = 79.5, Answer.

* * * * *

7. Two straight bevel gears have a velocity ratio of 1.5 to 1. If the gears are transmitting 10 horsepower at pinion's 250 rpm, determine:
- The torque on the pinion.
 - The torque on the gear.

GEARS EXAMPLES

Solution:

Refer to torque equation (19) **TORQ** (GEAR/GNRL)

a. Torque on pinion:

For **hp**=10 hp and **n**=250 rpm (pinion's rpm)

$$T \text{ (pinion)} = 2521 \text{ in-lb, Answer for (a)}$$

b. Torque on gear:

For **hp**=10 hp and **n**=250*1/1.5=166.7 rpm (gear's rpm)

$$T \text{ (gear)} = 3781 \text{ in-lb, Answer for (b)}$$

* * * * *

8. Two (2) spur gears are required to transmit 25 hp. The pinion's speed is 1200 rpm and the velocity ratio is 3.5 to 1. Both gears have 20° stub tooth profiles. The allowable stress for the pinion is 15,000 psi and for the gear is 10,000 psi.

Based on the above, determine:

- a. The diametral pitch.
- b. The face width of the gears.

Solution:

It appears that in this problem, the pinion and the gear are made of two (2) different materials.

By referring to spur gear actual stress equation (10) $\sigma = \frac{W_t * P}{Y * F}$ and with the consideration that **W_t** and **F** have the same values for both pinion and the gear, therefore **P** is the function of $\sigma * Y$.

And since **P** must be calculated for the weaker gear/pinion, calculate $\sigma * Y$ for both and pick the one with the lower value.

Step 1 Select the weaker gear/pinion for calculation:

1. Assume number of teeth for pinion and gear:

Assume **N_p**=18 teeth.

$$N_p = 18 \text{ teeth}$$

Based on the velocity ratio, **N_g**=18*3.5

$$N_g = 63 \text{ teeth.}$$

2. Look up for Lewis Form Factor (Y):

For 20° stub tooth, refer to CHOTKEH's Form factor equation (34) **STUB**
(GEAR/TABLE/FORM/ 20°)

GEARS EXAMPLES

For $N=18$ (pinion)

Y (pinion) .377

For $N=63$ (gear)

Y (gear) .485

3. Calculate the $\sigma * Y$ for gears:

$\sigma * Y = 5655$

For pinion = **15000 (allowable)*.377**

$\sigma * Y = 4850$

For gear = **10000 (allowable)*.485**

Since the calculated value is smaller for the gear, select the gear for calculations.

Step 2 Calculate the diametral pitch:

Refer to spur gear's diametral pitch equation (05) **DIA.P** (GEAR/SPUR)

Remember that all the data are the gear's data.

For $\sigma = 5000$ psi (assumed 50% of allowable gear stress), $Y = .485$, $N = 63$

(number of teeth in the gear), $F = 4 * \pi / P$, key in ' $4 * \pi / P$ ENTER press F,

$n = 1200/3.5 = 343$ rpm, and $hp = 25$ hp.

$P = 5.93$

NOTE: In order not to loose the variable **F**, solve the equation for **F** too.

Press $\leftarrow F$

$F = 2.12''$

The calculated **P** must be checked to see if the **design stress** > **5000** psi.

Step 3 Calculate the design stress:

1. calculate the gears linear velocity:

With the given number of teeth, refer to gear velocity equation (21) **TEETH** (FANS/GNRL/VELO).

For $N = 63$ teeth, $n = 343$ rpm, and $P = 5.93$

$v = 954$ fpm

2. calculate the design stress:

Refer to spur gear's design stress equation (12) $v < 2000$ (GEAR/SPUR/STRES/DSIGN).

For $v = 954$ fpm and $\sigma_A = 10000$ psi

$\sigma_D = 3861$ psi

Since $\sigma_D < \sigma$, therefore the calculated **P** is not correct.

Step 4 Assume **P=5** and take the following steps.

1. Calculate the new actual stress for $P=5$:

With the given **hp**, refer to spur gear's actual stress equation (11) **HP** (GEAR/SPUR/STRES/ACTU)

For **hp=25** hp, **P=5**, $Y = .485$, $N = 63$, $F =$ key in ' $4 * \pi / 5$ NUM = **2.51"**,

and $n = 343$ rpm.

$\sigma = 2995$ psi

GEARS EXAMPLES

2. Calculate the design stress:

Follow step 3:

$$v = 1131 \text{ fpm}$$

$$\sigma_D = 3446 \text{ psi}$$

Since $\sigma_D > \sigma$, therefore the new pitch is correct.

$$P = 5, \text{ Answer for (a)}$$

b. From $F = 4 * \pi / P$ key in ' 4 * π / 5 NUM

$$F = 2.51", \text{ Answer for (b)}$$

* * * * *

9. A pair of machined cast iron gears are required to transmit 12 hp. The characteristics of the gears are as follows:

General:

Error: .0012"

Diametral pitch: 6

Pressure angle: 20°

Full depth involute.

Gear:

No. of teeth: 55

Face width: 1.6"

Pinion:

No. of teeth: 33

Rotational speed: 1750 rpm

Based on the above, determine:

a. The dynamic tooth load

b. Limiting wear load.

c. Static tooth strength. Assume allowable stress is equal to 11,000 psi.

Solution:

- a. To calculate the dynamic load, take the following steps to determine the value of the variables used in the subject equation (06):

Step 1 Calculate the linear speed (v):

With the given number of teeth, refer to velocity equation (21) **TEETH**
(GEAR/GNRL/VELO)

For N=33 teeth (pinion), n=1750 rpm (pinion) and P=6 $v = 2520 \text{ fpm}$

GEARS EXAMPLES

Step 2 Calculate the transmitted load (**Wt**):

With the given **hp**, refer to transmitted static load equation (07) **HP**
(GEAR/SPUR/LOAD/STAT)

For **v=2520** fpm and **hp=12**.

$$\underline{W_t = 157 \text{ lbf.}}$$

Step 3 Determine the Deformation Factor:

For both gears in cast iron gears, full depth, and **20°** pressure angle, refer to CHOTKEH's table of deformation equation (22) **FULL** (GEAR/TABLE/DEFOR/CI.CI/ 20°)

For **EROR=.0012"**

$$\underline{C = 996}$$

Step 4 Calculate the dynamic load:

Refer to dynamic load (06) **DYNA** (GEAR/SPUR/LOAD)

For **Wt=157** lbf, **v=2520** fpm, **F=1.6"**, and **C=996**

Wd = 1471 lbf, <u>Answer</u> for (a)

b. To calculate the wear limit load, take the following steps:

Step 1 Determine the Fatigue Factor (**K**):

Refer to CHOTKEH's table of Fatigue Factor equation (31) **CI.CI**
(GEAR/TABLE/FATIG/ 20°)

For both gears in cast iron **K=208-284**, select the bigger. $\underline{K = 284}$

Step 2 Calculate the wear load (**Ww**):

Refer to spur gear wear load equation (09) **WEAR** (GEAR/SPUR/LOAD)

For **D=33/6=5.5"** (Number of pinions teeth divided by diametral pitch), **F=1.6"**, **K=284**,
NG=55 teeth, and **Np=33** teeth.

Ww = 3124 lbf, <u>Answer</u> for (a)

c. To calculate the static strength (calculate for pinion), refer to Lewis strength equation (08) **LEWIS**
(GEAR/SPUR/LOAD/STAT)

For **$\sigma = 11000$ psi**, **F=1.6"**, **Y=.367** (CHOTKEH's table of Form Factor equation (34)
FULL (GEAR/TABLE/FORM/ 20°), and **P=6**

Wt = 1077 lbf, <u>Answer</u> for (c)

GEARS EXAMPLES

10. A pair of gears are required to transmit 7 hp. The characteristics of the gears are as follows:

<u>General:</u>	<u>Pinion:</u>	<u>Gear:</u>
Velocity ratio: 3.5/1	No. of teeth: > 15	Steel
Pressure angle: 14.5°	Bronze	Allowable stress: 12000 psi
	Allowable stress: 15000 psi	
	Rotational speed: 1800 rpm	

Based on the above, determine:

- The pitch diameter of the pinion and gear
- The face width

Solution:

To calculate the gear/pinion diameters, calculate the diametral pitch.

By referring to spur gear actual stress equation (10) $\sigma = \frac{W_t * P}{Y * F}$ and with the consideration that W_t and F have the same values for both pinion and the gear, therefore P is the function of $\sigma * Y$. And since P must be calculated for the weaker gear/pinion, calculate $\sigma * Y$ for both and pick the one with the lower value.

Step 1 Select the weaker gear/pinion for calculation:

1. Assume number of teeth for pinion and gear:

Assume $N_p = 16$ teeth.

$N_p = 16$ teeth

Based on the velocity ratio, $N_g = 16 * 3.5$

$N_g = 56$ teeth.

2. Look up for Lewis Form Factor (Y):

For 14.5° , refer to CHOTKEH's Form factor equation (33) **14.5°**
(GEAR/TABLE/FORM)

For $N = 16$ (pinion)

Y (pinion) .253

For $N = 56$ (gear)

Y (gear) .35

3. Calculate the $\sigma * Y$ for gears:

$\sigma * Y = 3795$

For pinion = **15000 (allowable) * .253**

$\sigma * Y = 4200$

For gear = **12000 (allowable) * .35**

Since the calculated value is smaller for the pinion, select the pinion for calculations.

Step 2 Calculate the diametral pitch:

Refer to spur gear's diametral pitch equation (05) **DIA.P** (GEAR/SPUR)

Remember that all the data are the pinion's data.

For $\sigma = 7500$ psi (assumed 50% of allowable pinion stress), $Y = .253$, $N = 16$

(number of teeth in the pinion), $F = 4 * \pi / P$, key in ' $4 * \pi / P$ ENTER press F,

$n = 1800$ rpm, and $hp = 7$ hp.

$P = 9.2$

GEARS EXAMPLES

NOTE: In order not to lose the variable **F**, solve the equation for **F** too.

Press $\leftarrow$ **F**

$$\underline{F = 1.37''}$$

The calculated **P** must be checked to see if the **design stress** > **7500 psi**.

Step 3 Calculate the design stress:

1. calculate the gears linear velocity:

With the given number of teeth, refer to gear velocity equation (21) **TEETH** (GEAR/GNRL/VELO).

For **N=16** teeth, **n=1800** rpm, and **P=9.2**

$$\underline{v = 820 \text{ fpm}}$$

2. calculate the design stress:

Refer to spur gear's design stress equation (12) **v < 2000** (GEAR/SPUR/STRES/DSIGN).

For **v=820** fpm and **$\sigma_A = 15000$** psi

$$\underline{\sigma_D = 6338 \text{ psi}}$$

Since **$\sigma_D < \sigma$** , therefore the calculated **P** is not correct.

Step 4 Assume **P=8.5** and take the following steps.

1. Calculate the new actual stress for P=8.5:

With the given **hp**, refer to spur gear's actual stress equation (11) **HP** (GEAR/SPUR/STRES/ACTU)

For **hp=7** hp, **P=8.5**, **Y=.253**, **N=16**, **F** = key in ' $4 * \pi / 8.5$ NUM = **1.48"**,
and **n=1800** rpm.

$$\underline{\sigma = 5912 \text{ psi}}$$

2. Calculate the design stress:

Follow step 3:

$$\underline{v = 887 \text{ fpm}}$$

$$\underline{\sigma_D = 6052 \text{ psi}}$$

Since **$\sigma_D > \sigma$** , therefore the new pitch is correct.

$$\underline{P = 8.5}$$

For **D=N/P**: **D(pinion)=16/8.5** and **D(gear)=56/8.5**

$$\underline{D(\text{pinion}) = 1.88'' \text{ and } D(\text{gear}) = 6.59'', \text{ Answer for (a)}}$$

b. From **$F = 4 * \pi / P$** key in ' $4 * \pi / 8.5$ NUM

$$\underline{F = 1.48'', \text{ Answer for (b)}}$$

GEARS EXAMPLES

11. Determine the material for a pair of **14.5°** involute first class (commercial) gear, required to transmit **35 hp** at pinion's **1800 rpm**. The diameter of pinion is **5.5"** and the velocity ratio is **2.5/1**. Assume the diametral pitch equals to **6**.

Solution:

Based on the given information calculate the dynamic load, the fatigue factor, and finally decide the material.

Step 1 To calculate the dynamic load, take the following steps to determine the value of the variables used in the subject equation (06):

1. Calculate the linear speed (v):

With the given pinion's pitch diameter, refer to velocity equation (20) **DIAM**
(GEAR/GNRL/VELO)

For **D=5.5"** and **n=1800 rpm**. v = 2592 fpm

2. Calculate the transmitted load (Wt):

With the given **hp**, refer to transmitted static load equation (07) **HP**
(GEAR/SPUR/LOAD/STAT)

For **v=2592 fpm** and **hp=35**. Wt = 446 lbf.

3. Determine the action error (EROR):

For calculated linear velocity, refer to error table equation (28) **VELO**
(GEAR/TABLE/EROR)

For **v=2592 fpm** EROR = .00127"

4. Determine the Deformation Factor:

For both gears assumed to be in steel and **14.5°** pressure angle, refer to CHOTKEH's table of deformation equation (24) **14.5°** (GEAR/TABLE/DEFOR/ST.ST)

For **EROR=.00127"** C = 2032

5. Calculate the dynamic load:

Refer to dynamic load (06) **DYNA** (GEAR/SPUR/LOAD)

For **Wt=446 lbf**, **v=2592 fpm**, **F=4 * π / 6 = 2.1 "**, and **C=2032**
Wd = 3527 lbf

Step 2 Calculate Fatigue Factor:

Considering the wear load equal to dynamic load, to find the fatigue factor refer wear load equation (09) **WEAR** (GEAR/SPUR/LOAD)

For **Ww=3527 lbf** (assumed to be equal to Wd), **D=5.5"** (pinion), **F=2.1"**, **Ng=2.5**, and **Np=1**
K = 214

GEARS EXAMPLES

Step 3 Considering steel material for both pinion and gear, determine the Brinell Hardness

Number:

Refer to CHOTKEH's table of Fatigue Factor equation (29) **ST.ST**

(GEAR/TABLE/FATIG/ **14.5°**)

For **K=214**

BHN = 360

Select the steel with BHN = 375 with equivalent K=215

Steel with BHN = 375, Answer.

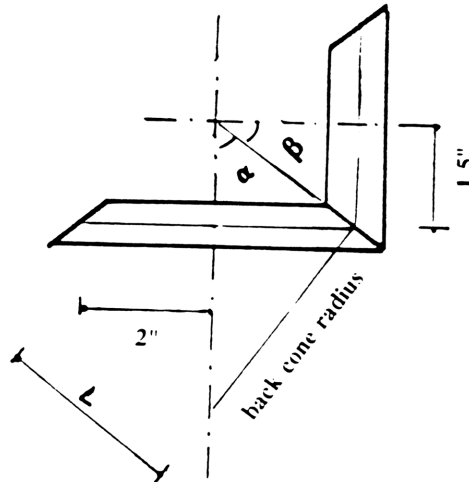
* * * * *

12. A pair **14.5°** bevel gears are required to transmit 3 hp at pinion's 1100 rpm. The pitch diameter of pinion and the gear are 3" and 4" respectively. If both gears are made of cast iron material, determine the face width of the gears.

Solution:

To solve the problem, the bevel gear must be converted to a hypothetical spur gear, then solved for the spur gears.

Step 1 Draw the sketch of the bevel gears and calculate **L**, **α**, and **β**



1. From $L = \sqrt{(D_g/2)^2 + (D_p/2)^2}$, key in ' $\sqrt{2^2 + 1.5^2}$ EVAL L = 2.5"

2. From $\text{ASIN}(\alpha) = 2''/2.5''$, key in ' 2/2.5 EVAL ASIN α = 53.13°

3. From $\text{ASIN}(\beta) = 1.5''/2.5''$, key in ' 1.5/2.5 EVAL ASIN β = 36.87°

GEARS EXAMPLES

Step 2 For bevel gear, assume $N_p=15$, $N_g=20$, and $P=5$

For imaginary spur gear:

$$Ni_p = N_p / \cos(\beta) \quad , \text{ key in ' 15/COS(36.87) EVAL } \quad \underline{Ni_p = 18.75}$$

$$Ni_g = N_g / \cos(\alpha) \quad , \text{ key in ' 20/COS(53.13) EVAL } \quad \underline{Ni_g = 33.33}$$

With these information, solve the spur gears problem.

To calculate the face width, take the following steps to determine the value of the variables used in the subject equation (02). Base all calculations on the pinion:

Step 1 Calculate the linear speed (v):

With the given pinion's pitch diameter, refer to velocity equation (20) **DIAM**
(GEAR/GNRL/VELO)

$$\text{For } D=3" \text{ (pinion) and } n=1100 \text{ rpm (pinion)} \quad \underline{v = 863.94 \text{ rpm}}$$

Step 2 calculate the design stress:

Refer to cut teeth bevel gear's design stress equation (03) **CUT**
(GEAR/BEVEL/TRESS/DSIGN).

$$\text{For } v=863.94 \text{ fpm and } \sigma_A=8000 \text{ psi (assumed for cast iron gear)} \\ \underline{\sigma_D = 4651 \text{ psi}}$$

Step 3 Calculate the torque on the pinion (T):

Refer to torque equation (19) **TORQ** (GEAR/GNRL)

$$\text{For } hp=3 \text{ hp and } n=1100 \text{ rpm (pinion)} \quad \underline{T = 171.89 \text{ in-lbf.}}$$

Step 4 Calculate the transmitted load (Wt):

Refer to load equation (18) **LOAD** (GEAR/GNRL)

$$\text{For } T=171.89 \text{ in-lb and } D=3" \quad \underline{W_t = 114.59 \text{ lbf.}}$$

Step 5 Determine the Form Factor:

For **14.5°** pressure angle, refer to CHOTKEH's table of form equation (33) **14.5°**
(GEAR/TABLE/FORM)

$$\text{For } N=18.75 \text{ teeth} \quad \underline{Y = .276}$$

Step 6 Calculate the Face width:

Refer to bevel gear actual stress equation (02) **ACTU** (GEAR/BEVEL/STRES)

$$\text{For } \sigma = \sigma_D = 4651 \text{ , } W_t = 114.59 \text{ lbf, } P=5, Y=.276, \text{ and } L=2.5"$$

GEARS EXAMPLES

NOTE: The subject equation is a quadratic equation. To find both answers, use the guess method.

1. Enter **0** for **F**, solve for **F** F = .582

2. Enter **1** for **F**, solve for **F** F = .582

3. Enter **1.5** for **F**, solve for **F** F = 1.92

Answers: F = .582, F = 1.92

NOTE: If the guessing number is not within the range of answers, calculator keeps running.
Try **3** for **F** and solve for **F**. Calculator keeps running. Press **ENTER** key to see the run.
Press **ON** key to cancel.

Step 7 Since the calculated answers are not close to **L/3** or **.833"**, change the assumptions.

Assume **P=6**, therefore **Np=18**, **Nip=22.5**, and **Y=.295**.

Repeat step 4 F = 1.8", F = .7"

Since **.7"** is close to **.833"**

F = .7", Answer.

HEAT TRANSFER EXAMPLES

1. For a wet steam at 60 psia with 90% quality, determine:
- The enthalpy of the steam.
 - The enthalpy of the steam if heated up to 820 oF at the same pressure, 60 psia.

Solution (REFERENCE: CHOTKEH MANUAL AND STEAM TABLES):

- a. For **P=60 psia**.
From CHOTKEH's SAT.P: $h_f = 262.05 \text{ btu/lbm}$ $h_g = 1177.63 \text{ btu/lbm}$
To find the enthalpy refer to steam equation (51) **ENTH** (HIT.TR/STIM)
For **hf=262.05** btu/lbm, **X=.9**, and **hg=1177.63** btu/lbm

$$h = 1086.07 \text{ btu/lbm, Answer for (a)}$$

- b. For **P=60 psia** and **t=820 oF**.
From CHOTKEH's SUPHT table

$$h = 1440.9 \text{ btu/lbm, Answer for (b)}$$

* * * * *

2. Determine overall Coefficient of 8" thick wall (**K=15** btu/hr-ft-oR) at 11 mph wind. Assume the film coefficient for still air and 15 mph wind to be 1.5 btu/hr-sf-oR and 6 btu/hr-sf-oR respectively.

Solution (REFERENCE: CHOTKEH MANUAL):

To calculate the overall coefficient of heat transfer, the film coefficient for 11 mph must be calculated first. Use the interpolation equation (42) **INTRP** (HIT.TR)

For **A1=1.5**, **A2=6**, **Bm=11**, **B1=0**, and **B2=15** $h(11) = 4.8 \text{ btu/hr-sf-oR}$.

Refer to slab equation (01) **SLAB** (HIT.TR/UCOEF)

For $\Sigma L/K = 8/12/15 = .0444$ and $\Sigma 1/h = \frac{1}{h_i} + \frac{1}{h_o} = 1/1.5 + 1/4.8 = .875$

$$U = 1.088 \text{ btu/hr-sf-oR, Answer.}$$

* * * * *

3. A composite wall is made of 6" thick of material A (**K=.1** btu/hr-ft-oR) and 8" thick wall of material B (**K=.8** btu/hr-ft-oR). If the temperatures at surface A and B are 900 oF and 100 oF respectively, determine:

Temperature at the interface of composites.

Solution (REFERENCE: CHOTKEH MANUAL):

To calculate the interface temperature, (1) calculate the heat flow through both slabs. Then based on the constant heat flow through the composite, calculate the temperature at the interface.

HEAT TRANSFER EXAMPLES

Step 1 For 2K slab, refer to equation (34) **2K** (HIT.TR/HIT.FL/SLAB)

For $A=1$ sf, $\Delta t = 900-100=800$ oF, $L_1=6/12=.5$ ft, $K_1=.1$ btu/hr-ft-oR,
 $L_2=8/12=.6667$ ft, and $K_2=.8$ btu/hr-ft-oR. $q = 137.14$ btu/hr

Step 2 For single slab, with the given L & K, refer to equation (32) **K+L**
(HIT.TR/HIT.FL/SLAB/SINGL)

For $q=137.14$ btu/hr, $K=.1$ btu/hr-ft-oR, $A=1$ sf, $L=.5$ ft $\Delta t=685.7$ oF

$$t \text{ (interface)} = 900 - 685.7 = 214.3 \text{ oF, Answer.}$$

* * * * *

4. A fluid in a storage tank must be heated and maintained at 90 oF, by a hot water coil. If the temperatures of the water at the entrance and exit are 200 oF and 165 oF respectively, determine: The mean temperature difference.

Solution (REFERENCE: CHOTKEH MANUAL):

For heat exchanger, general equation in English units, refer to equation (16) **ENG**
(HIT.TR/HIT.EX/LMTD/GNRL)

For $\Delta t_i=200-90=110$ oF and $\Delta t_o=165-90=75$ oF

$$\text{LMTD} = 91.4 \text{ oF, Answer.}$$

* * * * *

5. By a heat recovery from flue gas, the temperatures of water was raised, from 50 oF to 90 oF. If the stack's flue gas is cooled from 380 oF down to 290 oF, determine: The mean temperature difference.

Solution (REFERENCE: CHOTKEH MANUAL):

This is a heat exchanger problem in English units. Assume counter flow and refer to equation (14) **ENG** (HIT.TR/HIT.EX/LMTD/COUNT)

For $T_i=380$ oF, $t_o=90$ oF, $T_o=290$ oF, and $t_i=50$ oF

$$\text{LMTD} = 264.2 \text{ oF, Answer.}$$

NOTE: Down arrows on the screen menu denotes the **ti** and **to** in lower case.

HEAT TRANSFER EXAMPLES

6. A 6" O.D. steel pipe (5.4" I.D. and $K=26$ btu/hr-ft-oF) is carrying 240 oF hot water. The pipe is insulated with 2" insulation ($K=.095$ btu/hr-ft-oF). If the outside temperature measured at 50 oF, determine:

The heat loss for 250 ft of the pipe. Assume no convection heat loss.

Solution (REFERENCE: CHOTKEH MANUAL):

For an insulated pipe (2K), refer to equation (29) **2K** (HIT.TR/HIT.FL/PIPE/INSUL)

For $l=250$ ft, $\Delta t = 240-50 = 190$ oF, $r_o = 3/12 = .25$ ft, $r_i = 2.7/12 = .225$ ft,

$K_p = 26$ btu/hr-ft-oR, and $r_t = .25 + 2/12 = .4167$ ft, and $K_{ins} = .095$ btu/hr-ft-oR.

$q = 55453 \text{ btu/hr, Answer.}$

* * * * *

7. In a heat recovery program, a stack gas with the flow quantity rate of 50000 cfh is used to heat up the primary feed water, from 50 oF to 78 oF, through a counter flow shell and tube heat exchanger. If the inlet and outlet temperatures of the gas are 550 oF and 100 oF respectively, determine:

The heat exchanger's surface area.

Assumptions: h_o (for gas) = 7.5 btu/sf-hr-oF. h_i (for water) = 500 btu/sf-hr-oF

For gas: $P=1$ atm., $R=53.3$ ft-lbf/lbm-oF, and $cp=.24$ btu/lbm-oF.

Neglect thickness of the tube.

Solution (REFERENCE: CHOTKEH MANUAL):

To solve this problem, for a single pass heat flow exchanger, refer to equation (10) **LMTD** (HIT.TR/HIT.EX/FLOW/SINGL) which is $q=U \cdot A \cdot \text{LMTD}$:

As it appears, the q , U , and **LMTD** must be calculated first.

Step 1 Calculate the heat flow, q :

- a. Take the gas side. Calculate the mass of the gas, refer to ideal gas equation (41)

IDEAL (HIT.TR)

For $p = 14.7 \cdot 144 = 2116.8$ psf, $V = 50000$ cf/hr, $R = 53.3$ ft-lbf/lbm-oR, and $T = (550 + 100)/2 + 460 = 785$ oR. (assumed the flow quantity measured at midway through the exchanger). $m(\text{gas}) = 2530 \text{ lbm/hr.}$

- b. Calculate the heat requirement. Refer to equation (13) **HIT-RE** (HIT.TR/HIT.EX)

For $m = 2530$ lbm/hr, $cp = .24$ btu/lbm-oR, and $\Delta t = 450$ oF

$$q = 273240 \text{ btu/hr.}$$

Step 2 Calculate the Coefficient of heat transfer, U :

Refer to equation (01) **SLAB** (HIT.TR/UCOEF).

For $\Sigma L + K = 0$ and $\Sigma 1/h = 1/500 + 1/7.5 = .1353$

$$U = 7.39 \text{ btu/hr-ft}^2\text{-oF.}$$

HEAT TRANSFER EXAMPLES

Step 3 Calculate the Logarithmic Mean Temperature Difference, LMTD:

For single pass and counter flow heat exchanger in English units, refer to equation (14)

ENG (HIT.TR/HIT.EX/LMTD/COUNT)

For $T_i=550$ oF, $t_o=78$ oF, $T_o=100$ oF, $t_i=50$ oF

$$\underline{LMTD = 187.98 \text{ oF.}}$$

Step 4 Calculate the surface area, **A**:

With the calculated LMTD, refer to heat exchanger heat flow equation (10) **LMTD**

(HIT.TR/HIT.EX/FLOW/SINGL)

For $q=273240$ btuh, $U=7.39$ btu/hr-ft-oR, and **LMTD = 187.98** oF

$A = 196.69 \text{ sf, Answer.}$

* * * * *

8. 600 oF steam is flowing through a 4.5" pipe (I.D. 3.82", $K=27$ btu/hr-ft-oF). The pipe is insulated ($K=.032$ btu/hr-ft-oF) and is exposed to 80 oF environment ($h_o=1.65$ btu/hr-sf-oF). If the desired surface temperature is 130 oF or less, determine:
The thickness of the insulation:

Solution (REFERENCE: CHOTKEH MANUAL):

Based on the fact that the heat outflow through the pipe section remains constant, to solve this problem take the following steps.

Step 1 Determine the flow up to the insulation surface.

For 2K insulated pipe, refer to equation (29) **2K** (HIT.TR/HIT.FL/PIPE/INSUL) and insert the values:

$$q_1 = \frac{2\pi l \Delta T}{\ln 1.178/27 + \ln\left(\frac{r_t}{.1875}\right) / .032} = \frac{2\pi l * 470}{.006 + 31.25 * \ln\left(\frac{r_t}{.1875}\right)}$$

Step 2 Determine the flow through the environment.

For 2K insulated pipe and 1h outside film, refer to equation (30) **2K1H**

(HIT.TR/HIT.FL/INSUL) and insert the values:

$$q_2 = \frac{2\pi l \Delta T}{\frac{\ln 1.178}{27} + \frac{\ln\left(\frac{r_t}{.1875}\right)}{.032} + \frac{1}{r_t * h_o}} = \frac{2\pi l * 520}{.006 + 31.25 * \ln\left(\frac{r_t}{.1875}\right) + \frac{1}{1.65 * r_t}}$$

Step 3 For $q_1=q_2$: (cancel $2\pi l$)

HEAT TRANSFER EXAMPLES

For HP48GX: Press $\rightarrow$ SOLVE ENTER type:

$$\frac{470}{(.006 + 31.25 \cdot \ln(\frac{r_t}{.1875}))} = \frac{520}{(.006 + 31.25 \cdot \ln(\frac{r_t}{.1875}) + \frac{1}{(1.65 \cdot r_t)})}$$

ENTER press SOLVE

$$r_t = .33 \text{ ft} = 4"$$

For HP48SX: Press $\leftarrow$ SOLVE key in:

$$, \frac{470}{(.006 + 31.25 \cdot \ln(\frac{r_t}{.1875}))} = \frac{520}{(.006 + 31.25 \cdot \ln(\frac{r_t}{.1875}) + \frac{1}{(1.65 \cdot r_t)})}$$

press STEQ SOLVR $\leftarrow$ RT

$$r_t = .33 \text{ ft} = 4"$$

NOTE: For this type of complex equation with more than one answer, you have to guess the answer. If calculator keeps thinking press ON, make a guess, i.e. 0.2 for RT and press solve.

For thickness = $r_t - r_o = 4 - 2.25 = 1.75"$

Thickness = 1.75" = 2", Answer.

* * * * *

9. If 1" O.D. copper pipe (7/8" I.D. and $K=56$ btu/hr-ft-oF) is carrying 70 oF liquid Freon, determine:

The best alternative, from the following options, to minimize the heat loss.

Assume $h_o=1.3$ btu/hr-sf-oF.

- a. The pipe insulated with 3/8" insulation ($K=.095$ btu/hr-ft-oR)
- b. The pipe insulated with 5/8" of the same insulation.
- c. No insulation.

Solution (REFERENCE: CHOTKEH MANUAL):

- a. For 2K and 1h insulated pipe, refer to equation (30) **2K1H** (HIT.TR/HIT.FL/PIPE/INSUL)

For $l=1$ ft, $\Delta t = 1$ oF, $r_o = .5/12 = .04167$ ft, $r_i = 7/16/12 = .03646$ ft, $K_p=56$ btu/hr-ft-oR, $r_t = (.04167 + 3/8/12) = .07292$ ft, $K_{ins} = .095$ btu/hr-ft-oR, and $h_o = 1.3$ btu/hr-sf-oF.

$$q(a) = .3821 \text{ btu/hr-oF/ft of pipe}$$

- b. Use the same equation and same data, but $r_t = (.04167 + 5/8/12) = .09375$.

$$q(b) = .3753 \text{ btu/hr-oF/ft of pipe}$$

HEAT TRANSFER EXAMPLES

- c. For 1K and 1h bare pipe, refer to equation (27) **1K1H** (HIT.TR/HIT.FL/PIPE/BARE)
For the same data and **K=56** btu/hr-ft-oR.

$$q(c) = .34 \text{ btu/hr-oF/ft of pipe}$$

Best alternative = no insulation, Answer.

* * * * *

10. A furnace is made of the following composite materials:
8" thick refractory brick, K=8 btu/hr-ft-oF;
Layer of insulation brick, K=.15 btu/hr-ft-oF; and
.3" thick steel cover, K=26 btu/hr-ft-oF.
If the inside and outside surface temperature of the furnace are **2000 oF** and **110 oF** respectively and it is desired to the heat loss to a maximum of **240** btu/hr-sf, determine:
The thickness of the insulation brick. Neglect convection and radiation.

Solution (REFERENCE: CHOTKEH MANUAL):

For a 3 layer composite slab, **3K**, refer to equation (35) **3K** (HIT.TR/HIT.FL/SLAB)

For **q=240** btu/hr, **A=1** sf, **$\Delta t = 2000 - 110 = 1890$** oF, **L1=8/12=.6667** ft, **K1=8** btu/hr-ft-oR,
K2=.15 btu/hr-ft-oR, **L3=.3/12=.025** ft, and **K3=26** btu/hr-ft-oR.

$$L2 = 1.17 \text{ ft} = 14", \text{ Answer.}$$

* * * * *

11. A **6" O.D.** pipe is carrying a saturated steam, at **320 psia**, at the rate of **15000** lbm/hr. If the pipe is not insulated and is exposed to **68 oF** environment (**h=1.8** btu/hr-sf-oF), determine:
The quality of steam 200 ft from the source.

Solution (REFERENCE: CHOTKEH MANUAL AND STEAM TABLE):

To solve the problem, (1) identify the steam's property at the source, (2) calculate the heat loss in 200 ft of pipe, and (3) calculate the quality of steam.

Step 1 Identify the steam's property, For **P=320** psia.

From CHOTKEH's SAT.P: t=423.3 oF hf=400.41 btu/lbm hg=1203.28 btu/lbm

Step 2 Find the heat loss. Neglecting the thickness of the pipe, calculate the convection and radiation heat losses.

Convection: For a heat flow through a film, 1h, in a bare pipe, refer to equation (26) **1H** (HIT.TR/HIT.FL/PIPE/BARE)

For **l=200** ft, **r=6/2/12=.25** ft, **h=1.8** btu/hr-sf-oF, and **$\Delta t = 423.3 - 68 = 355.3$** oF,
(assumed)

HEAT TRANSFER EXAMPLES

$$q \text{ (conv.)} = 200917.4$$

Radiation: For a heat flow by radiation, in English units, refer to equation (43) **ENG** (HIT.TR/RADIA/RADIA)

For **A** = key in ' π *6/12*200 **NUM**=**314.16** sf, **Fe**=**.8** (assumed), **Fa**=**1**,

T1=423.3+460=**883.3** oR, and **T2**=68+460=**528** oR

$$q_r = 228617.7$$

$$q(\text{total}) = 429535.1 \text{ btu/hr.}$$

Step 3 Find the quality of steam:

a. Calculate the drop in enthalpy, which is $429535.1 \text{ btu/hr} / 15000 \text{ lbm/hr} = 28.64 \text{ btu/lbm}$.

b. Find the reduced enthalpy, which is $1203.28 - 28.64 = 1174.64 \text{ btu/lbm}$.

c. Refer to steam enthalpy equation (51) **ENTH** (HIT.TR/STIM)

For **h**=**1174.64** btu/lbm, **hf**=**400.41** btu/lbm, and **hg**=**1203.28** btu/lbm

$X = .964 = 96.4\%, \text{ Answer.}$

* * * * *

12. **250 lbm/min of 2 psia steam at 92% quality enters to a condenser and transfers the heat to 1250 gpm of water with entering temperature of 72 oF. If the heat transfer surface area measured as 45000 sf, determine:**

The coefficient of heat transfer. Assume no sub cooled of condensed steam.

Solution (REFERENCE: CHOTKEH MANUAL AND STEAM TABLE):

To solve the problem, (1) identify the steam's property, (2) calculate the leaving temperature of water, (3) calculate the heat exchanger's LMTD, and (4) calculate the coefficient of heat transfer.

Step 1 Identify the steam's property. For **P**=**2** psia.

From CHOTKEH's SAT.P: $t = 126 \text{ oF}$ $hf = 95 \text{ btu/lbm}$ $hg = 1116.4 \text{ btu/lbm}$

To find the enthalpy of steam at 92% quality, refer to equation (51) **ENTH** (HIT.TR/STIM)

For **hf**=**95** btu/lbm, **X**=**.92**, and **hg**=**1116.4** btu/lbm. $h = 1034.7 \text{ btu/lbm}$

Step 2 Find the water's to. With the given Δh , use the heat exchanger's heat balance equation

(08) **ΔH** (HIT.TR/HIT.EX/HIT.BA)

For (steam) **m1**=250 lbm/min*60 min=**15000** lbm/hr, **Δh1** = 1034.7-95=**939.7** btu/lbm,

HEAT TRANSFER EXAMPLES

For (water) $m_2 = 1250 \text{ gpm} \times 60 \text{ min} \times .1337 \text{ cf/gal} \times 62.4 \text{ pcf} = 625716 \text{ lbm/hr}$ and $cp_2 = 1 \text{ btu/lbm-oF}$

$$\Delta t_2 = 22.5 \text{ oF or: } t_o = 72 + 22.5 = 94.5 \text{ oF}$$

Step 3 Calculate the Logarithmic Mean Temperature Difference, **LMTD**:

For single pass and counter flow heat exchanger, in English units, refer to equation (14)

ENG (HIT.TR/HIT.EX/LMTD/COUNT)

For $T_i = 126 \text{ oF}$, $t_o = 94.5 \text{ oF}$, $T_o = 126 \text{ oF}$, $t_i = 72 \text{ oF}$

$$\text{LMTD} = 41.74 \text{ oF.}$$

Step 4 Calculate the coefficient of heat transfer, **A**:

Refer to equation (10) **LMTD** (HIT.TR/HIT.EX/FLOW/SINGL)

For $q = 15000 \times 939.7 = 14,095,500 \text{ btu/hr}$, $A = 45000 \text{ sf}$, and **LMTD** = 41.74 oF

$$U = 7.5 \text{ btu/hr-sf-oR, Answer.}$$

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Problems 13 - 14

Following are the characteristics of an air pre-heater:

Air: Entering at 68 oF, leaving at 290 oF, $m = 160000 \text{ lbm/hr}$, and $cp = .24 \text{ btu/lbm-oF}$

Flue gas: Entering at 580 oF, $m = 167000 \text{ lbm/hr}$, and $cp = .25 \text{ btu/lbm-oF}$.

Based on the above, solve the following problems:

13. Determine:

The leaving temperature of flue gas:

Solution (REFERENCE: CHOTKEH MANUAL):

With the given Δt , use the heat exchanger's heat balance equation (07) ΔT
(HIT.TR/HIT.EX/HIT.BA)

For (air): $m_1 = 160000 \text{ lbm/hr}$, $cp_1 = .24 \text{ btu/lbm-oR}$, and $\Delta t_1 = 290 - 68 = 222 \text{ oF}$

For (gas): $m_2 = 167000 \text{ lbm/hr}$, $cp_2 = .25 \text{ btu/lbm-oR}$

$$\Delta t_2 = 204.2 \text{ or: } t_o = 580 - 204.2$$

$$t_o = 375.8 \text{ oF, Answer.}$$

14. Determine:

The tubes surface area, assume coefficient of heat transfer = 110 btu/hr-sf-oR

a. For parallel flow

b. For counter flow.

HEAT TRANSFER EXAMPLES

Solution (REFERENCE: CHOTKEH MANUAL):

- a. Step 1 Calculate the Logarithmic Mean Temperature Difference, LMTD:
For single pass and parallel flow heat exchanger, in English units, refer to equation (18) ENG (HIT.TR/HIT.EX/LMTD/PARAL)
For $T_o=375.8$ oF, $t_o=290$ oF, $T_i=580$ oF, and $t_i=68$ oF
$$\underline{LMTD = 238.6 \text{ oF.}}$$

Step 2 Calculate the surface area, A:
Refer to equation (10) LMTD (HIT.TR/HIT.EX/FLOW/SINGL).
For $q = \text{key in } 160000 \times .24 \times 222 = 8524800$ btu/hr, $U = 110$ btu/hr-sf-oR, and
LMTD = 238.6

$$A = 324.8 \text{ sf, Answer for (a).}$$

- b. Step 1 Calculate the Logarithmic Mean Temperature Difference, LMTD:
For single pass and counter flow heat exchanger, in English units, refer to equation (14) ENG (HIT.TR/HIT.EX/LMTD/COUNT)
For the same data (check if necessary)
$$\underline{LMTD = 298.8 \text{ oF.}}$$

Step 4 Calculate the surface area, A:
Refer to equation (10) LMTD (HIT.TR/HIT.EX/FLOW/SINGL).
For the same data (check if necessary), but **LMTD = 298.8** oF

$$A = 259.4 \text{ sf, Answer for (b).}$$

* * * * *

15. The inside and outside surface temperatures of a furnace, with 14" thick wall ($K = .8$ btu/hr-ft-oF), are 2000 and 400 oF respectively. By adding .5" thick insulation ($K = .05$ btu/hr-ft-oF) to the outside surface, the outside temperature reduced to 110 oF. If the cost of insulation and heating are \$5/ft² and \$3.5/million btu respectively, determine:
How many years will it take for the cost of insulation to pay for itself. Assume the burner works 24 hours/day and 180 days/year.

Solution (REFERENCE: CHOTKEH MANUAL):

To solve the problem, (1) find the heat loss with no insulation, (2) calculate the heat loss with insulation and the difference in the loss, (3) Find the number of years to break even.

Step 1 Calculate the heat loss with no insulation:
For single slab, with the given K & L, refer to equation (32) **K+L** (HIT.TR/HIT.FL/SLAB/SINGL).
For $K = .8$ btu/hr-ft-oR, $A = 1$ sf, $\Delta t = 2000 - 400 = 1600$ oF, and $L = 14/12 = 1.167$ ft.

$$\underline{q_1 = 1096.8 \text{ btu/hr-sf.}}$$

HEAT TRANSFER EXAMPLES

Step 2 Calculate the heat loss with insulation:

For two slab composite, refer to equation (34) **2K** (HIT.TR/HIT.FL/SLAB)

For **A=1 sf**, $\Delta t = 2000-110=1890$ oF, **L1=14/12=1.167 ft**, **K1=.8 btu/hr-ft-oF**,

L2=.5/12=.0417 ft, and **K2=.05 btu/hr-ft-oF**

$$q2 = 824.3 \text{ but/hr-sf.}$$

$$dq = q1 - q2 = 272.5 \text{ btu/hr-sf}$$

Step 3 Calculate number of years:

To break even, if **N** is the number of years, the following equation pertains:

$$5(\text{cost of ins.}) = 272.5/1000000*3.5(\text{cost of heat/hr})*180 \text{ days/year}*24 \text{ hr/day}*N \text{ years}$$

For **HP48GX**: Press $\rightarrow$ **SOLVE** **ENTER** type: $5=272.5/1EE6*3.5*180*24*N$

ENTER press **SOLVE**

For **HP48SX**: Press $\leftarrow$ **SOLVE** key in: $5=272.5/1EE6*3.5*180*24*N$

press **STEQ** **SOLVR** press $\leftarrow$ **N**

$$N = 1.2 \text{ years, Answer.}$$

* * * * *

16. A water tank contains 210 oF water which is exposed to 68 oF environment. If it takes 1.5 hour for the water's temperature to drop by 15 oF, determine:

The time required to cool down the water to 120 oF from the original temperature of 210 oF.

Solution (REFERENCE: CHOTKEH MANUAL):

This is a transient heat flow problem in English units. To find the required time, the time constant (r) must be calculated first.

Step 1 Refer to equation (65) **TIME** (HIT.TR/TRNS/ENG)

For **t=1.5 hr**, **Tt=210-15=195 oF**, **T_∞ = 68 oF**, and **To=210 oF**.

$$r = 7.443EE-2$$

Step 2 Calculate the time. Use the same equation and data, but **Tt=120 oF** and **r=7.443EE-2**

$$t = 13.5 \text{ hr, Answer.}$$

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Problems 17 - 18

Water is heated up, from 55 oF to 150 oF, at the rate of 200 gph. The water is running through a 1.5" O.D. pipe (1.25" I.D. and **K=56 btu/hr-ft-oR**) and surrounded by steam. If the steam's pressure is 8.6 psia at 91% quality, solve the following problems:

HEAT TRANSFER EXAMPLES

17. Determine the length of the pipe in heat exchanger. Assume: h_i (water) = 600 btu/hr-ft²-oR and h_o (steam) = 2100 btu/hr-sf-oR.

Solution (REFERENCE: CHOTKEH MANUAL AND STEAM TABLE):

Consider this as a heat flow through a bare pipe with inside and outside film (1K and 2H). To solve the problem, (1) find the amount of transferred heat, (2) identify the steam's property, (3) calculate Δt , and (4) find the length.

Step 1 Calculate the heat flow:

Take the water side. For a single path flow, with the given Δt , refer to equation

(11) ΔT (HIT.TR/HIT.EX/FLOW/SINGL)

For $m = 200 \text{ gph} \cdot 1.337 \text{ cf/gal (unit conversion)} \cdot 62.4 \text{ pcf} = 1669 \text{ lbm/hr}$, $cp = 1 \text{ btu/lbm-oF}$

and $\Delta t = 150 - 55 = 95 \text{ oF}$. $q = 158555 \text{ btu/hr}$.

Step 2 Identify the steam's property. For $P = 8.6 \text{ psia}$.

From CHOTKEH's SAT.P: $t = 186.1 \text{ oF}$ $hf = 154 \text{ btu/lbm}$ $hg = 1140.5 \text{ btu/lbm}$

Step 3 Calculate the Temperature Difference, Δt :

In this case Δt is the heat exchanger's LMTD. Assume counter flow. For English units, refer to equation (14) **ENG** (HIT.TR/HIT.EX/LMTD/COUNT)

For $T_i = 186.1 \text{ oF}$, $t_o = 150 \text{ oF}$, $T_o = 186.1 \text{ oF}$, $t_i = 55 \text{ oF}$

LMTD = 73.66 oF.

Step 4 Find the length:

For a bare pipe with two films, refer to equation (28) **1K2H** (HIT.TR/HIT.FL/PIPE/BARE)

For $q = 158555 \text{ btu/hr}$, $\Delta t = \text{LMTD} = 73.66 \text{ oF}$, $r_i = 1.25/2/12 = .0521 \text{ ft}$,

$h_i = 600 \text{ btu/hr-sf-oF}$, $r_o = 1.5/2/12 = .0625 \text{ ft}$, $K = 56 \text{ btu/hr-ft-oF}$, and $h_o = 2100 \text{ btu/hr-sf-oF}$

$$L = 14.7 \text{ ft, Answer.}$$

18. Determine the required steam in lbm/hr.

Solution (REFERENCE: CHOTKEH MANUAL AND STEAM TABLE):

To calculate the mass of the steam:

Step 1 Calculate the steam's enthalpy at 91% quality.

Refer to equation (51) **ENTH** (HIT.TR/STIM)

For $hf = 154 \text{ btu/lbm}$, $X = .91$, and $hg = 1140.5 \text{ btu/lbm}$

$h = 1051.7 \text{ btu/lbm}$

HEAT TRANSFER EXAMPLES

Step 2 For English units, refer to steam rate equation (54) **ENG** (HIT.TR/STIM/RATE)
For $q = 158555$ btu/hr, $h_1 = 1140.5$, $h_2 = 1051.7$

$$M \cdot 496 \text{ lbm/sec} = 1786 \text{ lbm/hr, Answer.}$$

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19. A vertical wall which is exposed to solar radiant energy is in the following condition:
- a. The surrounding temperature: 92 oF
 - b. The conductive heat transfer at the wall: 19 btu/hr-ft²
 - c. The film coefficient: estimated as 1.9 btu/hr-ft²-oF
 - d. Solar energy received: 95 btu/hr-ft².
- Based on the information, determine:
The wall's surface temperature. Assume surface emissivity $\epsilon = .95$.

Solution (REFERENCE: HP48 CALCULATOR):

For the stabilized condition the following equation pertains:
heat (from solar) = Heat transfer by Conduction + Convection + Radiation or:
For TW = wall temperature and reference to equation (43) **RADIA** for radiation.

$$95 = 19 + 1.9 \cdot (TW - (92 + 460)) + .1713 \text{EE-}8 \cdot .95 \cdot (TW^4 - (92 + 460)^4)$$

For HP48GX: Press $\rightarrow$ SOLVE ENTER type:

$$76 = 1.9 \cdot (TW - 552) + .1713 \text{EE-}8 \cdot .95 \cdot (TW^4 - 552^4) \quad \text{ENTER press SOLVE}$$

For HP48SX: Press $\leftarrow$ SOLVE key in:

$$76 = 1.9 \cdot (TW - 552) + .1713 \text{EE-}8 \cdot .95 \cdot (TW^4 - 552^4) \quad \text{press STEQ SOLVR press } \leftarrow TW$$

$$TW = 576.75 \text{ oR} = 116.75 \text{ oF, Answer.}$$

Problems 20 - 21

An infinite 1 ft slab has the following conditions:

Hot side temperature: $T_H = 980$ oF

Cold side surface: exposed to 60 oF air

Convective heat transfer coefficient: 18 btu/hr-ft²-oR

Conductivity of slab, $K = .045 + .011(T - 38)$.

Based on above solve the following problems:

HEAT TRANSFER EXAMPLES

20. Determine the slab's temperature at the cold side.

Solution (REFERENCE: CHOTKEH MANUAL AND HP48 CALCULATOR):

For the heat flow through the slab and air film, the following equation pertains:

heat flow through the slab = heat flow through the film, or: For TC = cold side temperature.

$$\int_{TC}^{TH} K \frac{dT}{dL} = h(TC - 60)$$

For $K = .045 + .011(T-38)$ btu/hr-ft-oF, $TH = 980$ oF, and $h = 18$ btu/hr-ft²-oF

For HP48GX: Press $\rightarrow$ SOLVE ENTER type: Key in:

$\int (TC, 980, .045 + .011 * (T - 38), T) = 18 * (TC - 60)$ ENTER
press SOLVE

For HP48SX: Press $\leftarrow$ SOLVE key in:

$\int (TC, 980, .045 + .011 * (T - 38), T) = 18 * (TC - 60)$ press STEQ
SOLVR press $\leftarrow$ TC

TC = 310 oF, Answer.

21. Determine:
- The amount of heat flow.
 - Temperature of slab at $X = 3"$ from the hot side.

Solution (REFERENCE: CHOTKEH MANUAL AND HP48 CALCULATOR):

- a. From $q = h * \Delta t$: For $h = 18$ btu/hr-sf-oF and $\Delta t = 310 - 60 = 250$ oF

$q = 4500$ btu/hr-sf, Answer for (a).

- b. For the point at $X = 3" = .25$ ft from the hot side or $.75$ ft from the cold side, the following pertains:

$$.75 \int_{TC}^{TX} K \frac{dT}{dL} = .25 \int_{TX}^{TH} K \frac{dT}{dL}$$

For $K = .045 + .011(T-38)$ btu/hr-ft-oF, $TH = 980$ oF, and $TC = 310$ oF

For HP48GX: Press $\rightarrow$ SOLVE ENTER type: Key in:

$.75 * \int (980, TX, .045 + .011 * (T - 38), T) = .25 * \int (TX, 310, .045 + .011 * (T - 38), T)$
ENTER press SOLVE

For HP48SX: Press $\leftarrow$ SOLVE key in:

$.75 * \int (980, TX, .045 + .011 * (T - 38), T) = .25 * \int (TX, 310, .045 + .011 * (T - 38), T)$
press STEQ SOLVR press $\leftarrow$ TX

TX = 865 oF, Answer for (b).

NOTE: The answer should be a positive number. If not, make a guess. Pick a number between 310 and 980, i.e. 500.

HEAT TRANSFER EXAMPLES

22. The following two (2) thermocouple are used to measure the stack's flue gas temperature:
1- Thermocouple "A" in the stream with emissivity factor = .8 and reading of 1150 oF
2- Thermocouple "B" on the stack wall with emissivity factor = .7 and reading of 950 oF
If the coefficient of convection heat transfer is 18 btu/hr-ft²-oF, determine:
The flue gas temperature.

Solution (REFERENCE: CHOTKEH MANUAL):

To find the gas temperature with $T_P > T_W$, in English units, refer to equation (45) ENG
(HIT.TR/RADIA/COUPL/ $T_P > T_W$)

Neglect radiation to wall thermocouple because of its insignificant area, compared to the area of wall.
For $T_P = 1150 + 460 = 1610$ oR, $F_e = .8$, $T_W = 950 + 460 = 1410$ oR, and $h = 18$ btu/hr-sf-oF.

$$T_G = 1821 \text{ oR} = 1361 \text{ oF, Answer.}$$

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23. Street asphalt is exposed to solar radiant energy at the rate of 200 btu/hr-ft². If the environment temperature is estimated at 88 oF and the coefficient of convection heat transfer is 3 btu/hr-ft²-oF, determine:
The street's equilibrium temperature. Assume surface emissivity $F_e = .97$

Solution (REFERENCE: CHOTKEH MANUAL):

For the stabilized condition the following equation pertains:

Heat gain (from solar) = Heat loss (through Convection + radiation) or:

For T_S = Street temperature and with reference to radiation equation (43)

$$200 = 3 \cdot (T_S - (88 + 460)) + .1713 \text{EE-}8 \cdot .97 \cdot (T_S^4 - (88 + 460)^4)$$

For HP48GX: Press $\rightarrow$ SOLVE ENTER type:

$$200 = 3 \cdot (T_S - 548) + .1713 \text{EE-}8 \cdot .97 \cdot (T_S^4 - 548^4) \quad \text{ENTER press SOLVE}$$

For HP48SX: Press $\leftarrow$ SOLVE key in:

$$'200 = 3 \cdot (T_S - 548) + .1713 \text{EE-}8 \cdot .97 \cdot (T_S^4 - 548^4)$$

press STEQ SOLVR press $\leftarrow$ TS

$$T_S = 595 \text{ oR} = 135 \text{ oF, Answer.}$$

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24. A bronze tube with 1.5"/1.7" inside/outside diameter is surrounded by 8.5 psia saturated steam.
If the tube wall temperature remains at 63 oF, determine:
The outside film coefficient.

Solution (REFERENCE: CHOTKEH MANUAL):

To solve the problem, with the data in English units, equation (05) must be used. To do so, all unknowns in the equation must be identified or calculated first:

HEAT TRANSFER EXAMPLES

Step 1 Identify the required characteristics of water, from water property table (CHOTKEH MANUAL, ENG units), for mean bulk temperature: $(63 + 185.6)/2 = 124.3$ oF. 185.6 oF is the steam temperature at 8.5 psia, CHOTKEH STEAM TABLE, SAT.P

For 124.3 oF water (by interpolation, use (HIT.TR/INTRP):

$$\mu = 1.17\text{E-}5 \text{ lbf-sec/ft}^2 \text{ and } K = .374 \text{ btu/hr-ft-oF}$$

For 124.3 oF steam (Use STEAM TABLE SAT.T):

$$\rho_l = 1/v_f = 1/.016224 = 61.64 \text{ lbm/ft}^3 \quad \rho_v = 1/v_g = 1/181.4 = .0055 \text{ lbm/ft}^3$$

For 185.6 oF steam:

$$h_{fg}(185.6) = 986.2 \text{ btu/lbm}$$

Step 2 Calculate the outside film coefficient, refer to equation (05) **ENG** (HIT.TR/FILMC/OUT)

For $\rho_l = 61.64 \text{ lbm/ft}^3$, $\rho_v = .0055 \text{ lbm/ft}^3$, $h_{fg} = 986.2 \text{ btu/lbm}$, $K = .374 \text{ btu/hr-ft-oF}$,

$Do = 1.7/12 = .1417 \text{ ft}$, $\mu_l = 1.17\text{E-}5 \text{ lbf-sec/ft}^2$, $tsv = 185.6 \text{ oF}$, and $ts = 63 \text{ oF}$

$$h_o = 989.6 \text{ btu/hr-ft}^2\text{-oF, Answer.}$$

* * * * *

25. 55 oF water is entering to a heat exchanger tubing with the velocity of 25 fps. The tube has 2.5"/2.75" inside/outside diameter. The wall temperature of the tube remains at 165 oF. If the temperature of water has to be increased to 125 oF, determine:
The length of the tube. Assume $U_o = h_i$.

Solution (REFERENCE: CHOTKEH MANUAL):

For the assumed $U_o = h_i$, to solve the problem, equations (04) and (20) must be used. To do so, all unknowns in the equations must be identified or calculated first:

Step 1 Identify the required characteristics of water, from water property table (CHOTKEH MANUAL, ENG units), for the mean bulk temperature: $(55 + 125)/2 = 90$ oF

For 90 oF water:

$$\rho = 62.1 \text{ lbm/ft}^3, \text{ cp} = .997 \text{ btu/lbm-oF}, \text{ v} = .825\text{E-}5 \text{ ft}^2/\text{sec}, K = .359 \text{ btu/hr-ft-oF}, \text{ and } N_{pr} = 5.13$$

Step 2 Calculate the Reynolds number. With the identified kinetic viscosity, refer to equation (50) **KINET** (HIT.TR/REYN)

$$\text{For } D = 2.5/12 = .2083 \text{ ft}, \text{ v} = 25 \text{ fps, and } \text{v} = .825\text{E-}5 \text{ ft}^2/\text{sec} \quad \underline{N_{Re} = 631212}$$

Step 3 Calculate the Logarithmic Mean Temperature Difference (LMTD)

For English units, refer to heat exchanger general equation (14) **ENG** (HIT.TR/HIT.EX/LMTD/GNRL)

$$\text{For } \Delta T_1 = 165 - 55 = 110 \text{ oF and } \Delta T_o = 165 - 125 = 40 \text{ oF} \quad \underline{LMTD = 69.2 \text{ oF}}$$

Step 4 Calculate inside film coefficient, h_i . Refer to film coefficient equation (04) **IN** (HIT.TR/FILMC)

For $K = .359 \text{ btu/hr-ft-oF}$, $N_{Re} = 631212$, $N_{pr} = 5.13$, $n = .4$ ($t(\text{bulk}) < t(\text{wall})$), and

$$Di = .2083 \text{ ft} \quad \underline{h_i = 3257 \text{ btu/hr-sf-oF}}$$

HEAT TRANSFER EXAMPLES

- Step 5 Determine the length of the tube. For English units, refer to heat exchanger tube length equation (20) **ENG** (HIT.EX/TUBE/LNTH)
For $\rho = 62.1$ lbm/ft³, $D_i = .2083$ ft, $c_p = .997$ btu/lbm-oF, $t_o = 125$ oF, $t_i = 55$ oF $v = 25$ fps,
 $U_o = h_i = 3257$ btu/hr-ft²-oF, $D_o = 2.75/12 = .2292$ ft, and $LMTD = 69.2$ oF

$$l = 81.9 \text{ ft. Answer.}$$

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Problems 26 - 29

A water feeder to heat up the water, from 65 oF to 185 oF, at the flow rate of 3200 lbm/hr. The water runs at 3.5 ft/sec in the copper tube with 1"/1.125" inside/outside diameter. If 125 psia saturated steam is condensing on the outer space of the tubing, solve the following problems:

26. Determine the film coefficient of water inside of the tube.

Solution (REFERENCE: CHOTKEH MANUAL):

To solve the problem, equations (04) must be used. To do so, all unknowns in the equation must be identified or calculated first:

- Step 1 Identify the required characteristics of water, from water property table (CHOTKEH MANUAL, ENG units), for the mean bulk temperature: $(65 + 185)/2 = 125$ oF

For 125 oF water, using INTRP equation:

$\rho = 61.6$ lbm/ft³, $c_p = .999$ btu/lbm-oF, $v = .609\text{EE-}5$ ft²/sec, $\kappa = .374$ btu/hr-ft-oF, and $NP_r = 3.63$

- Step 2 Calculate the Reynolds number. With the identified kinetic viscosity, refer to equation (50) **KINET** (HIT.TR/REYN)

For $D = 1/12 = .0833$ ft, $v = 3.5$ fps, and $v = .609\text{EE-}5$ ft²/sec $NRe = 47874$

- Step 3 Calculate inside film coefficient, h_i . Refer to equation (04) **IN** (HIT.TR/FILMC)

For $\kappa = .374$ btu/hr-ft-oF, $NRe = 47874$, $NP_r = 3.63$, $n = .4$, and $D_i = .0833$ ft

$$h_i = 939 \text{ btu/hr-ft}^2\text{-oF. Answer.}$$

27. Determine the film coefficient of steam outside of the tube. Assume 20 oF difference in temperature between saturated vapor and tube surface.

Solution (REFERENCE: CHOTKEH MANUAL):

To solve the problem, with the data in English units, equation (05) must be used. To do so, all unknowns in the equation must be identified or calculated first:

- Step 1 Identify the required characteristics of water and steam, from water property table (CHOTKEH MANUAL, ENG units and CHOTKEH STEAM TABLE), for the mean bulk temperature: $(344 + 324)/2 = 334$ oF

HEAT TRANSFER EXAMPLES

344 oF is the 125 psia steam temperature (from CHOTKEH STEAM table, SAT.P)

324 oF is tube surface temperature: $344 - 20 = 324$.

For 334 oF water (by interpolation, use HIT.TR/INTRP):

$$\mu = .347\text{EE-5 lbf-sec/ft}^2 \text{ and } K = .392 \text{ btu/hr-ft-oF}$$

For 334 oF steam (Use STEAM TABLE, SAT.T):

$$\rho_l = 1/v_f = 1/.0178 = 56.14 \text{ lbm/ft}^3, \quad \rho_v = 1/v_g = 1/4.086 = .245 \text{ lbm/ft}^3$$

For 344 oF steam:

$$h_{fg}(344) = 875.4 \text{ btu/lbm}$$

Step 2 Calculate the outside film coefficient, refer to equation (05) **ENG** (HIT.TR/FILMC/OUT)

For $\rho_l = 56.14 \text{ lbm/ft}^3$, $\rho_v = .245 \text{ lbm/ft}^3$, $h_{fg} = 875.4 \text{ btu/lbm}$, $K = .392 \text{ btu/hr-ft-oF}$,

$Do = 1.125/12 = .0938 \text{ ft}$, $\mu_l = .347\text{EE-5 lbf-sec/ft}^2$, $tsv = 344 \text{ oF}$, and $ts = 344 - 20 = 324 \text{ oF}$

$$h_o = 2242.3 \text{ btu/hr-ft}^2\text{-oF, Answer.}$$

28. Determine the outside overall heat transfer coefficient of tubing, including inside/outside film coefficients. Assume the thermal conductivity of copper as 216 btu/hr-ft-oF for the working temperature (320 oF).

Solution (REFERENCE: CHOTKEH MANUAL):

To determine the U_o (associated with outside surface area of the tube for calculation of heat transfer), refer to equation (03) **OUT** (HIT.TR/UCOEF/PIPE)

For $h_o = 2242.3 \text{ btu/hr-sf-oF}$ (problem 27), $ro = 1.125/(2 \times 12) = .0469 \text{ ft}$, $K = 216 \text{ btu/hr-ft-oF}$, $ri = 1/(2 \times 12) = .0417$, and $hi = 939 \text{ btu/hr-sf-oF}$ (problem 26)

$$U_o = 599.1 \text{ btu/hr-sf-oF, Answer.}$$

29. Determine the required surface area of tubing.

Solution (REFERENCE: CHOTKEH MANUAL):

Step 1 Calculate the rate of the required heat. Refer to heat exchanger heat required equation (13) **HIT.RE** (HIT.TR/HIT.EX)

$$\text{For } m = 3200 \text{ lbm/hr, } cp = .999 \text{ btu/lbm-oF, and } \Delta t = 185 - 65 = 120 \text{ } q = 383616 \text{ btu/hr}$$

Step 2 Calculate the Logarithmic Mean Temperature Difference (LMTD)

For English units, refer to heat exchanger general equation (16) **ENG** (HIT.TR/HIT.EX/LMTD/GNRL)

$$\text{For } \Delta T_1 = 344 - 65 = 279 \text{ oF and } \Delta T_o = 344 - 185 = 159 \text{ oF} \quad \underline{LMTD = 213.4 \text{ oF}}$$

Step 3 Calculate surface area. Refer to heat exchanger tube area (22) **AREA** (HIT.TR/HIT.EX/TUBE)

$$\text{For } q = 383616 \text{ btu/hr, } U = U_o = 599.1 \text{ btu/hr-ft}^2\text{-oF, and } LMTD = 213.4 \text{ oF}$$

HEAT TRANSFER EXAMPLES

$A = 3 \text{ sf. Answer.}$

* * * * *

30. Determine the density of 85% quality (15% wet) steam at 0.35 MPa pressure.

Solution (REFERENCE: CHOTKEH MANUAL AND CHOTKEH STEAM TABLE):

Step 1 From CHOTKEH Steam table SAT.P, read the specific volumes, v_f and v_g , for 0.35 MPa:

$$v_f = .00108 \text{ m}^3/\text{kg} \quad v_g = .52358 \text{ m}^3/\text{kg}$$

Step 2 Calculate the specific volume for 85% quality steam. Refer to specific volume equation (53) SPCV (HIT.TR/STIM)

$$\text{For } v_f = 0.00108 \text{ m}^3/\text{kg}, X = .85, \text{ and } v_g = 0.52358 \text{ m}^3/\text{kg} \quad v = 0.445205 \text{ m}^3/\text{kg}$$

For the density being inverse of the specific volume, press $1/x$

$\text{Density} = 2.25 \text{ kg/m}^3, \text{ Answer.}$

* * * * *

31. 15 oC of air was heated to 30 oC by 180 oC flue gas. If the temperature of flue measured as 130 oC at the exit, determine:

The LMTD (Logarithmic Mean Temperature Difference.)

Solution (REFERENCE: CHOTKEH MANUAL):

Assuming the counter flow in SI system, refer to heat exchanger LMTD equation (15) SI (HIT.TR/HIT.EX/LMTD/COUNT)

For $T_i = 180 \text{ oC}$, $t_o = 30 \text{ oC}$, $T_o = 130 \text{ oC}$, and $t_i = 15 \text{ oC}$

$\text{LMTD} = 114 \text{ oC. Answer.}$

NOTE: The down arrow, on the screen menu, denotes the lower case t_i and t_o , i.e. air temperatures.

* * * * *

32. Determine the overall coefficient of heat transfer of 10 cm thick wall at 16 kph wind. Assume $K = 24 \text{ W/m}^2\cdot\text{K}$ for wall, $h = 9.4 \text{ W/m}^2\cdot\text{K}$ for zero (0) kph wind, and $h = 34 \text{ W/m}^2\cdot\text{K}$ for 24 kph wind.

Solution (REFERENCE: CHOTKEH MANUAL):

Step 1 With the given indoor film coefficient ($h_i = 9.4 \text{ W/m}^2\cdot\text{K}$ at 0 kph wind), determine the outdoor coefficient for 16 kph wind. Use the interpolation equation (42) INTRP (HIT.TR)

For $A_1 = 9.4 \text{ W/m}^2\cdot\text{K}$, $A_2 = 34 \text{ W/m}^2\cdot\text{K}$, $BM = 16 \text{ kph}$, $B_1 = 0 \text{ kph}$, and $B_2 = 24 \text{ kph}$

$$h_o = A_m = 25.8 \text{ W/m}^2\cdot\text{K}$$

HEAT TRANSFER EXAMPLES

Step 2 Calculate the overall coefficient. Refer to slab equation (01) **SLAB** (HIT.TR/UCOEF)
For $\Sigma L/k =$ key in '.1/24 EVAL = .00417 and $\Sigma 1/h =$ key in '.1/9.4 + 1/25.8 EVAL
= .145

$$U = 6.7 \text{ W/m}^2 \text{ K, Answer.}$$

* * * * *

33. A condenser must condensate three (3) kg of 110 oC saturated steam to 110 oC water within eight (8) minutes. If the inside and outside diameter of condenser tubing are 1 cm and 1.6 cm respectively, determine:
The length of the copper tube. Assume 25 oC ambient temperature and copper thermal conductivity as 390 W/m.K.

Solution (REFERENCE: CHOTKEH MANUAL AND CHOTKEH STEAM TABLE SAT.T):

Step 1 Determine the enthalpy of steam and water at 110 oC. Use SAT.T table.

$$h_g = 2691.4 \text{ kJ/kg} = 2691400 \text{ J/kg} \quad h_f = 461.3 \text{ kJ/kg} = 461300 \text{ J/kg.}$$

Step 2 Calculate the required heat. With the given steam rate, in SI units, refer to steam equation (55) **SI** (HIT.TR/STIM/RATE)

For $M =$ key in '.3/(8*60) = .00625 kg/s, $h_1 = h_g = 2691400 \text{ J/kg}$, and $h_2 = h_f = 461300 \text{ J/kg}$
 $q = 13938 \text{ W (J/s)}$

Step 3 Calculate the length. Refer to conduction bare pipe heat flow equation (25) **1K** (HIT.TR/HIT.FL/PIPE/BARE)

For $q = 13938 \text{ W}$, $K = 390 \text{ W/m.K}$, $\Delta t = 100 - 25 = 75 \text{ oC}$, $r_o = 0.008 \text{ m}$, and $r_i = 0.005 \text{ m}$

$$l = .0356 \text{ m} = 3.56 \text{ cm, Answer.}$$

* * * * *

Problems 34 - 35

The characteristics of 2 section 110 m² composite wall are as follows:

Section 1: Thickness=30 cm, thermal conductivity=203 W/m.K, surface temperature=540 oC

Section 2: Thickness=45 cm, thermal conductivity=47 W/m.K, surface temperature=230 oC Based on the above, determine:

34. The overall thermal resistance of the wall.

Solution (REFERENCE: CHOTKEH MANUAL AND CHOTKEH STEAM TABLE SAT.T):

Step 1 Determine the overall thermal coefficient of composite wall. Refer to slab coefficient equation (01) **SLAB** (HIT.TR/UCOEF).

For $\Sigma L/k =$ key in '.3/203 + .45/47 EVAL .011 and $\Sigma 1/h = 0$

$$U = 90.9 \text{ W/m}^2 \text{ K}$$

Step 2 From $R = 1/(U*A)$, key in '.1/(90.9*110) EVAL

$$R = .0001 \text{ K/W, Answer.}$$

HEAT TRANSFER EXAMPLES

35. Determine the amount of the heat flow through the composite wall.

Solution (REFERENCE: CHOTKEH MANUAL):

For 2 section composition slab, with no film, refer to slab heat flow equation (34) **2K** (HIT.TR/HIT.FL/SLAB)

For $A=110 \text{ m}^2$, $\Delta t=540-230=310 \text{ }^\circ\text{C}$, $L1=.3 \text{ m}$, $K1=203 \text{ W/m.K}$, $L2=.45 \text{ m}$, and $K2=47 \text{ W/m.K}$

$$q = 3.085 \text{ MW, Answer.}$$

* * * * *

Problems 36 - 38

A thin plate has $80 \text{ }^\circ\text{C}$ surface temperature when placed in sunlight. The plate receives 1100 W/m^2 and it is insulated on its dark side. If the emissivity factor of the plate is $.95$ and the ambient temperature measured as $24 \text{ }^\circ\text{C}$, solve the following problems.

36. Determine the amount of heat radiated from one (1) m^2 of the plate.

Solution (REFERENCE: CHOTKEH MANUAL):

To calculate the radiated heat, in SI units, refer to radiation equation (44) **SI** (HIT.TR/RADIA/RADIA)

For $A=1 \text{ m}^2$, $\epsilon=.95$, $F_a=1$, $T1=80 \text{ }^\circ\text{C}=353 \text{ K}$, and $T2=24 \text{ }^\circ\text{C}=297 \text{ K}$

$$q_r = 417.4 \text{ W/m}^2, \text{ Answer.}$$

37. Determine the amount of heat released by conductance.

Solution (REFERENCE: CHOTKEH MANUAL):

At the stabilized condition, when the surface temperature remains constant, the following equation pertains:

$$(\text{Heat transferred by conductance}) = (\text{Heat received}) - (\text{Heat radiated}) = 1100 - 417.4$$

$$\text{heat transferred} = 682.6 \text{ W/m}^2, \text{ Answer.}$$

38. Determine the unit surface conductance.

Solution (REFERENCE: CHOTKEH MANUAL):

To find the unit surface conductance, in a single slab, refer to equation (33) **U** (HIT.TR/HIT.FL/SLAB/SINGL)

For $q=682.6 \text{ W (J/s)}$, $A=1 \text{ m}^2$, and $\Delta t = 80-24=56 \text{ }^\circ\text{C}$

$$U = 12.2 \text{ W/m}^2\text{.K, Answer.}$$

HEAT TRANSFER EXAMPLES

39. A 5 m by 3 m wall consists of a 10 cm brick and 1 cm plaster. If the indoor and outdoor temperatures and the external wind speed are 20 oC and 0 oC respectively, determine: The heat loss through the wall. Consider the indoor/outdoor film effect and assume the following data:

Brick thermal conductivity: .66 W/m.K Outdoor air film coefficient: 34 W/m².K
 Plaster thermal conductivity: .52 W/m.K Indoor air film coefficient: 9.4 W/m².K

Solution (REFERENCE: CHOTKEH MANUAL):

To calculate the heat loss (flow) through a composite wall/slab with 2 films (2h) and 2 slabs (2K), refer to equation (39) 2H2K (HIT.TR/HIT.FL/SLAB)

For A=15 m², $\Delta t = 20$ oC, $h1=9.4$ W/m².K, $L1=0.1$ m, $K1=0.66$ W/m.K, $L2=0.01$ m, $K2=0.52$ W/m.K, and $h2=34$ W/m².K

$$q = 979 \text{ W, Answer.}$$

* * * * *

40. A 40 mm/45 mm inside/outside diameter bronze tube is surrounded by 60 kPa saturated steam. If the tube's wall temperature remains at 17 oC, determine: The outside film coefficient.

Solution (REFERENCE: CHOTKEH MANUAL):

To solve the problem, with the data in SI units, equation (06) must be used. To do so, all unknowns in the equation must be identified or calculated first:

Step 1 Identify the required characteristics of water, from water property table (CHOTKEH MANUAL, SI units), for mean bulk temperature: $(17 + 85.9)/2 = 51.45$ oC. 85.9 oC is the steam temperature at 60 kPa=.06 MPa, CHOTKEH STEAM TABLE, SAT.P

For 51.45 oC water (by interpolation; use HIT.TR/INTRP):

$\mu_l = 5.647\text{EE-5}$ kg.s/m² and $K = .647$ W/m.K

For 51.45 oC steam (Use STEAM TABLE SAT.T):

$\rho_l = 1/v_f = 1/.000101 = 987$ kg/m³, $\rho_v = 1/v_g = 1/11.27 = .0887$ kg/m³

For 85.9 oC steam:

$h_{fg}(85.9) = 2292$ kJ/kg

Step 2 Calculate the outside film coefficient, refer to equation (06) SI (HIT.TR/FILMC/OUT)

For $\rho_l = 987$ kg/m³, $\rho_v = .0887$ kg/m³, $g = 9.81$ m/sec², $h_{fg} = 2.292\text{EE6}$ J/kg, $K = .647$ W/m.K, $Do = .045$ m, $\mu_l = 5.647\text{EE-5}$ kg.s/m², $t_{sv} = 85.9$ oC, and $t_s = 17$ oC

$$h_o = 5560 \text{ J/m}^2.\text{K, Answer.}$$

HEAT TRANSFER EXAMPLES

41. 13 oC water is entering to a heat exchanger tubing with the velocity of 7.6 mps. The tube has 60 mm/70 mm inside/outside diameter and the wall temperature of the tube remains at 74 oC. If the temperature of water has to be increased to 52 oC, determine the length of the tube. Assume $U_o = h_i$.

Solution (REFERENCE: CHOTKEH MANUAL):

For the assumed $U_o = h_i$, to solve the problem, equations (04) and (17) must be used. To do so, all unknowns in the equations must be identified or calculated first:

- Step 1 Identify the required characteristics of water, from water property table (CHOTKEH MANUAL, SI units), for the mean bulk temperature: $(13 + 52)/2 = 32.5$ oC

For 32.5 oC water:

$\rho = 994.5$ kg/m³, $c_p = 4177$ J/kg.K, $\nu = .77\text{EE-}6$ m²/s, $K = .62$ W/m.K, and $N_{pr} = 5.14$

- Step 2 Calculate the Reynolds number. With the identified kinetic viscosity, refer to equation (50) **KINET** (HIT.TR/REYN)

For $D = .06$ m, $v = 7.6$ mps, and $\nu = .77\text{EE-}6$ m²/s $N_{Re} = 592208$

- Step 3 Calculate the Logarithmic Mean Temperature Difference (LMTD)

For SI units, refer to heat exchanger general equation (17) **SI** (HIT.TR/HIT.EX/LMTD/GNRL)

For $\Delta T_1 = 74 - 13 = 61$ oC and $\Delta T_2 = 74 - 52 = 22$ oC $LMTD = 20.5$ oC

- Step 4 Calculate inside film coefficient, h_i . Refer to film coefficient equation (04) **IN** (HIT.TR/FILMC)

For $K = .62$ W/m.K, $N_{Re} = 592208$, $N_{pr} = 5.14$, $n = .4$ ($t(\text{bulk}) < t(\text{wall})$), and $D_i = .06$ m

$$\underline{U_o = h_i = 18569 \text{ W/m}^2\text{.K}}$$

- Step 5 With the calculated U_o , determine the length of the tube. For SI units, refer to heat exchanger tube length equation (21) **SI** (HIT.TR/HIT.EX/TUBE/LNTH)

For $\rho = 994.5$ kg/m³, $D_i = .06$ m, $c_p = 4177$ J/kg.K, $t_o = 52$ oC, $t_i = 13$ oC, $v = 7.6$ mps, $U_o = h_i = 18569$ W/m².K, $D_o = .07$ m, and $LMTD = 20.5$ oC

$$l = 22.3 \text{ m, Answer.}$$

HVAC EXAMPLES

1. Determine:
(a) the Enthalpy and (b) the Specific Humidity of the air at 72 oF dry bulb temperature and 48% relative humidity.

Solution:

- a. With the given **dry bulb temperature** and **relative humidity**, in English system:
At LIBRARY press ↩ PREV PSYCH ENG DB.RH ENTH
For **tdb=72** oF and **RH%=48**

$$h = 26.05 \text{ BTU/lbda, Answer for (a)}$$

- b. press MENU SPC.H
For the same data.

$$H_s = .00803 \text{ lbw/lbda, Answer for (b)}$$

* * * * *

2. Determine:
(a) the Dew Point and (b) the Specific Volume of the air at 82 oF dry bulb temperature and 73 oF wet bulb temperature.

Solution:

- a. With the given **dry bulb temperature** and **wet bulb temperature**, in English system:
At LIBRARY press ↩ PREV PSYCH ENG DB.WB DEW.P
For **twb=73** oF and **tdb=82** oF

$$tdp = 69.3 \text{ oF, Answer for (a)}$$

- b. press MENU SPC.V
For the same data

$$v = 13.98 \text{ cf/lbda, Answer for (b)}$$

HVAC EXAMPLES

3. Determine the Specific Volume of the air with the dew point of 63 oF at 85 oF dry bulb temperature.

Solution:

To solve this problem, the Relative Humidity must be calculated first. For English system:

At LIBRARY press $\leftarrow$ PREV PSYCH ENG DB.RH DEW.P

For **tdp=63** oF and **tdb=85** oF

$$\underline{RH\% = 47.7}$$

press MENU SPC.V

For **tdb=85** oF and **RH%=47.7**

$$v = 13.99 \text{ cf/lbda, Answer.}$$

* * * * *

4. If the Specific Humidity of the air at 60% Relative Humidity equals to .01 lbw/lbda, determine the wet bulb temperature.

Solution:

To solve this problem, the dry bulb temperature must be calculated first. For English system:

At LIBRARY press $\leftarrow$ PREV PSYCH ENG DB.RH SPC.H

For **Hs=.01** lbw/lbda and **RH%=60**

$$\underline{tdb = 71.8 \text{ oF}}$$

Press MENU WET.B

For **tdb=71.8** oF and **RH%=60**

$$twb = 62.5 \text{ oF, Answer.}$$

* * * * *

5. If the Specific Volume of the air at 45% Relative Humidity equals to 13.8 cf/lbda, determine the enthalpy of the air.

Solution:

To solve this problem, the dry bulb temperature must be calculated first. For English system:

At LIBRARY press $\leftarrow$ PREV PSYCH ENG DB.RH SPC.V

For **v=13.8** cf/lbda and **RH%=45**

$$\underline{tdb = 79.9 \text{ oF}}$$

Press MENU ENTH

For **tdb=79.88** oF and **RH%=45**

$$h = 29.9 \text{ BTU/lbda, Answer.}$$

HVAC EXAMPLES

6. If 1200 cfm of 60 oF air at 80% relative humidity is mixed with 800 cfm of 70 oF air at 50% relative humidity, determine:
- The mixture's temperature.
 - The mixture's enthalpy.
 - The mixture's relative humidity.

Solution:

To solve this problem, determine the enthalpy and specific volume of each flow. Use CHOTKEH's PSYCH Chart (similar steps as to problems 1 thru 5).

For $t_{db1}=60$ oF and $RH\%1=80$ $h_1 = 24.0$ BTU/lbda $v_1 = 13.27$ cf/lbda

For $t_{db2}=70$ oF and $RH\%2=50$ $h_2 = 25.3$ BTU/lbda $v_2 = 13.50$ cf/lbda

- a. Find the temperature of the mixture: With the given volumetric flow of air, refer to equation (16) **TEMP** (HVAC/AIR/MIXTR/VOLM)

For $Q_1=1200$ cfm, $v_2=13.5$ cf/lbda, $t_1=60$ oF, $Q_2=800$ cfm, $v_1=13.27$ cf/lbda, and $t_2=70$ oF

$$t_{mix} = 64 \text{ oF, Answer for (a).}$$

- b. Find the enthalpy of the mixture: With the given volumetric flow of air, refer to equation (17) **ENTH** (HVAC/AIR/MIXTR/VOLM) **MENU**

For the same data, but $h_1=24$ BTU/lbda and $h_2=25.3$ BTU/lbda.

$$h_{mix} = 24.5 \text{ BTU/lbda, Answer for (b).}$$

- c. Find the relative humidity of the mixture: Use the Enthalpy equation of PSYCH table.

For $h=h_{mix}=24.5$ BTU/lbda and $t_{da}=t_{mix}=64$ oF

$$RH = 66\%, \text{ Answer for (c).}$$

* * * * *

7. How many cfm of air can be cooled with a 5 ton Freon 12 air conditioning system from 90 oF and 75% relative humidity to 75 oF and 45% relative humidity.

Solution:

To solve this problem, (1) determine enthalpy and specific volume of the air at both side of the air conditioner and (2) calculate the flow rate.

HVAC EXAMPLES

Step 1 From CHOTKEH's PSYCH Chart.

For **tdb=90** oF and **RH%=75**:

hi=47.02 BTU/lbda vi=14.35 cf/lbda

For **tdb=75** oF and **RH%=45**:

ho=27.11 BTU/lbda

Step 2 To find the air flow rate in English system, with the given tonnage and the flow required in **cfm**, refer to tonnage equation (77) **CFM (HVAC/TONR/ENG)**.

For **tonR=5** ton, **hi=47.02** BTU/lbda, **ho=27.11** BTU/lbda, and **vi=14.35** cf/lbda.

$\text{cfm} = 721 \text{ cfm, Answer.}$

* * * * *

Problems 8 - 10

For an air conditioning system which is described below and expected to provide the following:

Design Criteria

Outdoor:

dry bulb temperature: **95** oF

Relative Humidity: **70%**

Cooling load:

Sensible: **23,000** BTU/h

Latent: **6,000** BTU/h

Indoor:

dry bulb temperature: **80** oF

Relative Humidity: **40%**

Supply air entering area: **70** oF

Ventilation: **40%** of supply air, by weight.

Solve the following three (3) problems.

8. Determine: The air flow quantity entering the area:

a. In cfm.

b. In lbda/hr

Solution:

a. To find the fan's air flow rate (cfmF) in English system, refer to equation (10) **FAN (HVAC/AIR/FLOW/ENG)**

For **qs=23000** BTU/h, **tr=80** oF, and **ts=70** oF

$\text{cfmF} = 2130, \text{ Answer for (a).}$

HVAC EXAMPLES

- b. To find the mass of the dry air entering the area, for air as an ideal gas, refer to equation (73) **IDEAL** (HVAC).

For $p = 14.7 \times 144 = 2116.8$ psf (14.7 psi is assumed to be the dry air's partial pressure),

$V = 2130 \times 60 = 127800$ cf/h, $R = 53.3$ ft-lbf/lbda-oR, and $T = 70 + 460 = 530$ oR.

$$m = 9577 \text{ lbda/hr, Answer for (b).}$$

9. **Determine: The apparatus temperature.**

Solution:

- a. To find the apparatus temperature, **tap**, take the following steps:

Step 1 Find the RSHR (Room Sensible Heat Ratio). Refer to equation (75) **RSHR** (HVAC)

For $q_s = 23000$ BTUh and $q_l = 6000$ BTUh

$$\text{RSHR} = .793$$

Step 2 Use the graphical Psychometric chart:

- Locate .793 on Sensible Heat Factor scale.
- From this point, draw a line through the **small circle** (at the center of the chart.) This is the **RSHR slope line**.
- Locate the area's condition point on the Chart ($t_{db} = 80$ oF, $RH = 40\%$)
- From this point, draw a line parallel to slope line. Extend the line to intersect the saturation curve.
- Read the apparatus temperature.

$$tap = 47 \text{ oF, Answer.}$$

10. **Determine: The amount of bypassed air.**

Solution:

To find the bypass air flow, take the following steps:

Step 1 Calculate the temperature of mixed air entering the coil:

With the calculated mass flow of air, refer to equation (21) **TEMP** (HVAC/AIR/MIXTR/MASS)

For $m_1 = 9577 \times .6 = 5746$ lbm/hr (given 40% ventilation), $t_1 = t_r = 80$ oF, $m_2 = 9577 \times .4 = 3831$ lbm/hr, and $t_2 = t_o = 95$ oF

$$t_{mix} = 86 \text{ oF}$$

HVAC EXAMPLES

Step 2 Calculate the bypass factor:

Refer to equation (26) **BYPAS** (HVAC)

For $t_{oc}=t_s=70$ oF, $t_{ap}=47$ oF, and $t_{ic}=t_{mix}=86$ oF BF = .59

Step 3 Find the amount of bypassed air:

For 59% bypass factor

Bypassed air = $9577 \times .59 = 5650$ lbda/hr, Answer.

* * * * *

Problems 11 - 12

A retail store has the following heating characteristics and conditions:

Design Criteria

Outdoor:

Dry bulb temperature: 30 oF

Relative Humidity: 25%

Indoor:

dry bulb temperature: 75 oF

Relative Humidity: 45%

Heat add by:

occupants, (latent): 140 BTU/person/hr

Number of occupants: 40

Ventilation: 850 cfm.

Humidifier: as needed

Based on the above information, solve the following two (2) problems:

11. If the indoor design criteria to be maintained, determine:

The mass of water to be added by humidifier (pound of water per hour) to provide the required moisture.

Solution:

The humidifier must provide enough water to compensate the moisture lost through the ventilation minus the moisture generated by the occupants.

To calculate the mass of water by humidifiers in English system, refer to humidifier equation (71)

ENG (HVAC/HUMID) For:

$cfmV = 850$ (ventilation, given)

$H_{si} = .00833$ lbw/lbda (Indoor air Specific Humidity, PSYCH table, $t_{db}=75$ oF, $RH\%=45$)

$v_i = 13.64$ cf/lbda (Indoor air Specific Volume, PSYCH table, $t_{db}=75$ oF, $RH\%=45$)

$H_{so} = .00087$ lbw/lbda (Outdoor air Specific Humidity, PSYCH table, $t_{db}=30$ oF, $RH\%=25$)

$v_o = 12.35$ cf/lbda (Outdoor air Specific Volume, PSYCH table, $t_{db}=30$ oF, $RH\%=25$)

HVAC EXAMPLES

NP=40 (Number of people, given)
LAT.H=140 BTU/hr/pers.(Latent Heat by occupants, given)
hfgi=1050.4 BTU/lbm (Enthalpy of vaporization of saturated steam at indoor temperature, SAT.T
table, t=75 oF)

$lbph = 22.22 \text{ lbw/hr. Answer.}$
--

12. Determine: What should be the window's indoor surface temperature to prevent the condensation?

Solution:

The indoor air will condensate at indoor air dew point temperature.

To find the dew point temperature, use CHOTKEH's PSYCH Chart.

For tdb=75 oF and RH%=45

tdp = 52.3 oF

window temperature > 52.3 oF, Answer.

* * * * *

Problems 13 - 15

A building has the characteristics and design conditions listed below:

Location: 40 oN latitude

Design temperature: Outside, 94 oF.

Inside, 78 oF

Film Coefficient: Outside, 4 BTU/hr-ft²-oF

Inside: 1.65 BTU/hr-ft²-oF

Based on the above, solve the following three (3) problems:

13. Determine the instantaneous heat gain at 4 p.m., through the followin specified walls:

North wall: 1450 sf

East wall: 1400 sf

South wall: 1300 sf

West wall: 1500 sf

Walls are brick face, constructed as follows:

4" brick:

R = .44 hr-ft²-oF/BTU

4" hollow clay tile:

k = .3 BTU/hr-ft-oF

4" insulation:

k = .024 BTU/hr-ft-oF

2x4 stud

5/8" dry wall gypsum:

R = .56 hr-ft²-oF/BTU

HVAC EXAMPLES

Solution:

To find the instantaneous heat gain take the following steps.

Step 1 Calculate the overall coefficient of heat transfer for the walls (U):

Refer to equation (31) **UCOEF (HVAC)**

For **$\Sigma L:k$** = key in ' 1/1.65+1/4 **Eval** = .856, **$\Sigma L:k$** = key in ' 4/12/.3+4/12/.024
Eval = 15, and **ΣR** = .44+.56=1 **U** = .0593 BTU/hr-ft²-oF

Step 2 Determine the walls Cooling Load Temperature Difference (CLTD):

From ASHRAE CLTD table, type C wall, 4 p.m.

CLTD (N) = 12 oF

CLTD (E) = 29 oF

CLTD (S) = 20 oF

CLTD (W) = 16 oF

Step 3 Calculate the heat gain:

Refer to, through the wall/roof/ heat gain equation (51) **WALL (HVAC/HEAT/GAIN)**

For **U** = .0593 BTU/hr-ft²-oF, **A(N)** = 1450 ft², **CLTD(N)** = 12 oF **qs(N)** = 1031.8 BTU/hr

For **U** = .0593 BTU/hr-ft²-oF, **A(E)** = 1400 ft², **CLTD(E)** = 29 oF **qs(E)** = 2407.6 BTU/hr

For **U** = .0593 BTU/hr-ft²-oF, **A(S)** = 1300 ft², **CLTD(S)** = 20 oF **qs(S)** = 1541.8 BTU/hr

For **U** = .0593 BTU/hr-ft²-oF, **A(W)** = 1500 ft², **CLTD(N)** = 16 oF **qs(W)** = 1423.2 BTU/hr

Press + + +

qs (walls) = 6,404 BTU/hr, Answer.

14. Determine the instantaneous heat gain at 4 p.m.. through the following specified roof:

Area: 10,000 ft²

Roof construction:

4" concrete: **k** = .76 BTU/hr-ft-oF

2" insulation: **k** = .023 BTU/hr-ft-oF

4 ply asphalt and paper: **R** = .35 ft²-oF-hr/BTU

1/2" plywood: **R** = .63 ft²-oF-hr/BTU

8" insulation: **k** = .022 BTU/hr-ft-oF

2x10 Joists:

5/8" dry wall gypsum: **R** = .56 ft²-oF-hr/BTU

1/2" acoustical tile: **R** = 1.2 ft²-oF-hr/BTU

Solution:

To find the instantaneous heat gain take the following steps.

Step 1 Calculate the overall coefficient of heat transfer for the roof (U):

Refer to equation (31) **UCOEF (HVAC)**

For **$\Sigma L:k$** = key in ' 1/1.65+1/4 **Eval** = .856, **$\Sigma L:k$** = key in ' 4/12/.76+2/12/.023+8/12/.022 **Eval** = 38, and **ΣR** = .35+.63+.56+1.2=2.74

U = .024 BTU/hr-ft²-oF

HVAC EXAMPLES

Step 2 Determine the walls Cooling Load Temperature Difference (CLTD):

From ASHRAE CLTD table, no suspended ceiling, 4" concrete + insulation, 4 p.m.

$$\text{CLTD} = 50 \text{ oF}$$

Step 3 Calculate the heat gain:

Refer to, through the wall/roof/ heat gain equation (51) **WALL** (HVAC/HEAT/GAIN)

For $U = .024$ BTU/hr-ft²-oF, $A = 10,000$ ft², and $\text{CLTD} = 50$ oF

$q_s (\text{roof}) = 12,000 \text{ BTU/hr, Answer.}$
--

15. Determine the instantaneous heat gain, at 4 p.m., through the following specified windows:

a: East window: 140 ft² South window: 120 ft²

1/4" single glazing: $k = .45$ BTU/hr-ft-oF

Shading factor: $.6$ (combination of glass and shading)

Solution:

To find the total heat gain take the following steps.

Step 1 Calculate the overall coefficient of heat transfer for window (U):

Refer to equation (31) **UCOEF** (HVAC)

For $\Sigma 1: h =$ key in ' 1/1.65 + 1/4 **EVAL** = .856, $\Sigma 2: k =$ key in ' .25/12/.45 **EVAL** = .0463, and $\Sigma R = 0$

$$U = 1.11 \text{ BTU/hr-ft}^2\text{-oF}$$

Step 2 Determine the windows Solar Heat Gain Factor (Fshg):

For 40 degree North latitude.

$$\text{Fshg(E)} = 216 \text{ BTU/hr-ft}^2$$

$$\text{Fshg(S)} = 117 \text{ BTU/hr-ft}^2$$

Step 3 Calculate the heat gain:

For total heat gain (instantaneous plus solar) through the windows, refer to heat gain equation (64) **TOTAL** (HVAC/HEAT/GAIN/WIND)

For $A(E) = 140$ ft², $C_s = .6$, $\text{Fshg(E)} = 216$ BTU/hr-ft², $U = 1.1$ BTU/hr-ft²-oF, $t_o = 94$ oF, and $t_i = 78$ oF

$$q_s (E) = 20608 \text{ BTU/hr}$$

For $A(S) = 120$ ft², $C_s = .6$, $\text{Fshg(S)} = 117$ BTU/hr-ft², $U = 1.1$ BTU/hr-ft²-oF, $t_o = 94$ oF, and $t_i = 78$ oF

$$q_s (S) = 10536 \text{ BTU/hr}$$

Press +

$q_s (\text{windows}) = 31,144 \text{ BTU/hr, Answer.}$

HVAC EXAMPLES

Problems 16 - 17

For an air conditioned space with the following criteria and conditions:

Outdoor:

Dry bulb temperature: 94 oF Sensible heat load: 225000 BTU/hr
Wet bulb temperature: 78 oF Latent heat load: 63000 BTU/hr

Indoor

Dry bulb temperature: 78 oF Required ventilation: 2200 cfm
Relative humidity: 50%

Solve the following two (2) problems.

16. Determine: The apparatus dew point:

Solution:

To determine the apparatus dew points, take the following steps;

Step 1 Find the RSHR (Room Sensible Heat Ratio). Refer to equation (75) **RSHR** (HVAC)

For $q_s = 225000$ BTU/hr, and $q_l = 63000$ BTU/hr $RSHR = .78$

Step 2 Use the graphical Psychrometric chart:

- Locate .78 on Sensible Heat Factor scale.
- From this point, draw a line through the **small circle** (at the center of the chart.) This is the **RSHR slope line**.
- Locate the area's condition point on the Chart (**tdb = 78 oF**, **RH = 50%**).
- From this point, draw a line parallel to slope line. This is the **condition line**. Extend the line to intersect the saturation curve.
- Read the dew point dry bulb temperature).

$tap = 53$ oF, <u>Answer.</u>

17. Determine: The flow rate of conditioned air:

Solution:

To calculate the flow of conditioned air through the coil in English system, with the conditioned area's sensible heat is given and the apparatus temperature is determined, refer to the air through the coil equation (12) **QS** (HVAC/AIR/FLOW/ENG/COIL).

For $q_s = 225000$ BTU/hr, $tr = 78$ oF, and $tap = 53$ oF.

$QC = 8333$ cfm, <u>Answer.</u>

HVAC EXAMPLES

Problems 18 - 19

For an auditorium of 1000 persons with the following design criteria and conditions:

Design Criteria

Outdoor:

dry bulb temperature: 95 oF

Relative Humidity: 70%

Indoor:

dry bulb temperature: 75 oF

Relative Humidity: 60%

Heat gain

Sensible: 50,000 BTU/hr

Latent: 25,000 BTU/hr

Heat added

occupants, (sensible): 180 BTU/person/hr

occupants, (latent): 130 BTU/person/hr

Temp. of supply air entering area: 65 oF

Ventilation: 250 cfm

18. Determine:

- The total sensible heat.
- The total latent heat.
- The capacity of the fan.

Solution:

a. Sensible heat loads are:

1. Sensible heat gain (given):

$$qs(1) = 50,000 \text{ BTU/hr}$$

2. Sensible heat added by occupants:

Refer to equation (54) **SENS** (HVAC/HEAT/ADD/OCCUP)

For **SEN.H=180** BTU/person, and **NP=1000**

$$qs(2) = 180,000 \text{ BTU/hr}$$

3. Sensible heat added by ventilation:

For English system, refer to equation (56) **SENS** (HVAC/HEAT/ADD/VENT/ENG)

For **cfmV=250**, **to=95** oF, and **ti=75** oF

$$qs(3) = 5,400 \text{ BTU/hr}$$

$qs = qs(1) + qs(2) + qs(3) = 235,400 \text{ BTU/hr. Answer for (a).}$
--

b. Latent heat loads are:

1. Latent heat gain (given):

$$ql(1) = 25,000 \text{ BTU/hr}$$

2. Latent heat added by occupants:

Refer to equation (55) **LATN** (HVAC/HEAT/ADD/OCCUP)

For **LAT.H=130** BTU/person, and **NP=1000**

$$ql(2) = 130,000 \text{ BTU/hr}$$

HVAC EXAMPLES

3. Latent heat added by ventilation:

Step 1 Identify the outdoor and indoors's air specific humidity.

Use CHOTKEH's PSYCH chart.

For **RH%=70** and **tdb=95** oF $H_{so} = .02525 \text{ lbw/lbda}$

For **RH%=60** and **tdb=75** oF $H_{si} = .01116 \text{ lbw/lbda}$

Step 2 For English system, refer to equation (57) **LATN** (HVAC/HEAT/ADD/VENT/ENG)

For **cfmV=250** cfm, **Hso=.02525** lbw/lbda, and **Hsi=.01116** lbw/lbda

$$ql(3) = 17,049 \text{ BTU/hr.}$$

$$ql = ql(1) + ql(2) + ql(3) = 172,049 \text{ BTU/hr, Answer for (b).}$$

- c. To find the capacity of fan in English System, refer to equation (10) **FAN** (HVAC/AIR/FLOW/ENG)
For **qs=235400** BTU/hr, **tr=75** oF, and **ts=65** oF

$$cfmF = 21796 \text{ cfm, Answer for (c).}$$

19. Determine: The other properties of the supplied air.

To find the other properties (**Hs**, **RH%**, **twb**), take the following steps:

Step 1 Find the RSHR (Room Sensible Heat Ratio). Refer to equation (75) **RSHR** (HVAC)

For **qs=50000+180000=230000** BTU/hr (room sensible heat w/o ventilation) and

ql=25000+130000=155000 BTU/hr.

$$RSHR = .60$$

Step 2 Use the graphical Psychometric chart:

- a. Locate .6 on Sensible Heat Factor scale.
- b. From this point, draw a line through the **small circle** (at the center of the chart.) This is the **RSHR slope line**.
- c. Locate the area's condition point on the Chart (**tdb=75** oF, **RH=60%**)
- d. From this point, draw a line parallel to slope line. This is the **condition line**.
- e. Locate the supply air's temperature (**ts=65** oF) on the **condition line**. Read all other properties.

$$twb = 59.5 \text{ oF, RH} = 73\%, Hs = .096 \text{ lbw/lbda, Answer .}$$

HVAC EXAMPLES

Problems 20 - 21

Heating system of an office building has the following characteristics:

Working hours: 9 a.m. to 6 p.m, 5 days a week. Number of weeks/season: 19

Design temperature: Outside, 32 oF. Inside, 72 oF

Ventilation rate: 9000 cfm during working (peak) hours
4000 cfm in off hours/week ends.

Walls surface area: 9,000 ft², U = .14 BTU/hr-ft²-oF

Windows surface area: 2,000 ft², U = 1.05 BTU/hr-ft²-oF

Roof surface area: 35,000 ft², U = .09 BTU/hr-ft²-oF

Based on the above, solve the following two problems:

20. Determine:

a. The fuel oil consumption per heating season, in gallon/season. Assume No. 2 oil with approximate heat value of 139,000 BTU/gal.

b. The natural gas consumption per heating season, in Therms (100,000 BTU)/season. Assume 80% efficiency for both boilers.

Solution:

Step 1 Determine the number of peak and off hours per season:

peak hours = key in ' 19*5*9 EVAL hrpik = 855 hours/season
off hours = key in ' 19*7*24-855 EVAL hroff = 2337 hours/season

Step 2 Calculate the heat loss by ventilation:

For English system, refer to sensible heat loss by ventilation equation (65) **SENS**
(HVAC/HEAT/LOSS/VENT/ENG)

peak hours: For cfmV=9000, ti=72 oF to=32 oF qven (peak) = 388,800 BTU/hr
off hours: For cfmV=4000, ti=72 oF, to=32 oF qven (off) = 172,800 BTU/hr

Step 3 Calculate the surface heat loss:

Refer to surface heat loss equation (64) **SURF** (HVAC/HEAT/LOSS)

Walls: For A=9,000 ft², U = .14 BTU/hr-ft²-oF, ti=72 oF, and to=32 oF
q (wall) = 50,400 BTU/hr

Windows: For A=2,000 ft², U=1.05 BTU/hr-ft²-oF, ti=72 oF, and to=32 oF
q (window) = 84,000 BTU/hr

Roof: For A=35,000 ft², U = .09 BTU/hr-ft²-oF, ti=72 oF, and to=32 oF
q (roof) = 126,000 BTU/hr

Step 4 Calculate the fuel consumption:

For calculation of fuel/gas consumption, with the computed heat loss, refer to fuel equation (49) **HEAT** (HVAC/FUEL/ENG)

HVAC EXAMPLES

- a. #2 oil For $h_{rpik}=855$ hrs/season, q_{pik} = key in ' 388800+50400+84000+126000
 EVAL = 649200 BTU/hr, $h_{roff}=2337$ hrs/season,
 q_{off} = key in ' 649200+172800-388800 EVAL = 433200 BTU/hr, $HV=139000$
 BTU/gal, and $\eta = .8$

$FC = 14,096 \text{ gal/season, Answer.}$

- b. gas For the same values, but $HV=100,000$ BTU/Therm

$FC = 19,593 \text{ Therm/season, Answer.}$

21. If during the off hours, including weekends, the inside temperature is reduced to 60 oF, determines:
- a. The fuel oil consumption per heating season.
 - b. The natural gas consumption per heating season.

Solution:

- a. #2 oil Use the same equation (49) **HEAT** (HVAC/FUEL/ENG)
 For all data the same as problem 8.a, but q_{off} = key in ' 433200*(60-32)/(72-32) = **303240**

$FC = 11,365 \text{ gal/season, Answer for (a)}$

- b. gas For all data the same as problem 8.b, but $q_{off}=303240$ BTU/hr

$FC = 15,797 \text{ Therm/season, Answer for (b).}$

* * * * *

Problems 22 - 25

A theater with 700 seating has an air conditioning system which is described below and expected to provide the following:

Design Criteria

Outdoor:

dry bulb temperature: 94 oF

wet bulb temperature: 75 oF

Heat gain

From outside: 110,000 BTU/hr

Heat added by:

lighting: neglect

equipment: neglect

HVAC EXAMPLES

Indoor: occupants, (sensible): 210 BTU/person/hr
dry bulb temperature: 76 oF occupants, (latent): 110 BTU/person/hr
Relative Humidity: 50%

Temp. of supply air entering area: 60 oF chilled water:
Ventilation: 5 cfm/occupant Entering temperature: 40 oF
Exiting temperature: 51 oF
Based on the above, solve the following four (4) problems:

22. Determine: The air flow quantity entering the air conditioned area.

Solution:

To find the fan's air flow quantity (cfmF), take the following steps:

Step 1 Calculate the area's sensible cooling load.

a. Outside heat gain (given): qs(a) = 110000 BTU/hr

b. Sensible heat, added by occupants:

Refer to occupant's sensible heat added equation (54) SENS (COOL/HEAT/ADD/OCCUP)

For SEN.H=210 BTU/person, and NP=700 qs(b) = 147000 BTU/hr

Total sensible load: Add qs(a) and qs(d): qs (total) = 257000 BTU/hr.

Step 2 Calculate the supply fan's flow quantity:

For English system, refer to air flow, through the fan, equation (10) FAN
(COOL/AIR/FLOW/ENG)

For qs=257000 BTU/hr, tr=76 oF, and ts=60 oF

$$\text{cfmF} = 14873 \text{ cfm, Answer.}$$

23. Determine: The temperature of mixed air, return and outdoor, entering the cooling coil.

To find the temperature of mixed air entering the coil (tic), (1) identify the outdoor and indoor's air specific volume and (2) calculate the mixed air temperature.

Step 1 Use CHOTKEH's Psychometric Chart.

Outdoor:

For tdb=94 oF and twb=75 oF vo = 14.26 cf/lbda.

Indoor:

For tdb=76 oF and RH%=50 vr = 13.76 cf/lbda

HVAC EXAMPLES

Step 2 Refer to cooling coil, entering air temperature, equation (32) **TMIX** (HVAC/COIL)

For $QV=3500$ (given, 5 cfm/occupant), $vr=13.76$ cf/lbda, $t0=94$ oF, $QF=14873$,
 $vo=14.26$ cf/lbda, and $tr=76$ oF.

$tic = 80.1$ oF, <u>Answer.</u>

24. Determine: The cooler's capacity.

To calculate the cooler's capacity, the latent heat related to occupants, as well as ventilation cooling load must be calculated and added to the loads calculated in problems 22 and 23

a. Sensible load (problem 22): $q(a) = 257000$ BTU/hr

b. Occupants latent load:

Refer to occupant's latent heat added equation (55) **LATN** (COOL/HEAT/ADD/OCCUP)

For **LAT.H=110** BTU/person, and **NP=700** $q(b) = 77000$ BTU/hr

c. Ventilation total load:

To find the load, (1) identify the outdoor and indoor's air enthalpy and (2) calculate the load.

Step 1 Use Psychometric Chart.

For **tdb=94** oF and **twb=75** oF $ho = 38.4$ BTU/lbda

For **tdb=76** oF and **RH%=50** $hr = 28.74$ BTU/lbda

Step 2 For English system, refer to total ventilation added heat equation (58) **TOTAL**
(COOL/HEAT/ADD/VENT/ENG)

For $cfmV=3500$ cfm, $ho=38.4$ BTU/lbda, and $hr=28.74$ BTU/lbda

$$q(c) = 152145 \text{ BTU/hr}$$

Total cooling load = $q(a) + q(b) + q(c) = 486145$ BTU/hr

From **tonR=q/12000**, while 486145 on level 1, type 12000 press ÷

$tonR = 40.5$ tons, <u>Answer.</u>

25. Determine: The required chilled water, in gpm.

Solution:

For English system, refer to chiller's water flow quantity equation (27) **GPM** (HVAC/CHILR/ENG)

For q =total cooling load=**486145** BTU/hr, $to=51$ oF (water exiting temperature), $ti=40$ oF (water entering temperature)

$flow = 88.3$ gpm, <u>Answer.</u>

HVAC EXAMPLES

Problems 26 - 28

A heating system is designed to work under the following characteristics and conditions:

Design data:

Outdoor temperature: 0 oF

Indoor temperature: 72 oF

Heat loss: 175000 BTU/hr

Based on the above information, solve the following three (3) problems

Other data

Number of heating days: 225

Degree days: 4920

boiler efficiency: 85%

26. Determine: The cost of fuel for heating season. Assume No. 2 oil, Heat value=139000 BTU/gal, and cost=\$.67/gal

Solution:

Step 1 Calculate the fuel consumption (FC):

For English system, with the given degree days, refer to fuel equation (48) **DEGD** (HVAC/FUEL/ENG)

For $q_d=175000$ BTU/hr, **DAYS=225** days, $t_{ia}=72$ oF (the actual indoor temperature equals to design indoor temperature), **DEGD=4920** degree days, $t_{id}=72$ oF, $t_{od}=0$ oF,

HV=139000 BTU/gal, and $\eta = .85$

$$\underline{FC = 3206.7 \text{ gal/season}}$$

Step 2 Find the cost:

Key in .67 press x

cost = \$2148.5/season, Answer.

27. Determine the additional fuel cost, if the actual indoor temperature is raised to 75 oF. All other data remain the same.

Solution:

Step 1 Calculate the fuel consumption (FC):

Stay with same equation

For all other values remain the same, but $t_{ia}=75$ oF

$$\underline{FC = 3540 \text{ gal/season}}$$

Step 2 Find the additional cost:

Key in .67 press x

Additional = 2371.8 - 2148.5

$$\underline{\text{cost (75)} = 2371.8 \text{ \$/season}}$$

Additional cost = 223.3/season, Answer.

HVAC EXAMPLES

28. Determine: The saving in fuel cost, if the actual indoor temperature is reduced from 75 oF to 68 oF. All other data remain the same.

Solution:

Step 1 Calculate the fuel consumption (FC):

Stay with same equation

For all other values remain the same, but $t_{ia} = 68$ oF

$$\underline{FC = 2762.4 \text{ gal/season}}$$

Step 2 Find the additional cost:

Key in .67 press x

$$\underline{\text{cost (68)} = 1850.8 \text{ \$/season}}$$

$$\text{Additional} = 2371.8 - 1850.8$$

Saving = 521 \\$/season, Answer.

* * * * *

Problems 29 - 31

350 cfm air (based on dry air at 65 oF and 14.7 psia) is compressed and then is cooled, under a constant volume, to its saturation point. Following data explain the process conditions:

Compressor:

Intake air (350 cfm): $t_{db} = 78$ oF, $RH = 75\%$, and $P = 13.6$ psia.

Outlet air: $t_{db} = 520$ oF and $P = 95$ psia.

Cooled Air

$t_{db} = 75$ oF, $RH = \text{saturated} = 100\%$

Based on the above information, solve the following three (3) problems:

29. Determine: The Specific Humidity (H_s) of the air, entering the compressor.

Solution:

If the intake air had the atmospheric pressure of 14.7 psia, the H_s could had been determined by PSYCH table. Now that the pressure is 13.6 psia, the weight of the dry air and its moisture content must be calculated separately.

Step 1 Determine the weight of the dry air, at the base condition (m_a):

With the base conditions of the dry air at the intake are known, refer to Ideal gas equation (73) IDEAL (HVAC)

$$\text{For } p = 14.7 \times 144 = 2116.8 \text{ psf, } V = 350 \text{ cfm, } R = 53.3 \text{ ft-lb/lbm-oR, and } T = 65 + 460 = 525 \text{ oR}$$
$$\underline{m_a = 26.48 \text{ lbda/min}}$$

HVAC EXAMPLES

Step 2 Determine the weight of the moisture (mwv):

a. Calculate the partial pressure of water vapor:

From $RH = P_{wv}/P_{wvs}$, for:

$RH = 75\% = .75$ (Relative Humidity of intake air, given)

$P_{wvs} = .4751$ psia (Absolute pressure of saturated vapor, SAT.T table, $t = 78^\circ F$)

Substitute the values and key in $.75 * .4751$ EVAL $P_{wv} = .3563$ psia.

b. Determine the weight of moisture, by calculating the number of moles of water:

Refer to vapor pressure of atmospheric air equation (05) **MOLE**

(HVAC/AIR/ATMO/PRESS/VAPOR), For:

$P_{wv} = .3563$ psia (Partial pressure of water vapor, calculated, step 1.a)

n_{wv} = to be calculated, (Number of moles of water vapor)

$n_{da} = .913$ (Number of moles of dry air/min = $26.48/29 = .913$)

$P_{tot} = 13.6$ psia (Intake air total pressure, given)

$$n_{wv} = .02456 \text{ mole/min}$$

For $m_{wv} = n_{wv} * 18$ (18 = MW of water) key in 18 press x $m_{wv} = .4421$ lbw/min

Step 3 Calculate Specific Humidity (Hs):

From $H_s = m_{wv}/m_{da} = .4421/26.48$

$H_{si} = .0167 \text{ lbw/lbda, Answer.}$
--

30. **Determine: The Specific Humidity (Hs) of the air, leaving the cooler.**

Solution:

Follow the steps in problem 29

Step 1 Determine the weight of the dry air (ma):

Calculated in problem 29

$$m_{da} = 26.48 \text{ lbda/min}$$

Step 2 Determine the weight of the moisture (mwv):

a. Calculate the pressure of air leaving the cooler:

For a constant volume process: $P_2 = P_1 * T_2 / T_1$

For $P_1 = 95$ psia, $T_2 = (75 + 460) = 535$ oR, and $T_1 = (520 + 460) = 980$ oR

P_2 = key in $95 * 535 / 980$ EVAL

$$P_{exit} = P_2 = 51.86 \text{ psia}$$

HVAC EXAMPLES

b. Calculate the partial pressure of water vapor:

From $RH = P_{wv}/P_{wvs}$, for:

$RH = 100\% = 1$ (Relative Humidity, of intake air, given)

$P_{wvs} = .43$ psia (Absolute pressure of saturated vapor, SAT.T table, $t = 75$ oF)

Substitute the values and key in '1' * .43 EVAL $P_{wv} = .43$ psia.

c. Determine the weight of the moisture, by calculating the number of **moles** of water:

Refer to vapor pressure of atmospheric air equation (05) **MOLE**

(HVAC/AIR/ATMO/PRESS/VAPOR), For:

$P_{wv} = .43$ psia (Partial pressure of water vapor, calculated, step 2.b)

$n_{wv} =$ to be calculated, (Number of moles of water vapor)

$n_{da} = .913$ (Number of moles of dry air/min = $26.48/29 = .913$)

$P_{tot} = 51.86$ psia (Cooled air pressure, step 2.a)

$$n_{wv} = .00763 \text{ mole/min}$$

From $m_{wv} = n_{wv} * 18$ key in 18 press x

$$m_{wv} = .1374 \text{ lbw/min.}$$

Step 3 Calculate Specific Humidity (H_s):

From $H_s = m_{wv}/m_{da} = .1374/26.48$

$$H_{si} = .00519 \text{ lbw/lbda, Answer.}$$

31. Determine: The mass of water added/removed from the air during the compression/cooling process.

Solution:

Refer to Exchangers equation (47) **MASS** (HVAC/SPRAY/WATR/MASS)

For $m_a = 26.48$ lbda/min, $H_{si} = .0167$ lbw/lbda, and $H_{so} = .00519$ lbw/lbda

$$m_w = .30478 \text{ lbw/min} = 18.3 \text{ lbw/hr, Answer.}$$

* * * * *

Problems 32 - 33

In a spray chamber, the temperature of a flow of 6 lb/min of dry air is reduced from 790 oF to 350 oF. The pressure at spray chamber is 80 psia and the water temperature entering the chamber measured as 70 oF, Based on these information, solve the following problems.

HVAC EXAMPLES

32. Determine: The flow quantity of spray water.

Solution:

This is a cooling by sprayer problem, assuming an adiabatic process. With the flow is given in mass of the air, refer to sprayer heat balance equation (38) **MASS** (HVAC/EXCH/HTBAL). For:

ma = mass of air = **6 lb/min** (given)

hia = enthalpy of entering air = **304.1** BTU/lbm (CHOTKEH AIR table, for $T = 790 + 460 = 1250$ oR)

hoa = enthalpy of exiting air = **194.2** BTU/lbm (CHOTKEH AIR table, for $T = 350 + 460 = 810$ oR)

mw = flow quantity of water, to be calculated.

how = enthalpy of exiting water vapor = **1217.6** BTU/lbm (Assumed super-heated steam with partial pressure equal to 11 psia. CHOTKEH SUPHT table for $P = 11$ psia and $t = 350$ oF)

hiw = enthalpy of entering water (h_f 70 oF) = **38** BTU/lbm (CHOTKEH SAT.T table for $t = 70$ oF)

$mw = .56$ lbm/min, <u>Answer.</u>
--

33. Determine: The relative humidity of the air leaving the spray chamber.

Solution:

To find the relative humidity use the equation: **$RH = P_{wv}/P_{swv}$** , where **P_{wv}** is the water vapor's partial pressure and **P_{swv}** represents the saturated water vapor's pressure at the exit temperature.

Step 1 Find the partial water's vapor pressure (**P_{wv}**):

With the computable number of moles of air and water, refer to air vapor pressure equation (05) **MOLE** (HVAC/AIR/ATMO/PRESS/VAPOR). For:

n_{wv} = number of moles of water vapor = **$.56/18 = .031$** mole of water/min

n_{da} = number of moles of dry air = **$6/29 = .2069$** mole of air/min

P_{tot} = Total (chamber) pressure = **80** psia (given)

$P_{wv} = 10.42$ psia.

Step 2 Determine the saturated pressure of water vapor (**P_{swv}**):

Refer to CHOTKEH's SAT.T table.

For **$t = 350$** oF

$P_{swv} = 134.63$ psia.

Step 3 Calculate the relative humidity:

Using the above equation, key in ' **$10.42/134.61$** **EVAL**

$RH = .077 = 7.7\%$, <u>Answer.</u>

HVAC EXAMPLES

34. If an air at 93 oF tdb and 73 oF twb enters a cooling tower and leaves at 83 oF and 90% relative humidity, determine:
- The added heat/lbda
 - The added moisture/lbda

Solution:

To solve this problem determine the enthalpy and specific humidity of the entering and leaving air. Use CHOTKEH's PSYCH Chart.

For **tdbi=93 oF** and **twbi=73 oF**: $hi=36.5 \text{ BTU/lbda}$ $Hsi=.0129 \text{ lbw/lbda}$

For **tdbo=83 oF** and **RH%=90**: $ho=44.2 \text{ BTU/lbda}$ $Hso=.0221 \text{ lbw/lbda}$

- a. From $dh=ho-hi=44.2-36.5$

$$dh = 7.7 \text{ BTU/lbda, Answer for (a).}$$

- b. From $dHs=Hso-Hsi=.0221-.0129$

$$dHs = .0092 \text{ lbw/lbda, Answer for (b).}$$

* * * * *

Problems 35 - 36

A cooling tower with the characteristics described below, is working under the following conditions:

Air:

Entering:

Dry bulb temperature: 73 oF

Relative Humidity: 42%

Pressure: 14.7 psia

Leaving:

Dry bulb temperature: 102 oF

Relative Humidity: 83%

Flow of air to the area: 5500 cfm

Ventilation: 600 cfm

Based on the above, solve the following two (2) problems.

Water:

Entering temperature: 120 oF

Leaving temperature: 80 oF

Flow quantity: 3150 gpm

Make-up water:

Temperature: 52 oF

Losses (blow-up, wind): 32% of make-up water

35. Determine: The flow quantity of air:
- In lbm/hr
 - In cfm

HVAC EXAMPLES

Solution:

To calculate the air flow quantity, use CHOTKEH's PSYCH and SAT.T Chart and determine the air and water's following properties:

Water:

hiw:hf(120 oF)=88 BTU/lbm (Enthalpy of entering water, SAT.T table for t=120 oF)
how:hf(80 oF)=48 BTU/lbm (Enthalpy of leaving water, SAT.T table for t=80 oF)
viw:vf(120 oF)=.01621 cf/lbm (Specific Volume of entering water, SAT.T table for t=120 oF)

Air:

hia=25.45 BTU/lbm (Enthalpy of entering air, PSYCH table for tdb=73 oF and RH%=42)
Hsi=.0073 lbw/lbda (Spec. Humidity of entering air, PSYCH table for tdb=73 oF and RH%=42)
via=13.57 cf/lbda (Spec. Volume of entering air, PSYCH table for tdb=73 oF and RH%=42)
hoa=66.21 BTU/lbm (Enthalpy of leaving air, PSYCH table for tdb=102 oF and RH%=83)
Hso=.03772 lbw/lbda (Spec. Humidity of leaving air, PSYCH table, tdb=102 oF and RH%=83)

- a. To calculate the mass flow, refer to air washer/sprayer Heat Balance equation (38) **MASS** (HVAC/EXCH/HTBAL)
For **hia=25.45 BTU/lbm**, **hoa=66.21 BTU/lbm**,
mw = key in ' 60*.13368*3150/.01621 **EVAL** = **1558638 lbm/hr** (.13368 is the gpm to cfm conversion factor), **how=48 BTU/lbm**, and **hiw=88 BTU/lbm**.

ma = 1,529,576 lbm/hr, Answer for (a).

- b. To calculate the volumetric flow in English system, refer to air washer/sprayer Heat Balance equation (39) **ENG** (HVAC/EXCH/HTBAL/VOLM)
For **via=13.57 cf/lbda**, **gpmw=3150**, **viw=.01621 cf/lbm**, and same value for the rest

cfma = 345,939 cfm, Answer for (b).

36. **Determine: The flow rate of make-up water, in gpm:**

Solution:

To calculate the amount of make-up water, take the following steps:

Step 1 Determine the amount of water added/removed from the air:

For English system and the air flow by volume, refer to equation (41) **VOLM** (HVAC/EXCH/WATR/VOLM/ENG)

For **viw=.016024 cf/lbw** (vf(52 oF), SAT.T table), **cfma=345,939**, **via=13.57 cf/lbda**,
Hsi=.0073 lbw/lbda, and **Hso=.03772 lbw/lbda** **gpm = -93**

NOTE: The negative sign means that the water is added to the air.

Step 2 Determine the make-up water:

Considering 32% loss, key in ' 93/(1-.32)

make-up water = 136.76 gpm, Answer.

HVAC EXAMPLES

Problems 37 - 38

Within an hour, 120,000 BTU of heat is removed from a building. The A/C unit conditions 4000 cfm of air, out of which 500 cfm is the fresh air. Considering the following design criteria:

Outdoor:

Dry bulb temperature: 95 oF

Wet bulb temperature: 75 oF

Other:

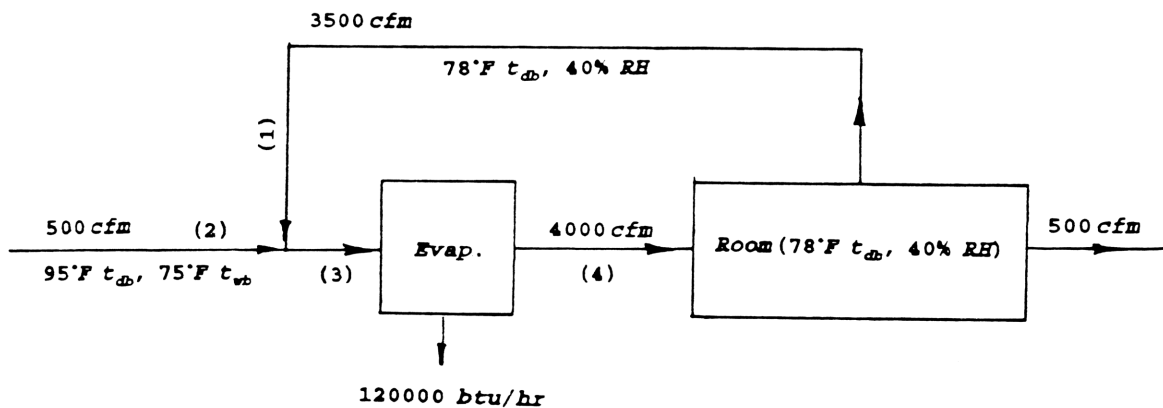
Cooling coil surface temperature: 50 oF

Based on the above, solve the following two (2) problems.

Indoor

Dry bulb temperature: 78 oF

Relative Humidity: 40%



37. Determine: The supply air characteristics, tdb and RH, entering the conditioned area.

Solution:

To calculate the supply air condition (assumed no bypass), (1) determine the enthalpy and specific heat of the mixed air entering the coil, (2) find the specific heat of the air at dew point (first characteristic of air after the coil), (3) calculate the enthalpy of the air after the coil (second characteristic of air after the coil), and finally (4), from the graphical Psychrometric Chart, determine other conditions, i.e. tdb and RH%.

Step 1 From CHOTKEH's PSYCH chart

For tdb=78 oF and RH%=40 % (indoor air)

$$h1 = 27.68 \text{ BTU/lbda} \quad v1 = 13.72 \text{ cf/lbda} \quad Hs1 = .00817 \text{ lbw/lbda} \quad m1 = 3500/13.69 = 255.1 \text{ lb/min}$$

For tdb=95 oF, twb=75 oF (fresh air)

$$h2 = 38.39 \text{ BTU/lbda} \quad v2 = 14.28 \text{ cf/lbda} \quad Hs2 = .01413 \text{ lbw/lbda} \quad m2 = 500/14.28 = 35 \text{ lb/min.}$$

HVAC EXAMPLES

Find the enthalpy of the mixture, **h3**: With the calculated mass flow of air, refer to equation (22) **ENTH** (HVAC/AIR/MIXTR/MASS) (mixed air before entering the coil)

For **m1=255.1** lbm, **h1=27.68** BTU/lbda, **m2=35** lbm, and **h2=38.39** BTU/lbda
h3 = 28.97 BTU/lbda.

Find the specific heat of the mixture, **Hs3**: With the calculated mass flow of air, refer to equation (23) **SPC.H** (HVAC/AIR/MIXTR/MASS) **MENU**

For **m1=255.1** lbm, **Hs1=.00817** lbw/lbda, **m2=35** lbm, and **Hs2=.01413** lbw/lbda
Hs3 = .00889 lbw/lbda.

Based on the above, the characteristics of the air entering the coil are:

h3 = 28.97 BTU/lbda **Hs3 = .00889** lbw/lbda

Step 2 Find the specific humidity at dew point, 50 oF (given): (supply air)

At this point that **RH%=100%**, for **tdb=50** oF: **Hs4 = .00766** lbw/lbda

Step 3 Find the enthalpy of air after the coil, **h4**:

From **m3(h3-h4)=heat removed**. For **m3=255.1+35=290.1** lbm/min., **h3=28.97** BTU/lbda, and **heat removed=120000/60=2000** BTU/min.

For HP48GX: Press $\rightarrow$ **SOLVE** **ENTER** key in **290.1*(28.97-H4)=2000** **ENTER** press **SOLVE**. **h4 = 22.1** BTU/lbda.

For HP48SX: key in **290.1*(28.97-H4)=2000** **ENTER**

Press $\leftarrow$ **SOLVE** **STEQ** **SOLVR** **ENTER**

Press $\leftarrow$ **H4** **h4 = 22.1** BTU/lbda.

Step 4 By knowing two (2) of the air characteristics, **Hs4=.00766** lbw/lbda and **h4=22.1** BTU/lbda, locate them on the graphical Chart and read **tdb** and **RH**

tdb = 57 oF and RH = 77%, Answer.

38. Determine: The amount of condensate water in the A/C unit.

Solution (REFERENCE: CHOTKEH MANUAL):

Refer to coil equation (35) **WATR** (HVAC/COIL)

For **ma=m3*60=290.1*60=17406** lbda/hr, **Hsi=Hs3=.00889** lbw/lbda, and **Hso=Hs4=.00766** lbw/lbda

mw = 21.4 lbw/hr, Answer.

HVAC EXAMPLES

Problems 39 - 44

An air conditioning system with the characteristics described below, is expected to provide the following:

Design Criteria

Outdoor:

dry bulb temperature: 94 oF

Relative Humidity: 55%

Indoor:

dry bulb temperature: 73 oF

Relative Humidity: 45%

Flow of air to the area: 5500 cfm

Ventilation: 600 cfm

Heat gain

From outside: 24,000 BTU/hr

Heat added by:

lighting: 14 kw

equipment: 8 kw

occupants, (sensible): 210 BTU/person/hr

occupants, (latent): 110 BTU/person/hr

Number of occupants: 15.

Chilled water:

Entering temperature: 41 oF

Leaving temperature: 51 oF

Based on the above, solve the following six (6) problems.

39. Determine: The temperature of air entering the area.

Solution:

To find the temperature of supply air (ts), take the following steps:

Step 1 Calculate the area's sensible cooling load.

a. Outside heat gain (given):

$$qs(a) = 24000 \text{ BTU/hr}$$

b. Heat added by lighting:

For English system, refer to equation (50) **LIGHT** (HVAC/HEAT/ADD/ENG)

For $watt = 14 \times 1000 = 14000$ watts, and $CL = .7$ (assumed) $qs(b) = 33418 \text{ BTU/hr}$

c. Heat added by equipment:

For English system, refer to equation (52) **EQMT** (HVAC/HEAT/ADD/ENG)

For $hp = 8 / .7457 = 10.73$ hp, and $\eta = .9$ (motor in area) $qs(c) = 30342 \text{ BTU/hr}$

d. Sensible heat, added by occupants:

Refer to occupant's sensible heat added equation (54) **SENS** (HVAC/HEAT/ADD/OCCUP)

For **SEN.H = 210** BTU/person, and **NP = 15**

$$qs(d) = 3150 \text{ BTU/hr}$$

Total sensible load:

Add qs(a) thru qs(d):

$$qs = 90190 \text{ BTU/hr.}$$

HVAC EXAMPLES

Step 2 Calculate the supply air temperature:

For English system, refer to air flow, through the fan, equation (10) **FAN**
(HVAC/AIR/FLOW/ENG)

For **cfmF=5500** cfm, **qs=90190** BTU/hr, and **tr=73** oF

$$ts = 57.8 \text{ oF, Answer.}$$

40. Determine: The mass of the air entering the coil.

Solution:

Step 1 Determine the Specific Volume of indoor and outdoor air. Use PSYCH Chart.

For **tdb=94** oF and **RH%=55**

$$vo = 14.37 \text{ cf/lbda}$$

For **tdb=73** oF and **RH%=45**

$$vi = 13.58 \text{ cf/lbda}$$

Step 2 Refer to Air Mixture equation (20) **MASS** (HVAC/AIR/MIXTR/VOLM)

For **Q1=5500-600=4900** cfm, **v1=13.58** cf/lbda, **Q2=600** cfm, and **v2=14.37** cf/lbda

$$mmix = 402.58 \text{ lbm/min} = 24155 \text{ lbm/hr, Answer.}$$

41. Determine: The air conditioner's capacity.

To calculate the unit's capacity, the added heat related to ventilation as well as the occupants latent heat must be calculated and added to the loads calculated in problems 39

a. Sensible load (problem 39):

$$q(a) = 90190 \text{ BTU/hr}$$

b. Occupants latent load

Key in ' 110*15 **EVAL**

$$q(b) = 1650 \text{ BTU/hr}$$

c. Ventilation total load:

To find the load, (1) identify the outdoor and area's air enthalpy, outdoor air specific volume, and (2) calculate the cooling load.

Step 1 Use PSYCH Chart.

For **tdb=94** oF and **RH%=55**

$$ho = 43.57 \text{ BTU/lbda}$$

For **tdb=73** oF and **RH%=45**

$$hr = 26.03 \text{ BTU/lbda}$$

Step 2 For English system, refer to total added heat, by ventilation, equation (58) **TOTAL**
(HVAC/HEAT/ADD/VENT/ENG)

For **cfmV=600**, **ho=43.57** BTU/lbda, and **hr=26.03** BTU/lbda

$$q(c) = 47358 \text{ BTU/hr}$$

HVAC EXAMPLES

$$\text{Total cooling load} = q(a) + q(b) + q(c) = 139198 \text{ BTU/hr}$$

From $\text{tonR} = q/12000$, while 139198 on level 1, type 12000 press $\div$

$$\text{tonR} = 11.6 \text{ tons, Answer.}$$

42. Determine: The apparatus Dew Point.

Solutio:

To solve this problem, the Room Sensible Heat Ratio (**RSHR**) must be calculated first, by using the Psychometric Chart, then the Dew Point (**tdp**) to be graphically identified.

Step 1 Calculate Room Sensible Heat Ratio (**RSHR**):

Refer to RSHR equation (75) **RSHR** (HVAC)

For $q_s = 90190 \text{ BTU/hr}$ (problem 39), and $q_l = 1650 \text{ BTU/hr}$ (problem 41) $\text{RSHR} = .982$

Step 2 Determine the Dew Point (**tdp**):

This must be done graphically:

- Locate **0.982** on RSHR scale. From this point draw a line through the **small circle** (at the center of the chart). This is the **RSHR slope line**.
- Locate the indoor condition (**tdb**=73 oF and **RH**=45%) on the chart. From this point draw a line parallel with RSHR slope line. This is the **condition line**.
- Locate the supply air dry bulb temperature (**tdb**=**ts**=57.8 oF) on the condition line. Read the corresponding Dew Point.

$$\text{tdp} = 50 \text{ oF, Answer.}$$

43. Determine: The amount of required chilled water, in gpm.

Solution:

To solve this problem in English system, refer to chiller's equation (27) **GPM** (HVAC/CHILR/ENG)

For $q = 139198 \text{ BTU/hr}$ (problem 41), $t_o = 51 \text{ oF}$ and $t_i = 41 \text{ oF}$

$$\text{gpm} = 27.81, \text{ Answer.}$$

HVAC EXAMPLES

44. Determine: The chiller's circulating hp, assuming the head added by pump equals to 25 ft.

Solution:

To solve this problem in English system, refer to chiller's equation (28) **HP** (HVAC/CHILR/ENG)
For **hA=25 ft**, **gpm=27.81**, **viw=.016 cf/lbw** (vf(51 oF) SAT.T table), and **$\eta=.85$** (assumed)

$hp = .21 \text{ hp. Answer.}$

* * * * *

Problems 45 - 46

An area is heated by a heat pump and a back up electrical heater. Following are the data and characteristics of the heat pump.

Design data:

Outdoor temperature: 0 oF

Indoor temperature: 72 oF

Heat loss: 320,000 BTU/hr

Other data

Internal added heat: 9000 BTU/hr

Cost of electricity: \$.11/kwh

Heat Pump's performance data

Outdoor ** Temperate (oF) toa	hours per season HRS	Output Capacity (BTU/hr) CAPA	Required Power (KW) KW
65	1100	62000	6.5
55	920	52000	6.1
45	520	43000	5.7
35	260	33000	5.3
25	120	24000	4.9
15	40	20000	4.5
5	20	7000	4.0

** Each number represents the indicated temperature +/- 5 oF

Based on the above information, solve the following two (2) problems:

HVAC EXAMPLES

45. Calculate the cost of energy consumed by electric heater.

Solution:

The required heat is primarily provided by the heat pump, up to a certain outdoor temperature, then the electric heater is engaged. The following equation is made to calculate the cost of energy, consumed by the electric heater. It must be noticed that the negative value means that the heat pump will serve the purpose by itself.

$$C = \frac{\left(\frac{q_d}{t_{id} - t_{od}} (t_{id} - t_{oa}) - CAPA - q_{ad} \right) HRS * RATE}{3410}$$

C = cost of energy/season

qd = design heat loss = **320000** BTU/hr

tid = Design indoor temperature = **0** oF

toa = Actual outdoor temperature, from performance table

tod = Design outdoor temperature = **72** oF

CAPA = Heat pump capacity, from performance data

qad = Added heat by interior sources = **9000** BTU/hr

HRS = Number of hours of recorded temperature, from performance data

RATE = rate of electricity = **\$.11/kwh**

Substitute the given values and write the equation

For HP48GX: Press $\rightarrow$ **SOLVE ENTER** key in:

$$C = (320000 / (72 - 0) * (72 - TOA) - CAPA - 9000) * HRS * .11 / 3410 \quad \underline{\text{ENTER}}$$

For HP48GX: Press $\leftarrow$ **SOLVE** key in:

$$C = (320000 / (72 - 0) * (72 - TOA) - CAPA - 9000) * HRS * .11 / 3410 \quad \underline{\text{ENTER}}$$

Press **STEQ SOLVR**

For **TOA=65, CAPA=62000, HRS=1100, C = -1415**

$$\underline{C(65) = 0}$$

For **TOA=55, CAPA=52000, HRS=920,**

$$\underline{C(55) = 432}$$

For **TOA=45, CAPA=43000, HRS=520,**

$$\underline{C(45) = 1141}$$

For **TOA=35, CAPA=33000, HRS=260,**

$$\underline{C(35) = 1027}$$

For **TOA=25, CAPA=24000, HRS=120,**

$$\underline{C(25) = 681}$$

For **TOA=15, CAPA=20000, HRS= 40,**

$$\underline{C(15) = 289}$$

For **TOA= 5, CAPA= 7000, HRS= 20,**

$$\underline{C(5) = 182}$$

Total cost is the sum of C(55) thru C(5)

cost (electrical heater) = \$3,752, Answer.

HVAC EXAMPLES

46. Calculate the cost of energy consumed by heat pump.

Solution:

There are two working condition for heat pump:

Condition #1: Heat pump capacity > heat loss, part time operation. This is when the outdoor temperature is 65 oF or more. The cost may be calculated by the following equation:

$$C = \frac{\left(\frac{q_d}{t_{id} - t_{od}} (t_{id} - t_{oa}) - q_{ad} \right)}{CAPA} * KW * HRS * RATE$$

KW= Power required by heat pump, from performance data

Substitute the given values and write the equation.

$$C = (320000 / (72 - 0) * (72 - TOA) - 9000) / CAPA * KW * HRS * .11$$

For **TOA=65**, **CAPA=62000**, **KW=6.5**, **HRS=1100**, C(65) = 280

Condition #2: Heat pump capacity < heat loss. This case is for the rest of the season and it is full time operation. The cost of the energy may be calculated from the following equation:

$$C = KW * HRS * RATE$$

Write the equation.

$$C = KW * HRS * .11$$

For KW=6.1 and HRS=920 ,	<u>C(55) = 617</u>
For KW=5.7 and HRS=520 ,	<u>C(45) = 326</u>
For KW=5.3 and HRS=260 ,	<u>C(35) = 152</u>
For KW=4.9 and HRS=120 ,	<u>C(25) = 65</u>
For KW=4.5 and HRS= 40 ,	<u>C(15) = 20</u>
For KW=4.0 and HRS= 20 ,	<u>C(5) = 9</u>

Total cost is the sum of C(65) thru C(5)

cost (heat pump) = \$1,469, Answer.

HVAC EXAMPLES

Problems 47 - 49

A 24 hour active area, with 250 occupants, is air conditioned by a system which is described below and expected to provide the following:

Design Criteria

Outdoor:

dry bulb temperature: 91 oF

wet bulb temperature: 75 oF

Indoor:

dry bulb temperature: 77 oF

Relative Humidity: 50%

Heat gain

From outside: 120,000 BTU/hr

Heat added by:

equipment: 30000 BTU/hr

occupants (active), (sensible): 300 BTU/person/hr

occupants (active), (latent): 350 BTU/person/hr

Indoor generated moisture: 49000 grain/hr.

Supply air temperature: 61 oF

Ventilation: 4600 cfm

Based on the above information, solve the following three (3) problems

47. Determine: The air flow quantity entering the conditioned area.

Solution:

To find the fan's air flow quantity (cfmF), take the following steps:

Step 1 Calculate the area's sensible cooling load.

a. Outside heat gain (given):

$$qs(a) = 120000 \text{ BTU/hr}$$

b. Heat added, by equipment (given):

$$qs(b) = 30000 \text{ BTU/hr}$$

c. Sensible heat, added by occupants:

Refer to occupant's sensible heat added equation (54) SENS (COOL/HEAT/ADD/OCCUP)

For **SEN.H=300** BTU/person, and **NP=250**

$$qs(c) = 75000 \text{ BTU/hr}$$

Total sensible load:

Add qs(a) thru qs(c):

$$qs = 225000 \text{ BTU/hr.}$$

Step 2 Calculate the flow quantity:

For English system, refer to flow, through fan, equation (10) **FAN** (COOL/AIR/FLOW/ENG)

For **qs=225000** BTU/hr, **tr=77** oF, and **ts=61** oF

$\text{cfmF} = 13021 \text{ cfm, Answer.}$
--

HVAC EXAMPLES

48. Determine: The Specific Humidity (Humidity Ratio) of supply air, entering the conditioned area.

Solution:

To solve this problem, the Room Sensible Heat Ratio (**RSHR**) must be calculated first then, by using the Psychometric Chart, the Specific Humidity (**Hs**) to be graphically decided.

Step 1 Find room's sensible heat:

From problem 47

$$q_s = 225000 \text{ BTU/hr}$$

Step 2 Find room's latent heat:

a. Occupants latent heat load:

Refer to occupant's latent heat added equation (55) **LATN** (COOL/HEAT/ADD/OCCUP)

For **LAT.H=350** BTU/person/hr, and **NP=250** $q_l(a) = 87500 \text{ BTU/hr}$

b. Indoor generated moisture latent heat load:

From **q=m*hfg**, for **m=49000** (grain/hr)/ 7000 (grain/lbm)=7 lbm/hr and **hfg=1058.6** BTU/lbm (From CHOTKEH SAT.T table, for **t=ts=61** oF) $q_l(b) = 7410 \text{ BTU/hr}$

Total room's latent heat, sum of $q_l(a)$ and $q_l(b)$

$$q_l = 94910 \text{ BTU/hr}$$

Step 3 Calculate Room Sensible Heat Ratio (RSHR):

Refer to RSHR equation (75) **RSHR** (HVAC)

For **qs=225000** BTU/hr, and **ql=94910** BTU/hr $RSHR = .7$

Step 4 Determine the Specific Humidity (Hs):

This must be done graphically:

a. Locate **0.7** on RSHR scale. From this point draw a line through the **small circle** (at the center of the chart). This is the **RSHR slope line**.

b. Locate the indoor condition (**tdb=77** oF and **RH%=50%**) on the chart. From this point draw a line parallel with RSHR slope line. This is the **condition line**.

c. Locate the supply air dry bulb temperature (**tdb=ts=61** oF) on the condition line. Read the corresponding Specific Humidity.

$$H_s = 58 \text{ grains/lbda} = .00825 \text{ lbw/lbda, Answer.}$$

49. Determine: The air conditioner's capacity.

Solution:

To calculate the unit's capacity, the ventilation cooling load must be calculated and added to the loads calculated in problems 47 and 48

HVAC EXAMPLES

- a. Sensible load (problem 47): $q(a) = 225000 \text{ BTU/hr}$
- b. Occupants' and moisture latent load (problem 48) $q(b) = 94910 \text{ BTU/hr}$
- c. Ventilation total load:
To find the load, (1) identify the outdoor and indoor's air enthalpy, outdoor air specific volume, and (2) calculate the cooling load.

Step 1 Use CHOTKEH's Psychometric Chart.

Outdoor:

Determine the outdoor's Relative Humidity first.

For **tdb=91** oF and **twb=75** oF

$$\underline{h_o = 38.43 \text{ BTU/lbda}}$$

For **tdb=91** oF and **twb=75** oF

$$\underline{v_o = 14.20 \text{ cf/lbda}}$$

Indoor:

For **tdb=77** oF and **RH%=50**

$$\underline{h_r = 29.34 \text{ BTU/lbda}}$$

Step 2 For English system, refer to total added heat, by ventilation, equation (58) **TOTAL** (COOL/HEAT/ADD/VENT/ENG)

For **cfmV=4600**, **h_o=38.43 BTU/lbda**, and **h_r=29.34 BTU/lbda**

$$\underline{q(c) = 188163 \text{ BTU/hr}}$$

$$\underline{\text{Total cooling load} = q(a) + q(b) + q(c) = 508073 \text{ BTU/hr}}$$

From **tonR=q/12000**, while 508073 on level 1, type 12000 press $\div$

tonR = 42.3 tons, Answer.

* * * * *

Problems 50 - 52

Through an air washer, the condition of 9000 cfm of air at tdb=77 and RH=50%, was changed to saturated 56 oF dry bulb temperature air. If the temperature of sprayed water was increased from 40 oF to 52 oF, solve the following three (3) problems.

50. Determine: The amount of water added to or removed from the air.

Solution:

The addition or removal of the water depends on the difference between the Specific Humidity of entering air and the leaving air. To solve the problem in English system, with the air flow given in cfm and the answer required in the mass flow of water, refer to water added/removed equation (45) ENG (HVAC/EXCH/WATR/MASS/VOLM) For:

HVAC EXAMPLES

cfma=9000 cfm (air cfm, given)
Hsi=.00992 lbw/lbda (Specific Humidity of entering air, PSYCH table, tdb=77 oF, RH%=50)
Hso=.00957 lbw/lbda (Specific Humidity of exiting air, PSYCH table, tdb=56 oF, RH%=100)
via=13.73 cf/lbda (Specific Volume of entering air, PSYCH table, tdb=77 oF, RH%=50)
NOTE: Since Hsi > Hso, the water is removed.

$m_w = .22942 \text{ lbw/min} = 13.77 \text{ lbw/hr, Answer.}$
--

51. Determine the refrigeration effect of the process.

Solution:

The refrigeration effect, in term of changing the condition of the air, may be determined, using the following equation:

From $q = \frac{60 * cfma}{v_{1a}} (h_1 - h_o)$, for:

cfma=9000 cfm (air cfm, given)
via=13.73 cf/lbda (Specific Volume of entering air, PSYCH table, tdb=77 oF, RH%=50)
hi=29.34 BTU/lbda (Enthalpy of entering air, PSYCH table, tdb=77 oF, RH%=50)
ho=23.84 BTU/lbda (Enthalpy of exiting air, PSYCH table, tdb=56 oF, RH%=100)
Key in ' 60*9000/13.73*(29.34-23.84) EVAL $q = 216315 \text{ BTU/hr}$
Key in 12000 press $\div$

$\text{tonR} = 18 \text{ tons, Answer.}$
--

52. Determine: The flow rate of chilled water, in gpm.

Solution:

In an assumed adiabatic process and with the consideration of balanced exchange of heat between air and water, to solve the problem in English system, refer to chiller's equation (27) **GPM** (HVAC/CHILR/ENG). For:

q=216315 BTU/hr (Cooling load, problem 51)
to=52 oF (Chilled water leaving temperature, given)
ti=40 oF (Chilled water entering temperature, given)

$\text{gpm} = 36, \text{ Answer.}$

HVAC EXAMPLES

Problems 53 - 55

For an air conditioning system which is described below and expected to provide the following:

<u>Design Criteria</u>		<u>Heat gain</u>	
<u>Outdoor:</u>		From outside:	75,000 BTU/hr
dry bulb temperature:	92 oF	<u>Heat added by:</u>	
Relative Humidity:	40%	lighting:	10 kw
		equipment:	10 hp
<u>Indoor:</u>		occupants, (sensible)	210 BTU/person/hr
dry bulb temperature:	78 oF	occupants, (latent)	110 BTU/person/hr
Relative Humidity:	50%	Number of occupants	350

Temp. of supply air entering area: 61 oF
Ventilation: 6 cfm/occupant

Solve the following three (3) problems.

53. Determine: The air flow quantity entering the area.

Solution:

To find the fan's air flow quantity (cfmF), the area's sensitive load must be calculated first.

Step 1 Calculate the area's sensible cooling load.

a. Outside heat gain (given): $qs(a) = 75000 \text{ BTU/hr}$

b. Heat added by lighting:

For English system, refer to equation (50) **ENG** (HVAC/HEAT/ADD/LIGHT)

For $watt = 10 \times 1000 = 10000$ watts, and $CL = .7$ (assumed) $qs(b) = 23870 \text{ BTU/hr}$

c. Heat added by equipment:

For English system, refer to equation (52) **ENG** (HVAC/HEAT/ADD/EQMT)

For $hp = 10$ hp, and $\eta = .9$ (assumed motor in the area) $qs(c) = 28278 \text{ BTU/hr}$

d. Sensible heat added by occupants:

Refer to equation (54) **SENS** (HVAC/HEAT/ADD/OCCUP)

For $SEN.H = 210$ BTU/person, and $NP = 350$ $qs(d) = 37500 \text{ BTU/hr}$

Total sensible load: Add $qs(a)$ through $qs(d)$: $qs = 164648 \text{ BTU/hr.}$

Step 2 Calculate the flow quantity.

For English system, refer to equation (10) **FAN** (HVAC/AIR/FLOW/ENG)

For $qs = 164648$ BTU/hr, $tr = 78$ oF, and $ts = 61$ oF

$cfmF = 8968 \text{ cfm, Answer.}$

HVAC EXAMPLES

54. Determine: The temperature of air entering the cooling coil.

To find the temperature of mixed air entering the coil, (1) identify the outdoor and area's air specific volume and (2) calculate the air mixed temperature.

Step 1 Use CHOTKEH's PSYCH chart.

For **tdb=92** oF and **RH%=40** $v_o = 14.18$ cf/lbda.

For **tdb=78** oF and **RH%=50** $v_r = 13.76$ cf/lbda

Step 2 Refer to coil equation (32) **TMIX** (HVAC/COIL)

For **QV=2100** cfm (6 cfm per occupant), $v_r = 13.76$ cf/lbda, **to=92** oF, **QF=8968** cfm, and **vo=14.18** cf/lbda.

$$t_c = 81.2 \text{ oF, Answer.}$$

55. Determine: The cooler's capacity.

Solution:

To calculate the cooler's capacity, the latent heat related to occupants, as well as ventilation cooling load must be calculated and added to the loads calculated in problem 53.

a. Sensible load: (problem 53) $q(a) = 164648$ BTU/hr

b. Occupants latent load: 350×110 $q(b) = 38500$ BTU/hr

c. Ventilation total load:

To find the load, (1) identify the outdoor and area's air enthalpy and (2) calculate the load.

Step 1 Use CHOTKEH's PSYCH chart.

For **tdb=92** oF and **RH%=40** $h_o = 36.29$ BTU/lbda

For **tdb=78** oF and **RH%=50** $h_r = 29.96$ BTU/lbda

Step 2 For English system, refer to equation (58) **TOTAL** (HVAC/HEAT/ADD/VENT/ENG)

For **cfmV=2100**, **ho=36.29** BTU/lbda, and **hr=29.96** BTU/lbda

$$q(c) = 59819 \text{ BTU/hr}$$

$$\text{Total cooling load} = q(a) + q(b) + q(c) = 262967 \text{ BTU/hr}$$

From **tonR=q/12000**, while 262967 on level 1, type 12000 press $\div$

$$\text{tonR} = 21.9 \text{ tons, Answer.}$$

HVAC EXAMPLES

Problems 56 - 59

Moist air was passed through a dehumidifier for moisture removal. The drying agent, silica gel, was used and reactivated after five (5) hour drying process. Following are the characteristics and data of the system.

Entering air to dehumidifier:

Flow quantity: 25000 cfm

Dry bulb temperature: 62 oF

Wet bulb temperature: 56 oF

Reactivation:

time: 1.5 hour

Heated up to: 162 oF

Cooled back down to: 87 oF

Leaving air from dehumidifier:

Specific Humidity: .0037 lbw/lbda

Cooling air for reactivation:

Entering temperature: 66 oF

Leaving temperature: 77 oF

Based on the above information, solve the following four (4) problems.

56. Determine:

- The weight of the dry air in the moist air, in 5 hour drying process.
- The amount of water removed from the moist air, in 5 hour drying process.

Solution:

To solve this problem, use CHOTKEH's PSYCH chart and find the following properties of moist air:

For **tdb=62 oF** and **twb=56 oF**

Hsi = .0082 lbw/lbda

For the same data

hi = 23.8 BTU/lbda

For the same data

vi = 13.31 cf/lbda

- a. To find the weight of the dry air use the following equation:

$$m_a = \frac{60 * cfm * hrs}{v_1}$$

Substitute the values and key in ' 60*25000*5/13.31 EVAL

$ma = 563486 \text{ lbda, Answer for (a).}$

- b. To find the weight of the removed water in English system, refer to Exchangers equation (45) **ENG** (HVAC/EXCH/WATR/MASS/VOLM)

For **cfma=25000**, **Hsi=.0082 lbw/lbda**, **Hso=.0037 lbw/lbda** (given), and **via=13.31 cf/lbda**

mw = 8.45 lb/min

For 5 hour process multiply the answer by **5*60**

$mw = 2535 \text{ lbw, Answer for (b).}$
--

HVAC EXAMPLES

57. If the moisture content of the gel was measured as 5% prior to and 28% after the dehumidification process, determine:
The mass (net) of the drying gel needed for each cycle.

Solution:

Assuming that the amount of water absorbed by the gel is equal to the weight of water released from the moist air, the following equations pertain:

$$mw_1 = \frac{PC_1 * m_{gel}}{100 - PC_1} \quad mw_2 = \frac{PC_2 * m_{gel}}{100 - PC_2}$$

$$mw_2 - mw_1 = 2535$$

mw1 = Mass of water in gel prior to the process
mw2 = Mass of water in gel after the process
PC1 = Percentage of water in a gel (gross) prior to the process
PC2 = Percentage of water in a gel (gross) after the process
MGEL = Mass of the used gel (net)
subtracting the top two equations and substituting the values.

For HP48GX: Press $\rightarrow$ SOLVE ENTER key in:
28*MGEL/(100-28)-5*MGEL/(100-5)=2535 ENTER
Press SOLVE MGEL = 7538
For HP48GX: Press $\leftarrow$ SOLVE key in:
' 28*MGEL/(100-28)-5*MGEL/(100-5)=2535 ENTER
Press STEQ SOLVR
Press $\leftarrow$ MGEL MGEL = 7538

mgel = 7538 lbm/5 hour process, Answer.

58. Determine the amount of air (in cfm) required to cool down/reactivate the gel. Assume the specific heat the gel is .21 BTU/lbm-oF and the reactivation process takes 1.5 hours.

Solution: Assumed heat released by the gel equals the heat taken out by the air.

$$\text{The heat released from the gel (BTU/1.5 hr)} = m_{gel} * C_{gel} * (t_{1_{gel}} - t_{2_{gel}})$$

$$\text{The heat taken out by the air (BTU/1.5 hr)} = 1.5 * 60 * \rho_a * cfm * C_a * (t_{2_a} - t_{1_a})$$

For:

$$mgel = 7538 \text{ lbm}$$

$$C_{gel} = .21 \text{ BTU/lbm-oF (given)} \quad \text{Specific heat of gel}$$

$$C_a = .24 \text{ BTU/lbm-oF (assumed)} \quad \text{Specific heat of air}$$

HVAC EXAMPLES

$t_{1gel} = 162$ oF (given)

$t_{2gel} = 87$ oF (given)

$\rho_a = .075$ lbm/cf (assumed) Density of air

$t_{2a} = 77$ oF (given)

$t_{1a} = 66$ oF (given)

Substitute the values and key in:

For HP48GX: Press $\rightarrow$ SOLVE ENTER key in:

$$7538 \cdot .21 \cdot (162 - 87) = 1.5 \cdot 60 \cdot .075 \cdot .24 \cdot CFM \cdot (77 - 66)$$

Press SOLVE

$$CFM = 6662$$

For HP48SX: Press $\leftarrow$ SOLVE key in:

$$7538 \cdot .21 \cdot (162 - 87) = 1.5 \cdot 60 \cdot .075 \cdot .24 \cdot CFM \cdot (77 - 66) \quad \text{ENTER}$$

Press STEQ SOLVR

Press $\leftarrow$ CFM

$$CFM = 6662$$

CFM = 6662, Answer.

59. Determine the dry bulb temperature of air, leaving the humidifier. Assume the absorption heat equals to 235 BTU/lbw

Solution:

Use the Psychrometric chart to solve this problem. From the two (2) properties needed to determine the dry bulb temperature, since the Specific Humidity is known, calculate the exit enthalpy. Considering an adiabatic process, the following equation pertains:

$$h_o = h_i + \frac{mw \cdot q_{abs}}{m_a}$$

NOTE: The absorption heat is the amount of heat released by the water vapor during the absorption.

For:

h_o = To be calculated.

$h_i = 23.8$ BTU/lbm (problem 56) Enthalpy of entering air

$mw = 2535$ lbw (problem 56) Mass of water absorbed

$q_{abs} = 235$ BTU/lbw (given) Heat of absorption.

$ma = 563486$ lbda (problem 56) Mass of dehumidified air

Substitute the values and key in:

$$23.8 + 2535 \cdot 235 / 563486 \quad \text{EVAL}$$

$$h_o = 24.86 \text{ BTU/lbm}$$

Locate $h_o = 24.86$ and $H_{so} = .0037$ on the chart and read dry bulb temperature.

tdb = 86.5 oF, Answer.

HVAC EXAMPLES

Problems 60 - 63

For an air conditioned room with the following criteria and conditions:

Indoor:

Dry bulb temperature: 78 oF

Relative humidity: 60%

Air flow

Total air entering the room: 600 cfm

Amount of passing thru A/C unit: 200 cfm

Bypass air flow: 400 cfm

Condition of air leaving the A/C unit: 52 oF, saturated.

60. Determine:

The temperature of supply air entering the room.

Solution:

To find the supply air temperature in English system with the given fan flow, refer to air flow through the coil equation (11) **CFMF** (HVAC/AIR/FLOW/ENG/COIL).

For **cfmC=200**, **tr=78 oF**, **tap=52 oF**, and **cfmF=600** (given)

$$ts = 69.3 \text{ oF, Answer.}$$

61. Determine:

The specific humidity of supply air (**Hss**) entering the room.

To solve this problem, (1) determine the room and the coil's air specific humidity and specific volume. Mixture of these two airs make entering room air, (2) calculate the specific humidity of the mixture.

Step 1 From CHOTKEH's PSYCH chart

For **tdb=78 oF** and **RH%=60**

$$Hsr = .0123 \text{ lbw/lbda} \quad vr = 13.81 \text{ cf/lbda}$$

For **tdb=52 oF** and **RH%=100**

$$Hsc = .0083 \text{ lbw/lbda} \quad vc = 13.05 \text{ cf/lbda}$$

Step 2 Refer to air mixture equation (15) **SPC.H** (HVAC/AIR/MIXTR/VOLM)

For **Q1=400 cfm**, **v2=13.05 cf/lbda**, **Hs1=.0123 lbw/lbda**, **Q2=200 cfm**, **v1=13.81 cf/lbda**, and **Hs2=.0083 lbw/lbda**.

$$Hss = Hsmix = .0109 \text{ lbw/lbda, Answer.}$$

HVAC EXAMPLES

62. **Determine:**
The relative humidity of supply (RHs) air entering the room.

Solution:

Use CHOTKEH's PSYCH chart

For **Hs**=.0109 lbw/lbda (problem 61) and **tdb**=69.3 oF (problem 60).

$RH_s\% = 71.1$, <u>Answer</u> .
--

63. **Determine:**
The tonnage of the A/C unit.

Solution:

To calculate the tonnage, (1) determine the enthalpy of the cooled air at both side of the coil and
(2) calculate the tonnage.

Step 1 From CHOTKEH's PSYCH chart

For **tdb**=78 oF and **RH**%=60

$$\underline{h_i = 32.25 \text{ BTU/lbda}}$$

For **tdb**=52 oF and **RH**%=100

$$\underline{h_o = 21.43 \text{ BTU/lbda}}$$

Step 2 With the flow in **cfm** in English system, refer to tons of refrigeration equation (77) **CFM**
(HVAC/TONR/ENG)

For **cfm**=200, **hi**=32.25 BTU/lbda, **ho**=21.43 BTU/lbda, and **vi**=13.81 cf/lbda
(problem 61).

$\text{tonR} = .78$ tons, <u>Answer</u>.
--

* * * * *

64. **Determine:**
(a) the Enthalpy and (b) the Specific Humidity of the air at 22 oC dry bulb temperature and 48% relative humidity.

Solution:

- a. With the given **dry bulb temperature** and **relative humidity**, in SI system:

At LIBRARY press $\leftarrow$ PREV PSYCH SI DB.RH ENTH

For **tdb**=22 oC and **RH**%=48

$h = 42.26 \text{ kJ/kgda}$, <u>Answer</u> for (a)
--

HVAC EXAMPLES

- b. press MENU SPC.H
For the same data.

$H_s = .00792 \text{ kgw/kgda}$, Answer for (b)

* * * * *

65. **Determine:**
(a) the Dew Point and (b) the Specific Volume of the air at 28 oC dry bulb temperature and 23 oC wet bulb temperature.

Solution:

- a. With the given **dry bulb temperature** and **wet bulb temperature**, in SI system:
At LIBRARY press $\leftarrow$ PREV PSYCH SI DB.WB DEW.P
For **twb=23** oC and **tdb=28** oC

$tdp = 21 \text{ oC}$, Answer for (a)

- b. press MENU SPC.V
For the same data

$v = 0.8738 \text{ m}^3/\text{kgda}$, Answer for (b)

* * * * *

66. **Determine the Specific Volume of the air with the dew point of 17 oC at 29 oC dry bulb temperature.**

Solution:

To solve this problem, the Relative Humidity must be calculated first. For SI system:

At LIBRARY press $\leftarrow$ PREV PSYCH SI DB.RH DEW.P

For **tdp=17** oC and **tdb=29** oC

RH% = 48.3

press MENU SPC.V

For **tdb=29** oC and **RH%=48.3**

$v = .8718 \text{ m}^3/\text{kgda}$, Answer.

HVAC EXAMPLES

67. If the Specific Humidity of the air at 60% Relative Humidity equals to .01 kgw/kgda, determine the wet bulb temperature.

Solution:

To solve this problem, the dry bulb temperature must be calculated first. For SI system:

At LIBRARY press $\leftarrow$ PREV PSYCH SI DB.RH SPC.H

For Hs = .01 kgw/kgda and RH% = 60

tdb = 22.1 oC

Press MENU WET.B

For tdb = 22.1 oC and RH% = 60

twb = 16.9 oC, Answer.

* * * * *

68. If the Specific Volume of the air at 45% Relative Humidity equals to 13.8 cf/lbda, determine the enthalpy of the air.

Solution:

To solve this problem, the dry bulb temperature must be calculated first. For SI system:

At LIBRARY press $\leftarrow$ PREV PSYCH SI DB.RH SPC.V

For v = .86 m³/kgda and RH% = 45

tdb = 26.1 oC

Press MENU ENTH

For tdb = 26.1 oC and RH% = 45

h = 50.5 kJ/kgda, Answer.

* * * * *

69. How much of air, in L/s, can be cooled with a 5 ton Freon 12 air conditioning system from 32 oC and 75% relative humidity to 24 oC and 45% relative humidity.

Solution:

To solve this problem, (1) determine enthalpy and specific volume of the air at both side of the air conditioner and (2) calculate the flow rate.

Step 1 From CHOTKEH's PSYCH Chart.

For tdb = 32 oC and RH% = 75:

hi = 90.53 kJ/kgda vi = .8952 m³/kgda

For tdb = 24 oC and RH% = 45:

ho = 45.49 kJ/kgda

HVAC EXAMPLES

Step 2 To find the air flow rate in SI system, with the given tonnage and the flow required in lps, refer to tonnage equation (79) LPS (HVAC.TONR/SI).

For **tonR=5 ton**, **hi=90530 J/kg**, **ho=45490 J/kg**, and **vi=.8952 m3/kgda**.

$\text{lps} = 353 \text{ L/s, Answer.}$

* * * * *

Problems 70 - 71

A retail store has the following heating characteristics and conditions:

Design Criteria

Outdoor:

Dry bulb temperature: 0 oC

Relative Humidity: 25%

Indoor:

dry bulb temperature: 24 oC

Relative Humidity: 45%

Heat add by:

occupants, (latent): 40 W/person

Number of occupants: 40

Ventilation: 400 L/s.

Humidifier: as needed

Based on the above information, solve the following two (2) problems:

70. If the indoor design criteria to be maintained, determine:

The mass of water to be added by humidifier (kg of water per hour) to provide the required moisture.

Solution:

The humidifier must provide enough water to compensate the moisture lost through the ventilation minus the moisture generated by the occupants.

To calculate the mass of water by humidifiers in SI system, refer to humidifier equation (72) SI (HVAC/HUMID) For:

lpsV=400 (ventilation, given)

Hsi=.00839 kgw/kgda (Indoor air Specific Humidity, PSYCH table, **tdb=24 oC**, **RH%=45**)

vi=.8523 m3/kgda (Indoor air Specific Volume, PSYCH table, **tdb=24 oC**, **RH%=45**)

Hso=.00094 kgw/kgda (Outdoor air Specific Humidity, PSYCH table, **tdb=0 oC**, **RH%=25**)

vo=.7742 m3/kgda (Outdoor air Specific Volume, PSYCH table, **tdb=0 oC**, **RH%=25**)

NP=40 (Number of people, given)

LAT.H=40 W/pers. (Latent Heat by occupants, given)

hfgi=2443000 J/kg (Enthalpy of vaporization of saturated steam at indoor temperature, SAT.T table, **t=24 oC**)

$\text{kgph} = 10.1 \text{ kgw/hr, Answer.}$
--

HVAC EXAMPLES

71. Determine: What should be the window's indoor surface temperature to prevent the condensation?

Solution:

The indoor air will condensate at indoor air dew point temperature.

To find the dew point temperature, use CHOTKEH's PSYCH Chart.

For **tdb=24** oC and **RH%=45**

$$\underline{\text{tdp} = 11.4 \text{ oC}}$$

window temperature > 11.4 oC, Answer.

* * * * *

Problems 72 - 77

An air conditioning system with the characteristics described below, is expected to provide the following:

Design Criteria

Outdoor:

dry bulb temperature: 34 oC

Relative Humidity: 55%

Indoor:

dry bulb temperature: 23 oC

Relative Humidity: 45%

Flow of air to the area: 2600 L/s

Ventilation: 280 L/s

Heat gain

From outside: 7,000 W

Heat added by:

lighting: 14 kW

equipment: 8 kW

occupants, (sensible): 60 W/person

occupants, (latent): 32 W/person

Number of occupants: 15.

Chilled water:

Entering temperature: 5 oC

Leaving temperature: 11 oC

Based on the above, solve the following six (6) problems.

72. Determine: The temperature of air entering the area.

Solution:

To find the temperature of supply air (ts), take the following steps:

Step 1 Calculate the area's sensible cooling load.

a. Outside heat gain (given):

$$\underline{qs(a) = 7000 \text{ W}}$$

b. Heat added by lighting:

For SI system, refer to equation (51) **LIGHT** (HVAC/HEAT/ADD/SI)

For **watt=14000** watts, and **CL=.7** (assumed)

$$\underline{qs(b) = 9800 \text{ W}}$$

HVAC EXAMPLES

c. Heat added by equipment:

For SI system, refer to equation (53) **EQMT** (HVAC/HEAT/ADD/SI)

For $hp = 8/.7457 = 10.73$ hp, and $\eta = .9$ (motor in area) $qs(c) = 8890$ W

d. Sensible heat, added by occupants:

Refer to occupant's sensible heat added equation (56) **SENS** (HVAC/HEAT/ADD/OCCUP)

For **SEN.H** = 60 W/person, and **NP** = 15 $qs(d) = 900$ W

Total sensible load: Add $qs(a)$ thru $qs(d)$:

$$qs = 26590 \text{ W}$$

Step 2 Calculate the supply air temperature:

For SI system, refer to air flow, through the fan, equation (13) **FAN** (HVAC/AIR/FLOW/SI)

For **lpsF** = 2600 lps, **qs** = 26590 W, and **tr** = 23 oC

$ts = 14.5 \text{ oC, Answer.}$

73. **Determine: The mass of the air entering the coil.**

Solution:

Step 1 Determine the Specific Volume of indoor and outdoor air. Use PSYCH Chart.

For **tdb** = 34 oC and **RH%** = 55

$$v_o = .8952 \text{ m}^3/\text{kgda}$$

For **tdb** = 23 oC and **RH%** = 45

$$v_i = .8487 \text{ m}^3/\text{kgda}$$

Step 2 Refer to Air Mixture equation (20) **MASS** (HVAC/AIR/MIXTR/VOLM)

For **Q1** = 2600-280 = 2320 lps = 2.32 kg/s. $v_1 = .8952 \text{ m}^3/\text{kgda}$, **Q2** = 280 lps = .28 kg/s, and $v_2 = .8487 \text{ m}^3/\text{kgda}$

$mmix = 2.92 \text{ kg/min} = 10512 \text{ kg/hr, Answer.}$

74. **Determine: The air conditioner's capacity.**

To calculate the unit's capacity, the added heat related to ventilation as well as the occupants latent heat must be calculated and added to the loads calculated in problems 39

a. Sensible load (problem 72):

$$q(a) = 26590 \text{ W}$$

b. Occupants latent load

Key in ' 32*15 **EVAL**

$$q(b) = 480 \text{ W}$$

HVAC EXAMPLES

c. Ventilation total load:

To find the load, (1) identify the outdoor and area's air enthalpy, outdoor air specific volume, and (2) calculate the cooling load.

Step 1 Use PSYCH Chart.

For **tdb=34** oC and **RH%=55** $\underline{h_o = 81.82 \text{ kJ/kgda}}$

For **tdb=23** oC and **RH%=45** $\underline{h_r = 43.21 \text{ kJ/kgda}}$

Step 2 For SI system, refer to total added heat, by ventilation, equation (61) **TOTAL** (HVAC/HEAT/ADD/VENT/SI)

For **lpsV=280**, **ho=81820** J/kgda, and **hr=43210** J/kgda $\underline{q(c) = 12973 \text{ W}}$

Total cooling load = q(a) + q(b) + q(c) = 40043 W

From **tonR=q/3517**, while 40043 on level 1, type 3517 press $\div$

tonR = 11.4 tons, Answer.

75. **Determine: The amount of required chilled water, in L/s.**

Solution:

To solve this problem in SI system, refer to chiller's equation (29) **LPS** (HVAC/CHILR/SI)

For **q=40043** W (problem 74), **to=11** oC and **ti=5** oC

lps = 1.6 L/s, Answer.

76. **Determine: The chiller's circulating hp, assuming the head added by pump equals to 7.5 m.**

Solution:

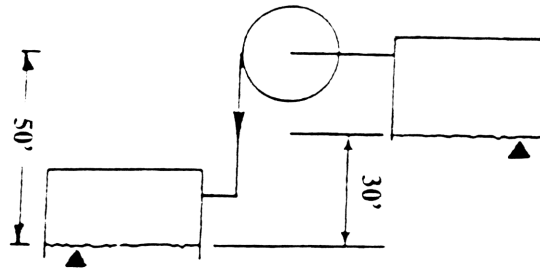
To solve this problem in SI system, refer to chiller's equation (30) **HP** (HVAC/CHILR/SI)

For **hA=7.5** m, **lps=1.6**, **viw=.001** m³/kg (vf(11 oC) SAT.T table), and **η=.85** (assumed)

hp = .19 hp, Answer.

HYDRAULIC MACHINES EXAMPLES

1. In the figure shown below, if the pipe's I.D. = 4", the equivalent length of the suction and discharge lines are 40 ft and 90 ft respectively, and the water flows at the rate of 300 gpm, determine:
- Velocity in discharge line;
 - Friction loss in suction line. Assume friction factor for both lines, $f=0.02$;
 - Friction loss in discharge line; and
 - Total dynamic head.



Solution: (REFERENCE: CHOTKEH MANUAL)

- a. To find the velocity in English system, for the flow quantity given in gpm, refer to equation (42) **GPM (HYDM/PIPE/VELO/ENG)**
For **gpm=300** and **D=4/12=.333 ft**.

$$v_d = 7.67 \text{ fps, Answer for (a).}$$

- b. To find the suction line friction loss in English system, for the flow quantity given in gpm, refer to Darcy equation (16) **GPM (HYDM/FRIC.H/DARCY/ENG)**
For **f=.02**, **Le=40 ft**, **gpm=300**, **g=32.2 ft/sec²**, and **D=4/12=.333 ft**.

$$h_{fs} = 2.2 \text{ ft, Answer for (b).}$$

- c. To find the discharge line's friction loss. Use the same equation and data, but **Le=90 ft**.

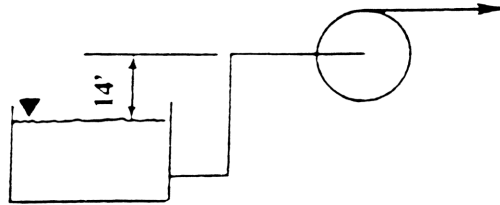
$$h_{fd} = 4.94 \text{ ft, Answer for (c).}$$

- d. To calculate the total dynamic head, refer to equation (33) **TOTAL (HYDM/HEAD/DYNA)**
For **h_{sd}=50 ft**, **h_{ss}=50-30=20 ft**, **v_d=7.67 fps**, **g=32.2 ft/sec²**, **h_{fs}=2.2 ft**, and **h_{fd}=4.94 ft**.

$$H = 38.05 \text{ ft, Answer for (d).}$$

HYDRAULIC MACHINES EXAMPLES

2. In the figure shown below, 100 oF water flows in a 4" inside diameter pipe at the rate of 300 gpm. If the equivalent length of the suction line is 50 ft, determine: The Net Positive Suction Head Available (NPSHA) at the pump. Consider standard atmospheric conditions and assume friction factor for the line, $f=0.02$.



Solution: (REFERENCE: CHOTKEH MANUAL)

To find the NPSHA in English system, refer to equation (57) **ENG** (HYDM/PUMP/NPSH)
It appears from the equation that the suction line's friction loss and water's vapor pressure must be calculated first.

Step 1 Find the suction's line friction loss in English system. For the flow quantity given in gpm, refer to Darcy equation (16) **GPM** (HYDM/FRIC.H/DARCY/ENG)

For $f=.02$, $Le=50$ ft, $gpm=300$, $g=32.2$ ft/sec², and $D=4/12=.333$ ft.

$$h_{fs} = 2.75 \text{ ft.}$$

Step 2 From the steam table, SAT.T in English system, water's vapor pressure at 100 oF,

$$P_{vp} = .95 \text{ psi.}$$

Step 3 Find the NPSHA. Call **NPSH** equation, (HYDM/PUMP/NPSH/ENG)

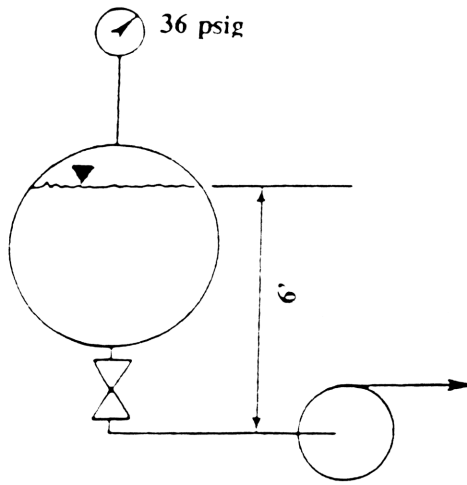
For $P=P_a=14.7$ psi, $P_{vp}=.95$ psi, $\rho=62.4$ pcf, $h_{ss}=-14$ ft, and $h_{fs}=2.75$ ft.

$NPSHA = 14.98 \text{ ft. Answer.}$

* * * * *

3. In the figure shown below, a fluid with the specific gravity of .58 and vapor pressure of 49 psi, at the operating temperature, must be pumped. If the suction line's friction head is estimated for 8 ft and the manufacturer's Net Positive Suction Head requirement is 6 ft, determine:
- If the design is acceptable.
 - If not, what changes in the design will improve the situation.

HYDRAULIC MACHINES EXAMPLES



Solution: (REFERENCE: CHOTKEH MANUAL)

- a. For an acceptable design, the available Net Positive Suction Head (NPSHA) must exceed the required Net Positive Suction Head (NPSHR).

To find the NPSHA in English system, refer to equation (57) **ENG** (HYDM/PUMP/NPSH)

For **P**= Tank's absolute pressure= $14.7 + 36 = 50.7$ psi, **P_{vp}**= **49** psi, **ρ** = $.58 \times 62.4 = 36.19$ pcf, **hss**=**6** ft, and **hfs**=**8** ft.

$$\text{NPSHA} = 4.76 \text{ ft. Answer.}$$

Since NPSHA (4.76 ft) < NPSHR (6 ft), therefore the design is not acceptable.

- b. Refer to the components of the equation. To improve the situation:
1. Raise the tank's elevation or lower the pump's elevation. Result: increasing **hss**.
 2. Increase size of the pipe. Result: decreasing **hfd**.
 3. Add a booster pump. Result: Increasing **P**.

* * * * *

4. For a pump operating under the following conditions:
- | | | |
|-------------------------|-------------------------|--------|
| Flow quantity: 700 gpm. | Head added by the pump: | 50 ft. |
| Fluid SG: .88 | Pump's efficiency: | 82% |
| | Motor's efficiency | 90% |

Determine:

- a. The pump's water horse power.
- b. The pump's brake horse power.
- c. The electric motor size.

HYDRAULIC MACHINES EXAMPLES

Solution: (REFERENCE: CHOTKEH MANUAL)

To solve this problem, use the pump's horsepower equation. Using different values for efficiency will provide answer for different type of horsepower.

- a. Find water horsepower in English system. For the flow given in **gpm**, refer to equation (53) **GPM** (HYDM/PUMP/HP/ENG)
For **hA=50 ft**, **gpm=700**, $\rho = .88 * 62.4 = 54.91$ pcf, and $\eta = 1$

$$\text{whp} = 7.79 \text{ hp, Answer for (a).}$$

- b. Find brake horsepower. Use the same equation and data, but $\eta = .82$

$$\text{bhp} = 9.49 \text{ hp, Answer for (b).}$$

- c. Find electric horsepower. Use the same equation and data, but $\eta = .82 * .9 = .738$

$$\text{ehp} = 10.55 \text{ hp, Answer for (c).}$$

NOTE: From Standard Motor Sizes table (bhp), select 10 hp motor.

* * * * *

5. A 25 bhp pump delivers 600 gpm at 120 ft head when running at 3500 rpm. If the speed is reduced to 3000 rpm, determine the estimated:
- Flow quantity;
 - Head, and;
 - Brake horsepower.

Solution: (REFERENCE: CHOTKEH MANUAL)

This is a pump affinity problem.

- a. To calculate the new flow quantity, as a result of change in **rpm**, refer to equation (01) **FLOW** (HYDM/AFFIN/RPM)
For **Q1=600 gpm**, **N1=3500 rpm**, and **N2=3000 rpm**.

$$Q2 = 514 \text{ gpm, Answer for (a).}$$

- b. To calculate the new head, refer to equation (02) **HEAD** (HYDM/AFFIN/RPM) MENU key.
For **H1=120 ft**, **N1=3500 rpm**, and **N2=3000 rpm**.

$$H2 = 88 \text{ ft, Answer for (b).}$$

HYDRAULIC MACHINES EXAMPLES

- c. To calculate the new brake horsepower, refer to equation (03) **BHP** (HYDM/AFFIN/RPM) MENU
For **bhp1**=25 hp, **N1**=3500 rpm, and **N2**=3000 rpm.

$$\text{bhp2} = 15.74 \text{ hp, Answer for (c).}$$

* * * * *

6. In a hydroelectric power plant, 60 cfs of water flows through a turbine. The discharge is 170 ft below the headwater level. If the efficiency of the turbine is 84%, determine:
The horsepower developed by the turbine. Assume lines total loss equals to 65 ft.

Solution: (REFERENCE: CHOTKEH MANUAL)

To solve this turbine problem in English system, with the flow given in **cfs**, refer to equation (66) **CFS** (HYDM/TURB/HP/ENG)

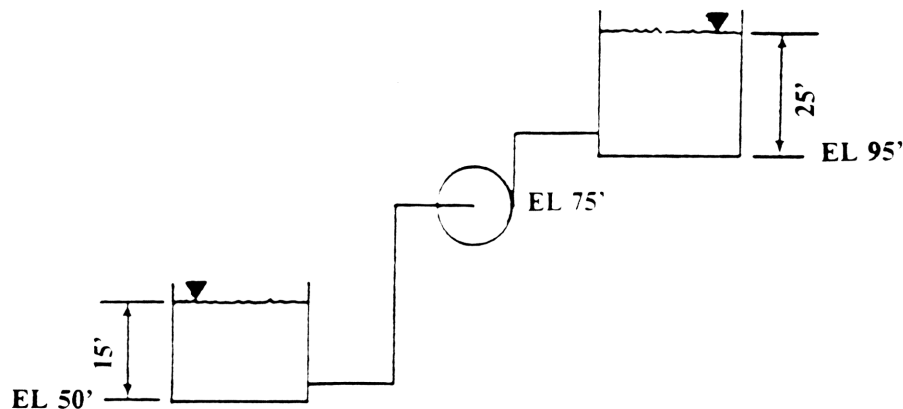
For **cfs**=60, **ρ** =62.4 pcf, **h**=170-65=105 ft, and **η** = .84

$$\text{hp} = 600 \text{ hp, Answer.}$$

* * * * *

Problems 7 - 10

A pump is delivering 130 gpm of 90 oF water as shown in the sketch below: The nominal size of schedule 40 steel pipe is 2.5" with the absolute roughness of .00016 ft. The equivalent length of the suction and discharge pipes are 95 ft and 560 ft respectively. If the pump's and electric motor's efficiencies are 70% and 90%, solve the following problems, 7 through 10.



HYDRAULIC MACHINES EXAMPLES

7. **Determine:**
a. Total static head.
b. Velocity of water in the pipe.

Solution: (REFERENCE: CHOTKEH MANUAL)

- a. From **H** (total static) = **hsd** - **hss**, for **hsd** = 95 - 75 + 25 = **45** ft and **hss** = 50 - 75 + 15 = **-10** ft.
H = 45 - (-10) = **55** ft.

H (total static) = 55 ft, Answer for (a).

- b. To find the velocity in English system, with the flow given in **gpm**, refer to velocity equation (42) **GPM** (HYDM/PIPE/VELO/ENG)
For **gpm** = **130** and **D** = **.2057** ft (This figure is extracted from the commercial steel pipe table, for schedule 40 pipe, and it represents the inside diameter of nominal 2.5" pipe.)

v = 8.71 fps, Answer for (b).

8. **Determine:**
The available Net Positive Suction Head (NPSHA).

Solution: (REFERENCE: CHOTKEH MANUAL)

To find the NPSHA in English system, refer to equation (57) **ENG** (HYDM/PUMP/NPSH)
It appears from the equation that the suction line's friction loss and water's vapor pressure must be calculated first.

To find the friction head, the friction factor of the pipe, for operation condition, must be calculated.
To do that, (1) identify the kinematic viscosity of 90 oF of water, (2) find the Reynolds number, and finally (3) by having the last two figures determine the friction factor.

Step 1 Find the friction factor:

1. From water tables, for **t** = 90 oF, **v** (kinetic viscosity) = .83EE-5 ft²/sec.
2. Find the Reynolds Number, refer to equation (63) **KINET** (HYDM/REYN)
For **D** = **.2057** ft, **v** = **8.71** fps, and **v** = .83EE-5 ft²/sec. **NRe** = 215861
3. Find the friction factor. For turbulent flow, refer to friction factor equation (14) **TURBU** (FLME/FRIC.F)
For **ε** = **.00016** ft (given), **D** = **.2057** ft, and **NRe** = **215861** **f** = .02

Step 2. Find the suction's line friction head. For English system and the flow quantity given in **gpm**, refer to Darcy equation (16) **GPM** (HYDM/FRIC.H/DARCY/ENG)
For **f** = **.02**, **Le** = **95** ft, **gpm** = **130**, **g** = **32.2** ft/sec², and **D** = **.2057** ft.
hfs = 10.9 ft.

HYDRAULIC MACHINES EXAMPLES

Step 3 Find the vapor pressure. From the steam tables, water's vapor pressure at 90 oF
 $P_{vp} = .7 \text{ psia}$.

Step 4 Now, by having **hfs** and **Pvp**, find NPSHA. For English system refer to equation (57) **ENG** (HYDM/PUMP/NPSH)

For **P=Pa=14.7 psi**, **Pvp=.7 psi**, **$\rho=62.11$ pcf** (density of 90 oF water), **hss=-10 ft** (problem 7 a), and **hfs=10.9 ft**.

$$\text{NPSHA} = 11.56 \text{ ft, Answer.}$$

9. **Determine:**
The total Dynamic Head.

For the calculation of total dynamic head, all components are known except, discharge line friction head. Since the characteristics of suction and discharge lines are identical, therefore:

hfd=hfs*Ld/Ls, key in '10.9*560/95 EVAL **hfd = 64.25 ft**

Refer to head equation (33) **TOTAL (HYDM/HEAD/DYNA)**

For **h_{sd}=45 ft**, **h_{ss}=-10 ft**, **vd=8.71 fps** (problem 32), **g=32.2 ft/sec²**, **hfs=10.9 ft**, and **hfd=64.25 ft**.

$$H = 131.3 \text{ ft, Answer for (b).}$$

10. **Determine:**
a. **The pump's water horse power.**
b. **The pump's brake horse power.**
c. **The pump's electric horse power.**
d. **The electric motor size.**

Solution: (REFERENCE: CHOTKEH MANUAL)

To solve this problem, use the pump's horsepower equation. Applying different values for efficiency, will provide answer for different type of horsepower.

- a. Find water horsepower. For English system and the flow given in **gpm**, refer to pump horsepower equation (53) **GPM (HYDM/PUMP/HP/ENG)**

For **hA=131.3 ft** (problem 9), **gpm=130**, **$\rho=62.11$ pcf**, and **$\eta=1$**

$$\text{whp} = 4.29 \text{ hp, Answer for (a).}$$

- b. Find brake horsepower. Use the same equation and data, but **$\eta=.7$**

$$\text{bhp} = 6.14 \text{ hp, Answer for (b).}$$

HYDRAULIC MACHINES EXAMPLES

- c. Find electric horsepower. Use the same equation and data, but $\eta = .7 * .9 = .63$

$$\text{ehp} = 6.8 \text{ hp, Answer for (c).}$$

- d. Select the motor. From Standard Motor Sizes table (bhp), select 7.5 hp motor.

* * * * *

11. Water is pumped through an 8" I.D. cast iron pipe at the rate of 4 cfs. If the equivalent length of the pipe is estimated for 1.5 mile and the storage tank's elevation is 140 ft above the water surface at the reservoir, determine:
The pump's motor horsepower. Assume pump's and motor's efficiency as 75% and 90%

Solution: (REFERENCE: CHOTKEH MANUAL)

Find the friction factor of the pipe. To do that: (1) identify the kinematic viscosity of water (assume 60 oF), (2) find the velocity of water in pipe, (3) find the Reynolds number, and finally (4) by having the last two figures determine the friction factor.

Step 1 Find the friction factor:

1. From water tables, for $t=60$ oF, ν (kinetic viscosity) = $1.22\text{EE-}5$ ft²/sec.
2. Find the velocity of the water in the pipe in English system. For the flow in cfs, refer to pipe equation (43) **CFS (HYDM/PIPE/VELO/ENG)**
For **cfs=4** and **D=8/12=.6667** ft $v = 11.46$ fps
3. Find the Reynolds Number, refer to equation (63) **KINET (HYDM/REYN)**
For **D=.6667** ft, **v=11.46** fps, and **$\nu=1.22\text{EE-}5$** ft²/sec. $\text{NRe} = 626261$
4. Find the friction factor. For turbulent flow, refer to friction factor equation (14) **TURBU (FLME/FRIC.F)**
For **$\epsilon = .0008$** (assumed), **D=.6667** ft, and **$\text{NRe}=626261$** $f = .021$

Step 2. Calculate the friction head. For English system and the flow quantity given in cfs, refer to Darcy equation (17) **cfs (HYDM/FRIC.H/DARCY/ENG)**
For **$f=.021$** , **Le=1.5 mile=7920** ft (unit conversion), **cfs=4**, **$g=32.2$** ft/sec², and **D=.6667** ft. $hf = 508.6$ ft.

Step 3 Find the horsepower. For English system and the flow given in cfs, refer to pump equation (54) **CFS (HYDM/PUMP/HP/ENG)**
For **$h_A=z+hf=140+508.6=648.6$** ft, **cfs=4**, **$\rho=62.37$** pcf (from water table for 60 oF. You may assume 62.4), and **$\eta = .75 * 90 = .675$**

$$\text{hp} = 436 \text{ hp, Answer.}$$

HYDRAULIC MACHINES EXAMPLES

Problems 12 - 13

50 oF glycerine, $\mu = .04$ lbf-sec/sf and $SG = 1.26$, must be pumped at the rate of 1200 gpm through 6" schedule 40 commercial steel pipe. The equivalent length of the piping is estimated for 2500 ft and the raise in the elevation is measured as 25 ft. Based on the above, solve the following two (2) problems:

12. The required horsepower for the pump.

Solution: (REFERENCE: CHOTKEH MANUAL)

To find the horsepower, determine the friction factor, friction head, then the horsepower.

Find the friction factor of the pipe. To do that: (1) find the velocity, (2) find the Reynolds number, and finally (3) determine the friction factor.

Step 1 Find the friction factor:

1. Find the velocity of the glycerine in the pipe in English system. For the flow in **gpm**, refer to pipe equation (42) **GPM** (HYDM/PIPE/VELO/ENG)
For **gpm=1200** and **D=.5054** ft (from commercial steel pipe data) $v = 13.3$ fps.
2. Find the Reynolds Number in English system. With the given absolute viscosity, refer to equation (62) **ENG** (HYDM/REYN/ABSO)
For **D=.5054** ft, **v=13.3** fps, $\rho = 1.26 \times 62.4 = 78.62$ pcf, $\mu = .04$ lbf-sec/sf, and $g = 32.2$ ft/sec². $NRe = 410$
3. Find the friction factor. Since $NRe < 2000$, refer laminar flow equation (13) **LAMI** (HYDM//FRIC.F)
For **NRe=410** $f = .156$

Step 2 Calculate the pipe's friction head/loss in English system. For the flow in **gpm**, refer to Darcy equation (16) **GPM** (HYDM/FRIC.H/DARCY/ENG)
For $f = .156$, **Le=2500**, ft, **gpm=1200**, $g = 32.2$ ft/sec², and **D=.5054** ft: $hf = 2128$ ft.

Step 3 Find the horsepower. For English system and the flow in **gpm**, refer to pump equation (53) **GPM** (HYDM/PUMP/HP/ENG)
For $h_A = z + hf = 25 + 2128 = 2153$ ft, **gpm=1200**, $\rho = 78.62$ pcf, and $\eta = .85$ (assumed).

$hp = 968$ hp. <u>Answer.</u>

13. Is it more economical, in term of energy, if glycerine is heated to 100 oF, before being pumped? Assume $\mu = .005$ lbf-sec/sf, $SG = 1.2$, and the specific heat of the glycerine equals to .576 btu/lbm-oF.

Solution: (REFERENCE: CHOTKEH MANUAL)

To find the total required power, determine the pump horsepower and add it to the heating power, then compare it with problem 12's answer.

HYDRAULIC MACHINES EXAMPLES

Follow the problem 12's steps, as required.

Step 1 Find the friction factor:

1. Find the Reynolds Number. For English system, refer to equation (62) **ENG** (HYDM/REYN/ABSO)

For $D = .5054$ ft, $v = 13.3$ fps, $\rho = 1.2 * 62.4 = 74.88$ pcf, $\mu = .005$ lbf-sec/sf, and $g = 32.2$ ft/sec².
 $NRe = 3126$

2. Find the friction factor. For turbulent flow, refer to friction factor equation (14) **TURBU** (FLME/FRIC.F)

For $\epsilon = .00015$ ft (from roughness chart for steel pipe), $D = .5054$ ft, and $NRe = 3126$
 $f = .0432$

Step 2 Calculate the pipe's friction head/loss in English system. For the flow in **gpm**, refer to Darcy equation (16) **GPM** (HYDM/FRIC.H/DARCY/ENG)

For $f = .0432$, $Le = 2500$ ft, $gpm = 1200$, $g = 32.2$ ft/sec², and $D = .5054$ ft:

$$hf = 589 \text{ ft}$$

Step 3 Find the horsepower. For English system and the flow given in **gpm**, refer to pump equation (53) **GPM** (HYDM/PUMP/HP/ENG)

For $hA = z + hf = 25 + 589 = 614$ ft, $gpm = 1200$, $\rho = 74.88$ pcf, and $\eta = .85$ (assumed).

$$hp \text{ (pump)} = 263$$

Step 4 Find the heating power requirement:

From $q = m * c * \Delta t$

For $m = 1200 \text{ gpm} * .002228 \text{ cfs/gpm} * 1.2 * 62.4$, key in '1200*.002228*1.2*62.4 **EVAL**:
 $m = 200.2$ lb/sec, $c = .576$ btu/lb-oF, and $\Delta t = 50$ oF. key in '200.2*.576*50 **EVAL**:
 $q = 5765$ btu/sec = 4,486,150 ft-lbf/sec (unit conversion), or $hp = 4486150/550$

$$hp \text{ (heating)} = 8157 \text{ hp}$$

Or $hp(13) = 263 + 8157 = 8420 > 957 \text{ hp (12)}$

Pumping 50 oF glycerin is more economical, Answer.

* * * * *

14. If in a 100 mm diameter pipe, water flows at the rate of 20 L/s, determine:
- a. The velocity of water in the pipe, assume equivalent length of the pipe as 30 m.
 - b. The friction loss in the pipe. Assume friction factor equals to 0.02

Solution: (REFERENCE: CHOTKEH MANUAL)

- a. To find the velocity in SI system, for the flow quantity given in **lps**, refer to equation (44) **LPS** (HYDM/PIPE/VELO/SI)

For $lps = 20$ and $D = 0.1$ m.

$$v = 2.55 \text{ mps, Answer for (a).}$$

HYDRAULIC MACHINES EXAMPLES

- b. To find the friction loss in SI system, for the flow quantity given in **lps**, refer to Darcy equation (18) **LPS (HYDM/FRIC.H/DARCY/SI)**
For $f = .02$, $L_e = 30$ m, $lps = 20$, $g = 9.81$ m/sec², and $D = 0.1$

$$h_f = 1.98 \text{ m, Answer for (b).}$$

* * * * *

15. For a pump operating under the following conditions:
- | | | |
|------------------------|-------------------------------|--|
| Flow quantity: 45 lps. | Head added by the pump: 15 m. | |
| Fluid SG: .88 | Pump's efficiency: 82% | |
| | Motor's efficiency: 90% | |
- Determine:
- The pump's water horse power.
 - The pump's brake horse power.
 - The electric motor size.

Solution: (REFERENCE: CHOTKEH MANUAL)

To solve this problem, use the pump's horsepower equation. Using different values for efficiency, will provide answer for different type of horsepower.

- a. Find water horsepower in SI system. For the flow given in **lps**, refer to equation (55) **LPS (HYDM/PUMP/HP/SI)**
For $h_A = 15$ m, $lps = 45$, $\rho = .88 * 1000 = 880$ kg/m³, and $\eta = 1$

$$whp = 7.8 \text{ hp, Answer for (a).}$$

- b. Find brake horsepower. Use the same equation and data, but $\eta = .82$

$$bhp = 9.5 \text{ hp, Answer for (b).}$$

- c. Find electric horsepower. Use the same equation and data, but $\eta = .82 * .9 = .738$

$$ehp = 10.6 \text{ hp, Answer for (c).}$$

* * * * *

16. A 25 bhp pump delivers 40 L/s at 40 m head when running at 3500 rpm. If the impeller's diameter is reduced from 200 mm to 150 mm, determine the estimated:
- Flow quantity;
 - Head, and;
 - Brake horsepower.

HYDRAULIC MACHINES EXAMPLES

Solution: (REFERENCE: CHOTKEH MANUAL)

This is a pump affinity problem.

- a. To calculate the new flow quantity, as a result of change in **D**, refer to equation (04) **FLOW** (HYDM/AFFIN/DIAM)
For **Q1=40** lps, **D1=200** mm, and **D2=150** rpm.

$Q2 = 30 \text{ lps, Answer for (a).}$
--

- b. To calculate the new head, refer to equation (05) **HEAD** (HYDM/AFFIN/DIAM) MENU key.
For **H1=40** m, **D1=200** mm, and **D2=150** mm.

$H2 = 22.5 \text{ m, Answer for (b).}$
--

- c. To calculate the new brake horsepower, refer to equation (06) **BHP** (HYDM/AFFIN/DIAM) MENU
For **bhp1=25** ft, **D1=200** mm, and **D2=150** mm.

$bhp2 = 10.55 \text{ hp, Answer for (c).}$
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17. In a hydroelectric power plant, 1700 L/s of water flows through a turbine. The discharge is 52 m below the headwater level. If the efficiency of the turbine is 84%, determine:
The horsepower developed by the turbine. Assume lines total loss equals to 20 m head.

Solution: (REFERENCE: CHOTKEH MANUAL)

To solve this turbine problem in SI system, with the flow given in lps, refer to equation (66) **LPS** (HYDM/TURB/HP/SI)

For $h=52-20=32$ m, $lps=1700$, $\rho=1000$ kg/m³, and $\eta = .84$

$hp = 600 \text{ hp, Answer.}$

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Problems 18 - 19

10 oC glycerine, $\mu=1.9152$ N.s/m² and SG=1.26, must be pumped at the rate of 75 L/s through 15 cm inside diameter pipe. The equivalent length of the piping is estimated for 750 m and the rise in the elevation is measured as 10 m. Based on the above, solve the following two (2) problems:

18. The required horsepower for the pump.

Solution: (REFERENCE: CHOTKEH MANUAL)

To find the horsepower, determine the friction factor, friction head, then the horsepower.

HYDRAULIC MACHINES EXAMPLES

Find the friction factor in the pipe. To do that: (1) find the velocity, (2) find the Reynolds number, and finally (3) determine the friction factor.

Step 1 Find the friction factor:

1. Find the velocity of glycerine in the pipe in SI system. For the flow in **lps**, refer to pipe equation (44) **LPS (HYDM/PIPE/VELO/SI)**
For **lps=75** and **D=.15 m** $v = 4.2 \text{ mps.}$
2. Find the Reynolds Number. For SI system and with the given absolute viscosity, refer to equation (63) **SI (HYDM/REYN/ABSO)**
For **D=.15 m**, **v=4.2 m/s**, **$\rho = 1.26 \times 1000 = 1260 \text{ kg/m}^3$** , **$\mu = 1.9152 \text{ N.s/m}^2$**
 $NRe = 414$
3. Find the friction factor. Since $NRe < 2000$, refer laminar flow equation (13) **LAMI (HYDM//FRIC.F)**
For **$NRe=414$** $f = .155$

Step 2 Calculate the pipe's friction head/loss in SI system. For the flow in **lps**, refer to Darcy equation (18) **LPS (HYDM/FRIC.H/DARCY/SI)**
For **$f=.155$** , **$Le=750 \text{ m}$** , **$lps=75$** , **$g=9.81 \text{ m/s}^2$** , and **$D=.15 \text{ m}$** $hf = 712 \text{ ft.}$

Step 3 Find the horsepower. For SI system and the flow in **lps**, refer to pump equation (55) **LPS (HYDM/PUMP/HP/SI)**
For **$hA = z + hf = 10 + 712 = 722 \text{ m}$** , **$lps=75$** , **$\rho = 1260 \text{ kg/m}^3$** , and **$\eta = .85$** (assumed).

$$hp = 1054 \text{ hp. Answer.}$$

19. Is it more economical, in term of energy, if glycerine is heated to 40 oC, before being pumped? Assume $\mu = .22 \text{ N.s/m}^2$, $SG=1.2$, and the specific heat of the glycerine equals to 2412 J/kg.oC

Solution: (REFERENCE: CHOTKEH MANUAL)

To find the total required power, determine the pump horsepower and add it to the heating power, then compare it with problem 18's answer.

Follow the problem 18's steps, as required.

Step 1 Find the friction factor:

1. Find the Reynolds Number. For SI system and with the given absolute viscosity, refer to equation (63) **SI (HYDM/REYN/ABSO)**
For **D=.15 m**, **v=4.2 m/s**, **$\rho = 1.2 \times 1000 = 1200 \text{ kg/m}^3$** , **$\mu = .22 \text{ N.s/m}^2$**
 $NRe = 3436$

HYDRAULIC MACHINES EXAMPLES

2. Find the friction factor. For turbulent flow, refer to friction factor equation (14) **TURBU** (FLME/FRIC.F)

For $\epsilon = .000046$ m (from roughness chart for steel pipe), $D = .15$ m, and
 $NRe = 3436$ $f = .042$

- Step 2 Calculate the pipe's friction head/loss in SI system. For the flow in **lps**, refer to Darcy equation (18) **LPS** (HYDM/FRIC.H/DARCY/SI)

For $f = .042$, $Le = 750$ m, $lps = 75$, $g = 9.81$ m/s², and $D = .15$ m $hf = 193$ m

- Step 3 Find the horsepower. For SI system and the flow given in **lps**, refer to pump equation (55) **LPS** (HYDM/PUMP/HP/SI)

For $hA = z + hf = 10 + 193 = 203$ m, $lps = 75$, $\rho = 1200$ kg/m³, and $\eta = .85$ (assumed)
 $hp \text{ (pump)} = 282$

- Step 4 Find the heating power requirement: From $q = m * c * \Delta t$

For $m = 75 \text{ lps} * 1 = 75$ kg/s, $c = 2412$ J/kg.oC, and $\Delta t = 30$ oC. key in '75*2412*30
EVAL $q = 5427000$ W (J/s) = 5427000/745.7 $hp \text{ (heating)} = 7278$ hp

Or $hp(19) = 282 + 7278 = 7560 > 1054$ hp (18)

No. Pumping 10 oC glycerin is more economical, <u>Answer.</u>

POWER CYCLE EXAMPLES

1. Determine the entropy of 123 psia steam if its quality is equal to 0.91.

Solution:

To find the entropy of steam, the entropy of saturated liquid (sf) and saturated steam (sg) must be calculated first.

Step 1 Find sf:

At LIBRARY press $\leftarrow$ PREV SAT.P ENTR ENG SF NXT **115 <PSI< 250**

For **P=123** psia sf = .495 BTU/lbm-oR.

Step 2 Find sg:

At LIBRARY press $\leftarrow$ PREV SAT.P ENTR ENG SG NXT **115 <PSI< 250**

For **P=123** psia sg = 1.5874 BTU/lbm-oR.

Step 3 Find the quality, x:

At LIBRARY press $\leftarrow$ PREV SAT.P ENTR ENG S

For **x=.91** and the stored calculated values for sf and sg (you may check by pressing $\rightarrow$ and the associated soft key for hf and hg.)

$s = 1.4891 \text{ BTU/lbm-oR, Answer}$

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2. Determine the quality of 293 oF steam if its enthalpy equals to 1052 BTU/lbm.

Solution:

To find the quality of steam, the enthalpy of saturated liquid (hf) and saturated steam (hg) must be calculated first.

Step 1 Find hf:

At LIBRARY press $\leftarrow$ PREV SAT.T ENTH ENG HF **212°F <T≤ 300°F**

For **T=293** oF hf = 262.1 BTU/lbm.

Step 2 Find hg:

At LIBRARY press $\leftarrow$ PREV SAT.T ENTH ENG HG **212°F <T≤ 300°F**

For **T=293** oF hg = 1177.6 BTU/lbm.

Step 3 Find the quality, x:

At LIBRARY press $\leftarrow$ PREV SAT.T ENTH ENG X

For **h=1052 BTU/lbm** and the stored calculated values for hf and hg (you may check by pressing $\rightarrow$ and the associated soft key for hf and hg.)

$x = .8627, \text{ Answer}$

POWER CYCLE EXAMPLES

3. Determine (a) the enthalpy and (b) the specific volume of 950 oF super-heated steam at 103 psig pressure. Assume atmospheric pressure equals to 14.6 psia.

Solution:

Reminder: Pressure in tables is the absolute pressure. Therefore, $P = 14.6 + 103 = 117.6$ psia.

- a. At LIBRARY press ↩ PREV SUPHT ENTH ENG NXT 67<PSI<135 750F<T<1200F
For T=950 oF and P=117.6 psia

$$h = 1506.3 \text{ BTU/lbm, Answer for (a)}$$

- b. At LIBRARY press ↩ PREV SUPHT SPC.V ENG NXT 67<PSI<135 750F<T<1200F
For T=950 oF and P=117.6 psia

$$v = 7.096 \text{ cf/lbm, Answer for (b)}$$

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4. Determine (a) the enthalpy and (b) the entropy of air at 387 oF.

Solution:

Reminder: Temperature in Air Table is in Rankin (oR) scale. Therefore, $T = 460 + 387 = 847$ oR

- a. At LIBRARY press ↩ PREV AIR ENG ENTH 550R<T<850R
For T=847 oR

$$h = 203.2 \text{ BTU/lbm, Answer for (a)}$$

- b. At LIBRARY press ↩ PREV AIR ENG ENTR 550R<T<850R
For T=847 oR

$$\phi = .70924 \text{ BTU/lbm-oR, Answer for (b)}$$

* * * * *

5. Determine the temperature of air (in oF) if its Pressure Ratio (Pr) equals to 26.

SOLUTION:

At LIBRARY press ↩ PREV AIR ENG PR. Since the temperature is not known, select the middle range, i.e. NXT 850R<T<1150R

For Pr=26

$$T = 1228.87 \text{ oR}$$

Since the calculated temperature (1228.87 oR) is out of the selected range (850R - 1150R), press prev. MENU key and select the proper range (1150 - 1450)

For Pr=26

$$T = 1225.79 \text{ oR} = 765.79 \text{ oF, Answer}$$

POWER CYCLE EXAMPLES

6. Determine the thermal efficiency of a jet engine compressor with the intake at -15 oF and 7 psia and the exhaust at 330 oF and 39 psia. Assume $k=1.4$.

Solution:

To find the efficiency of the compressor, take the following steps:

Step 1 Determine the enthalpy of air at the intake (**h1C**):

Refer to CHOTKEH's AIR table. For $T = -15 + 460 = 445$ oR

$$\underline{h1C = 106.3 \text{ BTU/lbm}}$$

Step 2 Determine the actual enthalpy of air at the exhaust (**h2C**):

From the same AIR table. For $T = 330 + 460 = 790$ oR

$$\underline{h2C = 189.4 \text{ BTU/lbm}}$$

Step 3 Determine the ideal enthalpy of air at the exhaust (**h2CI**):

Considering air as an ideal gas, for isentropic process, refer to gas equation (41)

$$\delta P / \delta T \quad (\text{PCYCL/GAS/ISENT})$$

For $p2=39$ psia, $p1=7$ psia, $T1=445$ oR, and $k=1.4$ $\underline{T2 = 726.9 \text{ oR}}$

Refer to CHOTKEH's AIR table. For $T=726.9$ oR

$$\underline{h2CI = 174.1 \text{ BTU/lbm}}$$

Step 4 Calculate the compressor's efficiency (η_c):

Refer to thermal efficiency of compressor equation (23) **THRM** (PCYCL/EFFI/COMP)

For $h2CI=174.1$ BTU/lbm, $h1C=106.3$ BTU/lbm, and $h2C=189.4$ BTU/lbm

$$\eta_c = .816 = 81.6\%, \text{ Answer}$$

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7. Determine the COP (Coefficient Of Performance) of an ideal heat pump, using R-12 as a refrigerant and operating between 29 psia and 167.5 psia.

Solution:

Step 1 Determine the low temperature (tl):

From R-12 table: for $P=20$ psia, $t=-8.2$ oF

 and $P=30$ psia, $t=11.1$ oF

By interpolation equation (59) **INTRP** (PCYCL)

POWER CYCLE EXAMPLES

For $A1 = -8.2$ oF, $A2 = 11.1$ oF, $B1 = 20$ psia, $B2 = 30$ psia, and $Bm = 29$ psia.

$$tL = Am = 9.2 \text{ oF}$$

Step 2 Determine the high temperature (th):

Use the same table, but $P = 167.5$ psia. (between 160 psia 180 psia)

$$tH = 118 \text{ oF}$$

Step 3 Calculate the COP:

With the temperatures are given, refer to refrigeration COP equation (84) **TEMP** (PCYCL/REFRI/ENG/COP).

For $TL = 9.2 + 460 = 469.2$ oR and $TH = 118 + 460 = 578$ oR

$$\text{COP} = 4.31 \text{ Answer}$$

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8. For a refrigeration cycle with an input power of 1.5 kw and cooling capacity of one (1) ton refrigeration, determine:
- The COP of the system.
 - The EER (Energy Efficiency Ratio) of the system.

Solution:

- a. With the given refrigeration tonnage, refer to equation (85) **TONR** (PCYCL/REFRI/ENG/COP).
For $\text{tonR} = 1$ ton and $\text{hp} = 1.5 * 1.341 = 2.01$ hp (unit conversion)

$$\text{COP} = 2.35 \text{ Answer for (a)}$$

- b. With the kw is given, refer to equation (88) **WATT** (PCYCL/REFRI/ENG/EER).
For $\text{tonR} = 1$ ton and $\text{watt} = 1.5 * 1000 = 1500$ watts

$$\text{EER} = 8 \text{ Answer for (b)}$$

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9. Determine the efficiency of a steam power plant, generating 425 MW electric power with the condensate load equals to 2.2EE9 BTU/hr. Neglect the power for auxiliary equipment.

POWER CYCLE EXAMPLES

Solution:

To find the system's efficiency, in English system, with the given output heat, refer to efficiency of system equation (35) **QOUT** (PCYCL/EFFI/SYST/ENG)

For **kW=425,000**, **kWin=0**, and **qout=2.2EE9 BTU/hr**

$$\eta_{SYS} = .397 = 39.7\% \text{ Answer}$$

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10. Determine the thermal efficiency of a gas turbine with the inlet at 166 psia and 1450 oF and the gas outlet at 21 psia and 1015 oF.

Solution:

To find the efficiency:

Step 1 Determine the enthalpy of air at the intake (h1G):

Refer to CHOTKEH's AIR table. For **T=1450+460=1910 oR**

$$h1G = 479.9 \text{ BTU/lbm}$$

Step 2 Determine the actual enthalpy of air at the exhaust (h2G):

Refer to CHOTKEH's AIR table. For **T=1015+460=1475 oR**

$$h2G = 362.5 \text{ BTU/lbm}$$

Step 3 Determine the ideal enthalpy of air at exhaust (h2CI):

Use the **Reduced Pressure** part of the CHOTKEH's AIR table.

For the isentropic process:

At intake: for **T=T1=1910 oR** **Pr1=144.6**

From **Pr2=Pr1*(P2/P1)** **Pr2=18.3**

From AIR table, for **Pr2=18.3** **T2=1115.4 oR**

Finally for **T=T2=1115.4 oR**

$$h2GI = 269.9 \text{ BTU/lbm}$$

Step 4 Calculate the gas turbine's efficiency (η_g):

Refer to efficiency of gas turbine equation (25) **G.TURB** (PCYCL/EFFI)

For **h1G=479.9 BTU/lbm**, **h2G=362.5 BTU/lbm**, and **h2GI=270.1 BTU/lbm**

$$\eta_g = .56 = 56\% \text{ Answer}$$

POWER CYCLE EXAMPLES

11. Determine the thermal efficiency of a steam turbine with the following characteristics:

Inlet:

Pressure: 850 psia

Temperature: 790 oF

Outlet:

Pressure: 180 psia

Actual enthalpy: 1260 BTU/lbm

Solution:

By knowing the actual outlet enthalpy, to find the efficiency, determine the inlet and ideal outlet enthalpies first, then calculate the efficiency.:

Step 1 Find the inlet enthalpy (h_{1S}):

Refer to CHOTKEH's SUPHT table. For $t=790$ oF and $P=850$ psia.

$$h_{1S} = 1391.8 \text{ BTU/lbm}$$

Step 2 Find the outlet ideal enthalpy (h_{2SI}), where $s_1=s_2$:

1. Find the entropy at the inlet (s_{1S}):

From CHOTKEH's SUPHT table. For $t=790$ oF and $P=850$ psia

$$s_{1S} = 1.58595 \text{ BTU/lbm-oF}$$

2. Determine the outlet temperature (t_{2SI}):

For isentropic process ($ds=0$) for outlet pressure $P=180$ psia and

$$s = 1.58595 \text{ BTU/lbm-oR}$$

$$t_{2SI} = 418.4 \text{ oF}$$

3. Assuming the super heated steam, from CHOTKEH's SUPHT table. For $t=418.4$ oF and $P=180$ psia

$$h_{2SI} = 1226 \text{ BTU/lbm.}$$

Step 3 Find the efficiency:

Refer to efficiency of steam turbine equation (34) $S.TURB$ (PCYCL/EFFI)

For $h_{1S}=1391.8$ BTU/lbm, $h_{2S}=1260$ BTU/hr (given), and $h_{2SI}=1226$ BTU/lbm.

$$\eta_s = .795 = 79.5\%, \text{ Answer}$$

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12. A gas turbine is operating at 27,000 feet altitude, where the atmospheric pressure equals to 5 psia. If the temperature and pressure of the gas entering the turbine are 280 oF and 52 psig, determine:
- The air temperature at the turbine's exit. Assume isentropic expansion and $k=1.4$
 - The turbine's efficiency. Assume exit temperature equals to -45 oF.
 - The turbine's brake horsepower at condition "b". Assume air mass flow and the mechanical efficiency are 68 lbm/sec and 97% respectively.

POWER CYCLE EXAMPLES

Solution:

- a. For an isentropic expansion in a gas turbine, refer to gas equation (41) $\delta P / \delta T$ (PCYCL/GAS/ISENT)

For $P_2 = 5$ psia, $P_1 = 52 + 5 = 57$ psia, $T_1 = 280 + 460 = 740$ oR, and $k = 1.4$

$T_{2GI} = 369.2 \text{ oR} = -90.8 \text{ oF, Answer for (a)}$

- b. To calculate the turbine's efficiency, find the enthalpies first.

Step 1 Find the inlet enthalpy (h_{1G}):

From CHOTKEH's AIR table, for $T = 280 + 460 = 740$ oR $h_{1G} = 177.3 \text{ BTU/lbm}$

Step 2 Find the ideal enthalpy at the exit (h_{2GI}):

From CHOTKEH's AIR table, for $T = -90.8 + 460 = 369.2$ oR $h_{2GI} = 88.2 \text{ BTU/lbm}$

Step 3 Find the actual enthalpy at the exit (h_{2G}):

From AIR table, for $T = -45(\text{given}) + 460 = 415$ oR $h_{2G} = 99.1 \text{ BTU/lbm}$

Now, by knowing the inlet/outlet enthalpies, solve the problem.

Find the turbine's efficiency:

Refer to efficiency, of gas turbine, equation (25) $G.TURB$ (PCYCL/EFFI)

From $h_{1G} = 177.3 \text{ BTU/lbm}$, $h_{2G} = 99.1 \text{ BTU/lbm}$, and $h_{2GI} = 88.2 \text{ BTU/lbm}$

$\eta_G = .878 = 87.8\%, \text{ Answer for (b)}$

- c. Calculate the brake horsepower:

With the flow in **lbps** in English system, refer to turbine power equation (49) **LBPS** (PCYCL/G.TURB/POWR/ENG/HP)

For $\dot{M}_G = 68 \text{ lbm/sec}$, $h_{1G} = 177.3 \text{ BTU/lbm}$, and $h_{2G} = 99.1 \text{ BTU/lbm}$ $\dot{h}_{pG} = 7522 \text{ hp}$

Considering 97% mechanical efficiency, key in .97 press x

$\dot{b}_{hpG} = 7,296 \text{ hp, Answer for (c)}$

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Problems 13 - 16

A process gas at 825 psig and 260 oF with the flow rate of 12 cfm expands in a gas turbine. The pressure of the gas at the turbine's exhaust is 95 psig:

Based on the above information solve the following problems.

POWER CYCLE EXAMPLES

13. Determine, the temperature of the gas at the turbine's exit. Assume efficiency = 79% and $k = 1.4$.

Solution:

To calculate the exit temperature, find the enthalpies first.

Step 1 Find the ideal temperature at the exit:

For an isentropic process, refer to gas equation (41) $\delta P / \delta T$ (PCYCL/GAS/ISENT)

For $P_2 = 95 + 14.7 = 109.7$ psia, $P_1 = 825 + 14.7 = 839.7$ psia, $T_1 = 260 + 460 = 720$ oR, and $k = 1.4$

$$\underline{T_{2GI} = 402.5 \text{ oR}}$$

Step 2 Find the ideal enthalpy at the exit (h_{2GI}):

From CHOTKEH's AIR table, for $T = 402.5$ oR

$$\underline{h_{2GI} = 96.1 \text{ BTU/lbm}}$$

Step 3 Find the inlet enthalpy (h_{1G}):

From CHOTKEH's AIR table, for $T = 720$ oR

$$\underline{h_{1G} = 172.5 \text{ BTU/lbm}}$$

Step 4 Find the actual enthalpy at the exit (h_{2G}):

Refer to gas turbine enthalpy equation (48) ENTH (PCYCL/G.TURB)

For $h_{1G} = 172.5$ BTU/lbm, $h_{2GI} = 96.1$ BTU/lbm, and $\eta_g = .79$

$$\underline{h_{2G} = 112.1 \text{ BTU/lbm}}$$

Step 5 Find the actual temperate at the exit (T_{2G}):

From CHOTKEH's AIR table, for $h = 112.1$ BTU/lbm

$$T_{2G} = 469.2 \text{ oR} = 9.2 \text{ oF, Answer}$$

14. Determine the amount of heat must be added to exhaust gas to raise its temperature to 55 oF.

To find the additional heat, find the mass of the flow first.

For air as an ideal gas, refer to gas equation (39) IDEAL (PCYCL/GAS)

For $P =$ key in $'(825 + 14.7) * 144 \text{ EVAL} = 120917$ psfa, $V = 12 * 60 = 720$ cfh, $R = 53.3$ ft-lbf/lbm-oR, and $T = 260 + 460 = 720$ oR

$$\underline{m = 2,269 \text{ lbm/hr}}$$

Calculate the added heat:

From $q = m * c_p * (t_2 - t_1)$

Key in $'2269 * .24 * (55 - 9.1) \text{ EVAL}$

$$q = 24,995 \text{ BTU/hr, Answer}$$

POWER CYCLE EXAMPLES

15. Determine the pressure of the gas at the intake, in order to get 55 oF temperature at the exit

To calculate the intake pressure, reverse problem 13.

Step 1 Find the actual enthalpy at the exit (h_{2G}):

From CHOTKEH's AIR table, for **T_{2G} = 55** (given) + **460 = 515** oR

$$\underline{h_{2G} = 123.1 \text{ BTU/lbm}}$$

Step 2 Find the ideal temperature at the exit (h_{2GI}):

1. Refer to enthalpy equation (48) **ENTH** (PCYCL/G.TURB)

For **h_{2G} = 123.1** BTU/lbm, **h_{1G} = 172.5** BTU/lbm, and **η_σ = .79**

$$\underline{h_{2GI} = 109.97 \text{ BTU/lbm}}$$

2. Refer to CHOTKEH's AIR table. For **h = 109.97** BTU/lbm **T_{2GI} = 460** oR

Step 3 Find the intake pressure (P_{1G}):

1. Find Pr_{1G} and Pr_{2G} (The relevant pressure at the intake and the exit): From AIR table:

For **T = T_{1G} = 720** oR

$$\underline{Pr_{1G} = 3.81}$$

For **T = T_{2GI} = 460** oR

$$\underline{Pr_{2G} = .7915}$$

2. Refer to relevant pressure equation (57) **PR** (PCYCL/G.TURB)

For **Pr_{2G} = .7915**, **P_{2G} = 109.7** psia, and **Pr_{1G} = 3.81**

$$\underline{P_{1G} = 528.1 \text{ psia}}$$

$$P_{1G} = 513.4 \text{ psig, Answer}$$

16. Determine the turbine's output, in hp, for both conditions in problems 14 and 15.

For the flow given in **lbps** in English system, refer to power equation (49) **LBPS**
(PCYCL/G.TURB/POWR/ENG/HP)

For situation "14":

For **MG = 2269/3600 = .63** lbm/sec, **h_{1G} = 172.5** BTU/lbm, and **h_{2G} = 112.1** BTU/lbm

$$hp_G(14) = 53.8 \text{ hp, Answer}$$

For situation "15":

For the same data, but **h_{2G} = 123.1** BTU/lbm

$$hp_G(15) = 44 \text{ hp, Answer}$$

POWER CYCLE EXAMPLES

17. A power plant is producing 600 psia at 650 oF steam which runs a turbine and a 5500 kw generator. If the thermal efficiency of the turbine and the outlet pressure are 79% and 2.5 INHG respectively, determine:
- The turbine's steam rate.
 - The turbine's heat rate, assume turbine auxiliaries require 4200 lbm/hr steam and the feed water gets back to the boiler at 175 oF.
 - The plant's heat rate. Assume 82% efficiency for the boiler and 115 kw power requirement to drive the boiler's auxiliary.
 - The plant's overall efficiency.

Solution:

To solve this problem the enthalpy at the inlet and the actual enthalpy at the outlet of the turbine must be determined first.

These may be determined by either steam tables or Mollier's diagram, the latter with less accuracy.

Let us try both.

FIRST: STEAM TABLES:

Step 1 Find the inlet enthalpy (h1S):

From CHOTKEH's SUPHT table, for $P=600$ psia, and $t=650$ oF

$$h1S = 1321.2 \text{ BTU/lbm}$$

Step 2 Find the ideal enthalpy at the exit (h2SI):

1. Determine the entropy at the inlet (s1S):

From CHOTKEH SUPHT table, for $P=600$ psia and $t=650$ oF

$$s1S = 1.56068 \text{ BTU/lbm-oR}$$

For an isentropic process this is the ideal entropy at the exit.

2. Determine the state of the steam at the exit:

Find the entropy of saturated steam (sg2S) at the exit

From CHOTKEH SAT.P table, for $P=2.5$ INHG = 1.23 psia (unit conversion)

$$sg2S = 1.96 \text{ BTU/lbm-oR}$$

Since $sg2S > s1S$, therefore the steam is sub-liquid.

NOTE: If $sg2S = s1S$, the steam is saturated or if $sg2S < s1S$, the steam is super heated.

3. Determine the quality of steam:

From CHOTKEH SAT.P table, for $P=1.23$ psia: $s=1.56068$ BTU/lbm-oR (step 2),

$sf=.14479$ BTU/lbm-oR (calculate, SAT.P table), and $sg=1.96$ BTU/lbm-oR (step 2.2)

$$X = .78$$

POWER CYCLE EXAMPLES

4. Calculate the ideal enthalpy (h_{2SI}):

From CHOTKEH SAT.P table, for $P=1.23$ psia: $h_f=76.48$ BTU/lbm (Calculate, SAT.P)
 $h_g=1108.45$ BTU/lbm (calculate SAT.P), and for $X=.78$ (Step 2.3)

$$h_{2SI} = 881.42 \text{ BTU/lbm}$$

Step 3 Find the actual enthalpy at the exit (h_{2S}):

To find the enthalpy at the exit, refer to equation (93) **EXIT** (PCYCL/S.TURB/ENTH)

For $h_{1S}=1321.2$ BTU/lbm, $h_{2SI}=881.42$, and $\eta_s=.79$ $h_{2S} = 973.77$ BTU/lbm

SECOND: MOLLIER DIAGRAM:

Step 1 Find the inlet enthalpy (h_{1S}):

Mark $P=600$ psia and $T=650$ oF on the chart. Read the enthalpy

$$h_{1S} = 1322 \text{ BTU/lbm}$$

Step 2 Find the ideal enthalpy at the exit (h_{2SI}):

From the marked point draw a vertical line to intersect the constant pressure line at $P=1.23$ psia. Read the enthalpy

$$h_{2SI} = 880 \text{ BTU/lbm}$$

Step 3 Find the actual enthalpy at the exit (h_{2S}):

Repeat the step 3 above. Refer to equation (93) **EXIT** (PCYCL/S.TURB/ENTH)

For $h_{1S}=1322$ BTU/lbm, $h_{2SI}=880$ BTU/lbm, and $\eta_s=.79$ $h_{2S} = 972.82$ BTU/lbm

Now, by knowing the inlet/outlet enthalpies, solve the problem.

a. Find the turbine's Steam Rate:

For English system, refer to turbine's steam rate equation (113) **STIM** (PCYCL/S.TURB/RATE/ENG)

From $h_{1S}=1321.2$ BTU/lbm and $h_{2S}=973.77$ BTU/lbm

$$\text{RATE} = 9.83 \text{ lbm/kw-hr, Answer for (a)}$$

b. Find the turbine's Heat Rate:

For English system, refer to turbine's heat rate equation (111) **TURB**

(PCYCL/S.TURB/RATE/ENG/HEAT)

From $q_{in} = \text{mass of steam} * (h_{2B} - h_{1B} \text{ (hf at 175 oF)})$, key in:

$^* (5500 * 9.83 + 4200) * (1321.2 - 143)$ **EVAL** = 68,647,823 BTU/hr, and $\text{kw}=5500$

$$\text{RATE (turbine)} = 12,481. \text{ BTU/kw-hr, Answer for (b)}$$

POWER CYCLE EXAMPLES

- c. Determine the plant's Heat Rate:

For English system, refer to equation (112) **PLNT** (PCYCL/S.TURB/RATE/ENG/HEAT).

For $q_{in}=68,647,823$ BTU/hr, $kW=5,500$, $kW_{in}=115$, and $\eta_B=.82$

$\text{RATE (plant)} = 15,546. \text{ BTU/kw-hr, Answer for (c)}$

- d. Determine the system's efficiency:

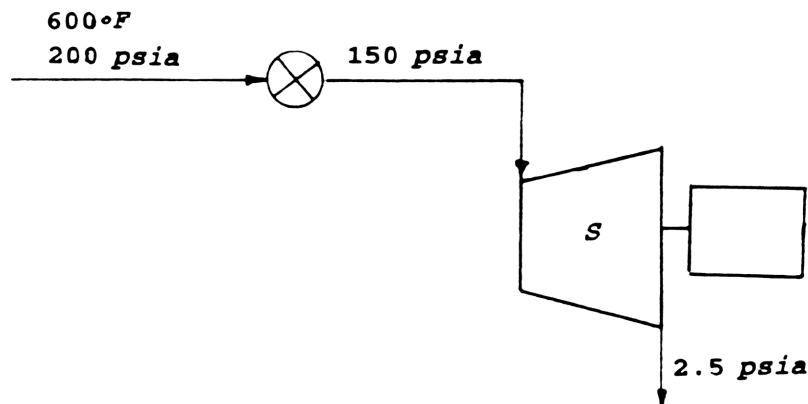
For English system, with the q_{in} known, refer to system efficiency equation (36) **QIN** (PCYCL/EFFI/SYST/ENG)

For $kW=5500$, $kW_{in}=115$, and $q_{in}=68,647,823/.82=83,716,857$ BTU/hr.

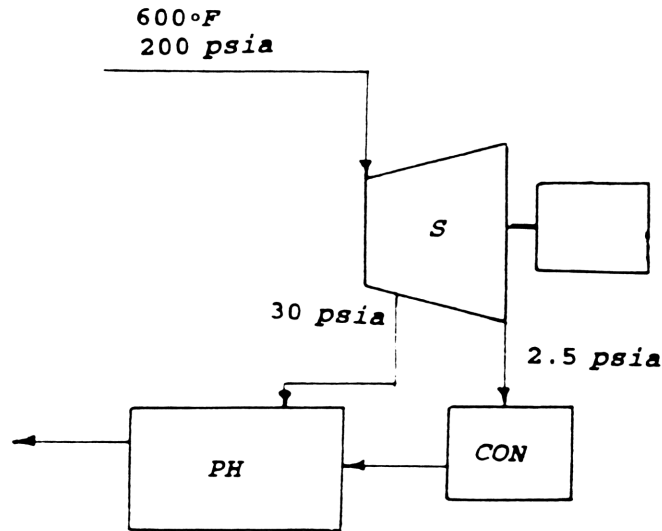
$\eta_{sys} = .22 = 22\%, \text{ Answer for (d)}$

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18. In the figures shown below, steam at 200 psia and 600 oF, throttles to 150 psia then enters to a steam turbine. The turbine exhausts at 2.5 psia. To conserve the energy, instead of throttling, a fraction of steam is bled at the point of 30 psia pressure. If the isentropic efficiency of the turbine is 83%, determine:
- The percentage of the steam that can be bled with no change in the turbine's original work.
 - The temperature of condensed water leaving the pre-heater.



POWER CYCLE EXAMPLES



Solution:

To solve this problem, determine the actual enthalpy of the steam at bleeding point and the exit. Use the Mollier diagram.

Step 1 Find the inlet enthalpy (h_{1S}):

Mark $P=200$ psia and $t=600$ oF on the chart (assumed $dh=0$ in throttling process). Read the enthalpy

$$\underline{h_{1S} = 1323 \text{ BTU/lbm}}$$

Step 2 Find the ideal enthalpy at the exit, throttling condition ($h_{2SI(1)}$):

Mark $P=150$ psia and $t=600$ oF on the chart (characteristics after throttling).

From the marked point draw a vertical line to intersect the constant pressure line at $P=2.5$ psia. Read the enthalpy

$$\underline{h_{2SI(1)} = 1012 \text{ BTU/lbm}}$$

Step 3 Find the ideal enthalpy at the bleeding point (h_{BLI}) and at the exit ($h_{2SI(2)}$):

Mark $P=200$ psia and $t=600$ oF on the chart.

From marked point draw a vertical line to intersect the constant pressure line at $P=30$ psia.

Read the enthalpy

$$\underline{h_{BLI} = 1150 \text{ BTU/lbm}}$$

Continue to intersect the constant pressure $P=2.5$ psia.

Read the enthalpy

$$\underline{h_{2SI(2)} = 989 \text{ BTU/lbm}}$$

Step 4 Find the actual enthalpy at the exit, for both conditions ($h_{2S(1)}$, $h_{2S(2)}$):

For the exit enthalpy, refer to equation (93) **EXIT** (PCYCL/S.TURB/ENTH)

For $h_{1S}=1323$ BTU/lbm, $h_{2SI(1)}=1012$ BTU/lbm, and $\eta_s = .83$

$$\underline{h_{2S(1)} = 1064.9 \text{ BTU/lbm}}$$

POWER CYCLE EXAMPLES

For $h_{1S}=1323$ BTU/lbm, $h_{2S(2)}=989$ BTU/lbm, and $\eta_s = .83$

$$h_{2S(2)} = 1045.8 \text{ BTU/lbm}$$

Step 5 Find the actual enthalpy at the bleeding point (h_{BL}):

For enthalpy at bleeding point, refer to equation (94) **BLID** (PCYCL/S.TURB/ENTH)

For $h_{1S}=1323$ BTU/lbm, $h_{BLI}=1150$ BTU/lbm, and $\eta_s = .83$ $h_{BL} = 1179.4$ BTU/lbm

Now, by knowing the inlet/outlet enthalpies, solve the problem.

a. 1. Calculate the work, with throttling:

For a single path turbine, refer to work equation (117) **SINGL** (PCYCL/S.TURB/WORK)

For $h_{1S}=1323$ BTU/lbm and $h_{2S(1)}=1064.9$ BTU/lbm $WS = 258.1$ BTU/lbm

2. Calculate percentage of bleed:

Assuming the amount of work remains the same, for a turbine with bleeding process, refer to work equation (118) **BLID** (PCYCL/S.TURB/WORK) MENU key.

For $WS=258.1$ BTU/lbm (from above), $h_{1S}=1323$ BTU/lbm, $h_{BL}=1179.4$ BTU/lbm, and $h_{2S(2)}=1045.8$ BTU/lbm

$BLD = .143 = 14.3\%$, <u>Answer for (a)</u>
--

b. To find the temperature of water leaving the pre-heater take the following steps:

Step 1 Determine the enthalpy of water leaving the pre-heater

Refer to pre-heater heat balance equation (104) **HTBAL** (PCYCL/S.TURB/PREHT)

For $h_{BL}=1179.4$ BTU/lbm, $BLD=.143$, $h_{1PH}=h_f(65 \text{ oF})=33$ BTU/lbm (SAT.T table)

$$h_{2PH} = 196.9 \text{ BTU/lbm}$$

Step 2 Determine the temperature

From CHOTKEH's SAT.T table, for $h_f=196.9$ BTU/lbm

$t=228.7 \text{ oF}$, <u>Answer for (b)</u>

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19. 100 lbm/min of steam, at 900 psia and 1000 oF. If the turbine's thermal efficiency is 85%, determine:

a. The turbine's horsepower. Assume exit pressure equals to 500 psia.

b. The actual property of steam at the exit.

POWER CYCLE EXAMPLES

Solution:

To calculate the horsepower, the enthalpy at the inlet and the actual enthalpy at the outlet must be determined first. Follow steps 1, 2, and 3 of problem 17, using steam tables.

Step 1 Find the inlet enthalpy (h_{1S}):

From CHOTKEH SUPHT table, for $P=900$ psia and $t=1000$ oF

$$\underline{h_{1S} = 1508.5 \text{ BTU/lbm}}$$

Step 2 Find the ideal enthalpy at the exit (h_{2SI}):

1. From SUPHT table, for $P=900$ psia and $t=1000$ oF

$$\underline{s_{1S} = 1.6663 \text{ BTU/lbm-oR}}$$

2. From SAT.P table, for $P=500$ psia

$$\underline{sg_{2S} = 1.4626 \text{ BTU/lbm-oR}}$$

Since $sg_{2S} < s_{1S}$, therefore the steam is super heated.

3. From SUPHT table, for $P=500$ psia and $s=1.6663$ BTU/lbm-oR (assume temperature range 750 oF - 1150 oF)

$$\underline{t(\text{ideal}) = 821.8 \text{ oF}}$$

4. From SUPHT table, for $P=500$ psia and $t=821.8$ oF

$$\underline{h_{2SI} = 1423.8 \text{ BTU/lbm}}$$

Step 3 Find the actual enthalpy at the exit (h_{2S}):

For enthalpy at the exit, refer to equation (65) **EXIT** (PCYCL/S.TURB/ENTH)

For $h_{1S}=1508.5$ BTU/lbm, $h_{2SI}=1423.8$ BTU/lbm, and $\eta_s = .85$

NOTE: The effect due to the change in velocity is neglected.

$$\underline{h_{2S} = 1436.5 \text{ BTU/lbm}}$$

a. Calculate the horsepower:

For sigle path and English system, refer to equation (68) **SINGL** (PCYCL/S.TURB/POWR/HP/ENG).

For $M=100/60=1.6667$ lbm/sec, $h_{1S}=1508.5$ BTU/lbm, $h_{2S}=1436.5$ BTU/lbm.

$$\underline{hp = 170 \text{ hp, Answer for (a)}}$$

b. The actual properties of steam at the exit are:

$P_2=500$ psia (given)

$h_2=1436.5$ BTU/lbm (step 3)

T_2 : From CHOTKEH's SUPHT table, for $P=500$ psia and $h=1436.5$ BTU/lbm: $\underline{t_2=845.2 \text{ oF}}$

$$\underline{P=500 \text{ psia, } t=845.2 \text{ oF, Answer for (b)}}$$

POWER CYCLE EXAMPLES

20. A steam turbine to drive a 120 hp feed pump. Based on the following data:

Steam at inlet: $P=600$ psia $T=650$ oF
Steam at outlet: $P=50$ psia
Efficiency: Pump:91% Turbine, thermal:82%
Determine:
The steams flow rate, in lbm/hr.

Solution:

To calculate the mass flow, the enthalpy at the inlet and the actual enthalpy at the outlet must be determined first. Follow steps 1, 2, and 3 of problem 17, using Mollier diagram.

Step 1 Find the inlet enthalpy (h_{1S}):

Mark $P=600$ psia and $T=650$ oF on the chart. Read the enthalpy

$$\underline{h_{1S} = 1322 \text{ BTU/lbm}}$$

Step 2 Find the ideal enthalpy at the exit (h_{2SI}):

From the marked point draw a vertical line to intersect the constant pressure line at $P=50$ psia

Read the enthalpy

$$\underline{h_{2SI} = 1095 \text{ BTU/lbm}}$$

Step 3 Find the actual enthalpy at the exit (h_{2S}):

For exit enthalpy, refer to equation (93) **EXIT** (PCYCL/S.TURB/ENTH)

$$\text{For } h_{1S}=1322 \text{ BTU/lbm, } h_{2SI}=1095 \text{ BTU/lbm, and } \eta_g = .82 \quad \underline{h_{2S} = 1135.9 \text{ BTU/lbm}}$$

Find the steams mass flow:

For a single path turbine and the given horsepower in English system, refer to turbine's power equation (96) **SINGL** (PCYCL/S.TURB/POWR/ENG/HP)

For $hp_S = 120/.91 = 131.9$ hp, $h_{1S}=1322$ BTU/lbm, and $h_{2S}=1135.9$ BTU/lbm

$$\underline{MS = .501 \text{ lbm/sec}}$$

$$m = 1804 \text{ lbm/hr, Answer}$$

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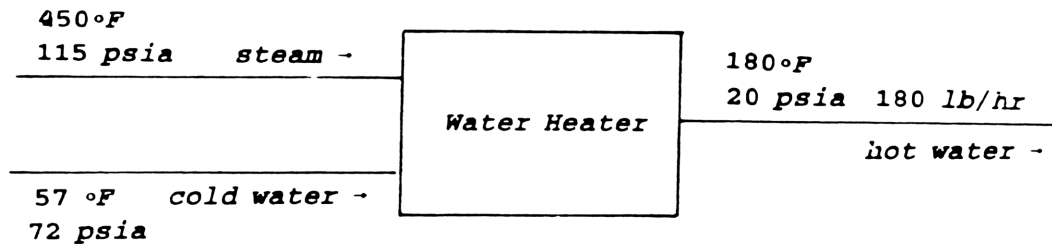
21. Waste steam is used to heat the cold water. The characteristics of the system is as follows:

Steam: Temperature= 450 oF Pressure= 115 psia
Cold water: " = 75 oF " = 72 psia
Hot water: " = 180 oF " = 20 psia
Mass flow of hot water= 1800 lbm/hr

POWER CYCLE EXAMPLES

Based on the above, determine:

The mass flow rate of the steam, in lbm/hr.



Solution:

To find the mass flow find the enthalpies first:

Steam enthalpy: $H_S = 1251.4$ BTU/lbm, SUPHT table for $P = 115$ psia and $t = 450$ oF

Cold water " : $H_W = h_f(75 \text{ oF}) = 43$ BTU/lbm, SAT.T table for $T = 75$ oF

Hot water " : $H_{MIX} = h_f(180 \text{ oF}) = 148$ BTU/lbm, SAT.T table for $T = 180$ oF

Refer to steam/water mixture heat balance equation (95) **HTBAL** (PCYCL/S.TURB/MIXT)

For $H_S = 1251.4$ BTU/lbm, $MW =$ key in ' **1800-MS ENTER** press MW, $H_W = 43$ BTU/lbm, and $M_{MIX} = 1800$ lbm/hr, and $H_{MIX} = 148$ BTU/lbm.

Press ↵ MS

MS (steam flow rate) = 156.4 lbm/hr

Press ↵ MW

MW (water flow rate) = 1643.6 lbm/hr

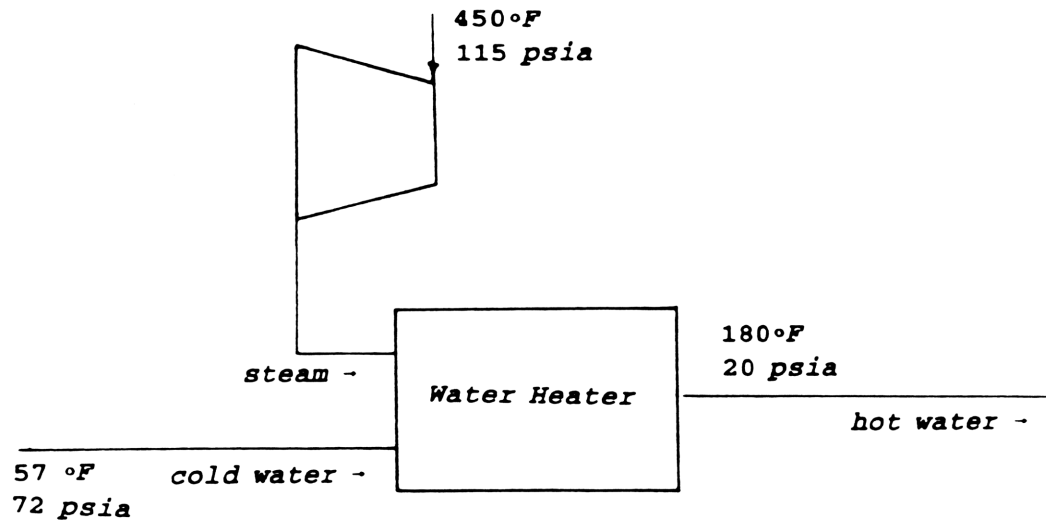
m (steam) = 156.4 lbm/hr, Answer.

NOTE: Ensure to solve for MS first, then for MW

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22. If in problem 21 steam is expanded through a low pressure turbine, before entering the water heater, determine:
- The turbine's horse power. Assume the thermal and mechanical efficiencies of turbine are 83% and 95% respectively. Consider maximum 4 psi pressure drop across the water heater.
 - The mass flow rate of the hot water. Assume all other conditions remain the same.

POWER CYCLE EXAMPLES



Solution:

- a. To calculate the horsepower, the enthalpy at the inlet and the actual enthalpy at the outlet must be determined first. Follow steps 1, 2, and 3 of problem 17, using steam tables.

Step 1 Find the inlet enthalpy (h_{1S}):

From CHOTKEH SUPHT table, for $P=115$ psia and $T=450$ oF

$$\underline{h_{1S} = 1251.4 \text{ BTU/lbm}}$$

Step 2 Find the ideal enthalpy at the exit (h_{2SI}):

1. From SUPHT table, for $P=115$ psia and $T=450$ oF

$$\underline{s_{1S} = 1.6659 \text{ BTU/lbm-oR}}$$

2. From SAT.P table, for $P(\text{at exit})=20(\text{hot water pressure})+4(\text{pressure drop})=24$ psia

$$\underline{sg_{2S} = 1.7173 \text{ BTU/lbm-oR}}$$

Since $sg_{2S} > s_{1S}$, therefore the steam is sub-liquid.

3. From SAT.P table, for $P=24$ psia: $sg=1.7173$ BTU/lbm-oR, $sf=.3498$ BTU/lbm-oR
and $s=1.6659$ BTU/lbm-oR

$$\underline{X(\text{ideal}) = .9624}$$

4. From SAT.P table, for $P=24$ psia: $hf=205.8$ BTU/lbm, $hg=1159.8$ BTU/lbm, and
 $X=.9624$

$$\underline{h_{2SI} = 1123.9 \text{ BTU/lbm}}$$

POWER CYCLE EXAMPLES

Step 3 Find the actual enthalpy at the exit (**h2S**):

For the exit enthalpy, refer to equation (93) **EXIT** (PCYCL/S.TURB/ENTH)

For **h1S=1251.4** BTU/lbm, **h2SI=1123.9** BTU/lbm, and $\eta_s = .83$

$$\underline{h2S = 1145.6 \text{ BTU/lbm}}$$

Step 4 Calculate the horse power:

For single path turbine in English system, refer to power equation (96) **SINGL**
(PCYCL/S.TURB/POWR/ENG/HP)

For **MS=156.4/3600=.0434** lbm/sec, **h1S=1251.4** BTU/lbm, and **h2S=1145.6** BTU/lbm

hpS = 6.49 hp. Considering 95% mechanical efficiency:

$$\text{hp} = 6.17 \text{ hp, Answer for (a).}$$

- b. To calculate the hot water mass flow, refer to steam/water mixture heat balance equation (95) **HTBAL**
(PCYCL/S.TURB/MIXT)

For **MS=156.4** lbm/hr, **HS=h2S=1145.6** BTU/lbm, **MW=** key in ' **MMIX-156.4 ENTER** press
MW, **HW= hf(75 oF)=43** BTU/lbm, and **HMIX= hf(180 oF) =148** BTU/lbm.

Press $\rightarrow$ **MMIX**

$$\underline{\text{MMIX (hot water)} = 1642.3 \text{ lbm/hr}}$$

Press $\rightarrow$ **MW**

$$\underline{\text{MW (cold water)} = 1485.9 \text{ lbm/hr}}$$

$$\text{m (hot water)} = 1642.3 \text{ lbm/hr, Answer for (b).}$$

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23. Steam at 550 oF and 120 psia is throttled through a pressure reducing valve, to 32 psia, and used in a heating plant. If the heating load and the condensate temperature are 2.5 EE7 BTU/hr and 185 oF respectively, determine:

The mass flow of the steam in lbm/hr.

Solution:

Assuming $dh=0$ at pressure reducing valve, use the following equation to calculate the mass:

$m=q/(h1-h2)$. For:

$q=2.5\text{EE}7$ BTU/hr (given)

h1=1302 BTU/lbm (From CHOTKEH's SUPHT table, for **P=120** psia and **T=550** oF)

h2=hf(185 oF)=153 BTU/lbm (From CHOTKEH's SAT.T table, for **T=185** oF)

key in ' **2.5EE7/(1302-153) EVAL**

$$\text{m} = 21,758 \text{ lbm/hr, Answer}$$

POWER CYCLE EXAMPLES

24. If in problem 23 the reduction valve is replaced with a steam turbine and all other conditions remain the same, determine:
- The new mass flow rate of the steam.
 - The power generated by turbine, in hp. Assume the turbine's thermal efficiency equals to 76%.

Solution:

To calculate the mass flow, the enthalpy at the inlet and the actual enthalpy at the outlet of the turbine must be determined first. Follow steps 1, 2, and 3 of problem 17, using steam tables.

Step 1 Find the inlet enthalpy (h_{1S}):

From CHOTKEH SUPHT table, for $P=120$ psia and $T=550$ oF $\underline{h_{1S} = 1302 \text{ BTU/lbm}}$

Step 2 Find the ideal enthalpy at the exit (h_{2SI}):

1. From SUPHT table, for $P=120$ psia and $T=550$ oF $\underline{s_{1S} = 1.7136 \text{ BTU/lbm-oR}}$

2. From SAT.P table, for $P=32$ psia $\underline{sg_{2S} = 1.6942 \text{ BTU/lbm-oR}}$

Since $sg_{2S} < s_{1S}$, therefore the steam is super heated.

3. From SUPHT table, for $P=32$ psia and $s=1.7136 \text{ BTU/lbm-oR}$ (assume temperature range 300 oF - 750 oF) $\underline{T \text{ (ideal)} = 295.8 \text{ oF}}$

4. From SUPHT table, for $P=32$ psia and $T=295.8$ BTU/lbm $\underline{h_{2SI} = 1184.9 \text{ BTU/lbm}}$

Step 3 Find the actual enthalpy at the exit (h_{2S}):

For enthalpy at the exit, refer to equation (93) **EXIT** (PCYCL/S.TURB/ENTH)

For $h_{1S}=1302 \text{ BTU/lbm}$, $h_{2SI}=1184.9 \text{ BTU/lbm}$, and $\eta_s = .76$

$\underline{h_{2S} = 1213 \text{ BTU/lbm}}$

Now, by knowing the inlet/outlet enthalpies, solve the problem.

- a. Calculate the new mass flow of the steam:

From $m = q/(h_1 - h_2)$ for:

$q = 2.5 \times 10^7 \text{ BTU/hr}$ (given)

$h_1 = h_{2S} = 1213 \text{ BTU/lbm}$

$h_2 = h_f(185 \text{ oF}) = 153 \text{ BTU/lbm}$

key in ' $2.5 \times 10^7 / (1213 - 153)$ **EVAL**

$$m = 23,585 \text{ lbm/hr, Answer for (a)}$$

POWER CYCLE EXAMPLES

b. Calculate the horsepower:

For a single path turbine in English system, refer equation (96) **SINGL**
(PCYCL/S.TURB/POWR/ENG/HP)

For $\dot{m}S = 23585/3600 = 6.55$ lbm/sec, $h1S = 1302$ BTU/lbm, $h2S = 1213$ BTU/lbm .

$hpS = 825$ hp, <u>Answer for (b)</u>

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25. If in problem 24 the required pressure at the heating system is reduced to 23 psia, determine:
The new mass flow rate of the steam. Assume all other conditions remain the same.

Solution:

Follow the steps in problem 24.

Step 1 Find the inlet enthalpy ($h1S$):

From CHOTKEH SUPHT table, for $P = 120$ psia and $T = 550$ oF $\underline{h1S = 1302 \text{ BTU/lbm}}$

Step 2 Find the ideal enthalpy at the exit ($h2SI$):

1. From problem 16 $\underline{s1S = 1.7136 \text{ BTU/lbm-oR}}$

2. Check the state of the steam at the exit:

From Mollier diagram, for $P = 32$ psia and $s = 1.7136$ BTU/lbm-oR, the steam is sub-liquid

3. Determine the quality of steam:

From CHOTKEH SAT.P table, for $P = 23$ psia: $sg = 1.7207$ BTU/lbm-oR, $sf = .346$
BTU/lbm-oR, and for $s = 1.7316$ BTU/lbm-oR. $\underline{X = .9948}$

4. Calculate the ideal enthalpy ($h2SI$):

From CHOTKEH SAT.P table, for $P = 23$ psia: $hf = 203.5$ BTU/lbm, $hg = 1159$ BTU/lbm, and
for $X = .9948$ $\underline{h2SI = 1154 \text{ BTU/lbm}}$

Step 3 Find the actual enthalpy at the exit ($h2S$):

For enthalpy at the exit, refer to equation (65) **EXIT** (PCYCL/S.TURB/ENTH)

For $h1S = 1302$ BTU/lbm, $h2SI = 1154$ BTU/lbm, and $\eta_s = .76$ $\underline{h2S = 1189.5 \text{ BTU/lbm}}$

Calculate the new mass flow of the steam:

From $\dot{m} = q/(h1 - h2)$ for:

$q = 2.5EE7$ BTU/hr (given)

POWER CYCLE EXAMPLES

$$h1 = h2S = 1189.5 \text{ BTU/lbm}$$

$$h2 = hf(185 \text{ oF}) = 153 \text{ BTU/lbm}$$

key in ' 2.5EE7/(1189.5-153) EVAL

$$m = 24,120 \text{ lbm/hr, Answer}$$

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26. If in problem 24 the heat load is replaced with a condenser and the condensed water is pumped back to the boiler, determine:
- The input heat to the boiler.
 - The thermal efficiency of the system.
 - The carnot efficiency.
 - The thermal efficiency, if the pump is rated at 3 hp with 80% efficiency.

Solution:

- a. For English system, to find the input heat to the system, refer to steam boiler (with burner) heat balance equation (91) **ENG** (PCYCL/S.TURB/BOILR/BURN).
- For $MS = m/3600 = 23585/3600 = 6.55 \text{ lbm/sec}$, $h2B = h1S = 1302 \text{ BTU/lbm}$, $h1B = 153 \text{ BTU/lbm}$ (hf of 185 oF water), $DR = 0$ (No drainage/blow-off), and $hDR = 0$ (no blow off)

$$q_{in} = 2.71EE7 \text{ BTU/hr, Answer for (a).}$$

- b. With the given q_{out} in English system, refer to system thermal efficiency equation (35) **QOUT** (PCYCL/EFFI/SYST/ENG)
- For $kW = 824.6 * .7457 = 614.9$ (problem 16.b), $kW_{in} = 0$, and $q_{out} = 2.5 \text{ EE7 BTU/hr}$ (given)

$$\eta_{sys} = .0775 = 7.75\%, \text{ Answer for (b).}$$

- c. Refer to Carnot efficiency equation (22) **CARNO** (PCYCL/EFFI)
- For $TH = 550 + 460 = 1010 \text{ oR}$ (given) and $TL = 295.8 + 460 = 755.8 \text{ oR}$ (step 2.3 problem 24)

$$\eta_{CAR} = .252 = 25.2\%, \text{ Answer for (b).}$$

POWER CYCLE EXAMPLES

- d. With the given q_{out} in English system, refer to system thermal efficiency equation (35) Q_{OUT} (PCYCL/S.TURB/EFFI/SYST/ENG)

For $kW = 824.6 * .7457 = 614.9$, $kW_{in} = '3/.8 * .7457 \underline{EVAL} = 2.8$, and $q_{out} = 2.5EE7$ BTU/hr

$$\eta_{sys} = .0771 = 7.71\%, \underline{\text{Answer for (d).}}$$

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27. A power plant generates 20 MW electrical energy and in addition it provides 90,000 lbm/hr steam out of which 50,000 lbm/hr is for process and the balance to re-heat the feed water.

The steams characteristics are as follows:

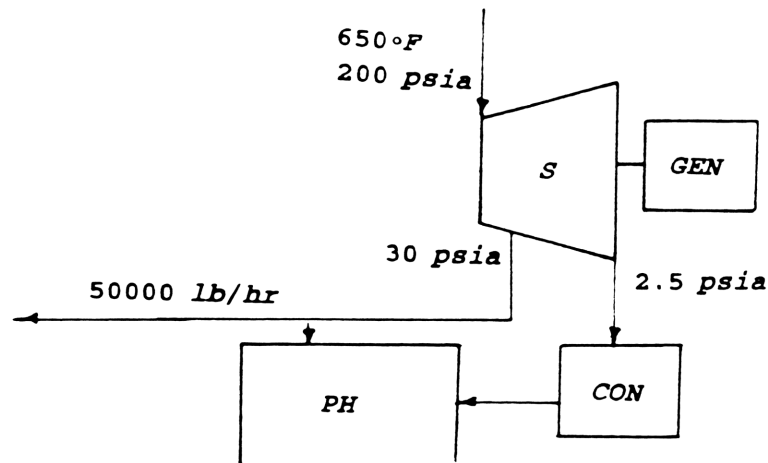
At turbine's entrance: $P = 200$ psia $t = 650$ oF

At the outlet: $P = 2.5$ psia

At the point of extraction/bleeding: $P = 30$ psia

Based on the above, determine:

The boiler's steam output capacity, in lbm/hr



POWER CYCLE EXAMPLES

Solution:

To solve this problem, determine the actual enthalpy of the steam at the outlet and bleeding points.
Use the Mollier diagram.

Step 1 Find the inlet enthalpy (h_{1S}):

Mark $P=200$ psia and $T=650$ oF on the chart Read the enthalpy

$$\underline{h_{1S} = 1348 \text{ BTU/lbm}}$$

Step 2 Find the ideal enthalpy at the exit (h_{2SI}):

From the marked point draw a vertical line to intersect the constant pressure line at $P=2.5$ psia. Read the enthalpy

$$\underline{h_{2SI} = 1000 \text{ BTU/lbm}}$$

Step 3 Find the ideal enthalpy at the bleeding point (h_{BLI}):

From marked point draw a vertical line to intersect the constant pressure line at $P=30$ psia.
Read the enthalpy

$$\underline{h_{BLI} = 1157 \text{ BTU/lbm}}$$

Step 4 Find the actual enthalpy at the exit (h_{2S}):

For enthalpy at the exit, refer to turbine equation (93) **EXIT** (PCYCL/S.TURB/ENTH)

For $h_{1S}=1348$ BTU/lbm, $h_{2SI}=1000$ BTU/lbm, and $\eta_s = .8$

$$\underline{h_{2S} = 1069.6 \text{ BTU/lbm}}$$

Step 5 Find the actual enthalpy at the bleeding point (h_{BL}):

For a turbine with bleeding process, refer to equation (94) **BLID** (PCYCL/S.TURB/ENTH)

For $h_{1S}=1348$ BTU/lbm, $h_{BLI}=1157$ BTU/lbm, and $\eta_s = .8$

$$\underline{h_{BL} = 1159.2 \text{ BTU/lbm}}$$

For a steam turbine with bleeding, power in **kW** in English system, refer to equation (99) **BLID** (PCYCL/S.TURB/POWR/ENG/KW)

For $k_{WS}=20 \times 1000 = 20000$, $h_{1S}=1348$ BTU/lbm, $h_{BL}=1195.2$ BTU/lbm,

$MBL=90000/3600=25$ lbm/sec, $h_{2S}=1069.6$ BTU/lbm, and $\eta_{\text{over}} = .95$

$$\underline{MS = 82.97 \text{ lbm/sec}}$$

$m = 298,692 \text{ lbm/hr, Answer}$

POWER CYCLE EXAMPLES

28. 115 psia and 265 oF compressed air enters a turbine. After the expansion and generating the electric power, the turbine outlet air cools an area at the set temperature of 79 oF and the pressure of 12.5 psia. Assuming the polytropic expansion with its efficiency equals to 79% and $n=1.2$, determine:
- The turbine's output in hp. Assume air flow is equal to 75 lbm/min
 - The amount of cooling capacity in tons of refrigeration.

Solution:

- a. To calculate the turbines output, find the enthalpies first.

Calculate the enthalpies:

Step 1 Find the polytropic temperature at the exit:

For polytropic process, refer to gas equation (44) $\delta P/\delta T$ (PCYCL/GAS/POLYT)

For $p_2=12.5 \times 144=1800$ psfa (cooled area's pressure), $p_1=115 \times 144=16560$ psfa,

$T_1=265+460=725$ oR, and $n=1.2$

$T_{2G} = T_2 = 500.8$ oR (40.8 oF)

Step 2 Find the polytropic enthalpy at the exit (h_{2GI}):

From CHOTKEH's air table, for $T=500.8$

$h_{2GI} = 119.7$ BTU/lbm

Step 3 Find the inlet enthalpy:

From CHOTKEH's air table, for $T=265+460=725$ oR

$h_{1G} = 173.7$ BTU/lbm.

Step 4 Find the actual enthalpy at the exit (h_{2G}):

Refer to enthalpy equation (48) $ENTH$ (PCYCL/G.TURB)

For $h_{1G}=173.7$ BTU/lbm, $h_{2GI}=119.7$ BTU/lbm, and $\eta_o = .79$

$h_{2G} = 131$ BTU/lbm

Calculate the horsepower:

For English system with the flow given in **lbpm** and the power required in **hp**, refer to power equation (49) **LBPS** (PCYCL/G.TURB/POWR/ENG/HP)

For $MG=75/60=1.25$ lbm/sec, $h_{1G}=173.7$ BTU/hr, and $h_{2G}=131$ BTU/lbm

$$hp_G = 75.5 \text{ hp, Answer for (a).}$$

- b. To calculate the cooling capacity, with the flow given in **lbm/sec** and the capacity required in **tons of refrigeration**, refer to refrigeration equation (82) **LBPS** (PCYCL/REFRI/ENG/CAPAC/TON.R)
- For $lbps=1.25$ lbm/sec, $cp=.24$ BTU/lbm-oF (assumed), $t_1=79$ oF (given), and $t_2=40.8$ oF (step 1)

$$tonR = 3.44 \text{ tons, Answer for (b).}$$

POWER CYCLE EXAMPLES

29. If in problem 28 it is assumed the isentropic expansion for turbine, with $k=1.4$, and the turbines air flow equals to 175 cfm, determine:
- The turbine's output in hp.
 - The amount of cooling in BTU/hr.

Solution:

- a. To calculate the turbines output, find the enthalpies first.

Calculate the enthalpies:

Step 1 Find the isentropic temperature at the exit:

For isentropic process, refer to gas equation (41) $\delta P / \delta T$ (PCYCL/GAS/ISENT)

For $p_2 = 12.5 \times 144 = 1800$ psfa (cooled area's pressure), $p_1 = 115 \times 144 = 16560$ psfa,

$T_{1G} = 265 + 460 = 725$ oR, and $k = 1.4$ $T_{2G} = T_2 = 384.6$ oR (-75.4 oF)

Step 2 Find the isentropic enthalpy at the exit (h_{2GI}):

From CHOTKEH's air table, for $T = 384.6$ oR $h_{2GI} = 91.9$ BTU/lbm

Step 3 Find the inlet enthalpy:

From CHOTKEH's air table, for $T = 265 + 460 = 725$ oR $h_{1G} = 173.7$ BTU/lbm.

Step 4 Find the actual enthalpy at the exit (h_{2G}):

Refer to enthalpy equation (48) **ENTH** (PCYCL/G.TURB)

For $h_{1G} = 173.7$ BTU/lbm, $h_{2GI} = 91.9$ BTU/lbm, and $\eta_o = .79$ $h_{2G} = 109$ BTU/lbm

Calculate the horsepower:

With the flow given in cfm, in English system, and turbine's power is required in hp, refer to power equation (50) **CFM** (PCYCL/G.TURB/POWR/ENG/HP)

For $p_{1G} = 16560$ psfa, $cfm = 175$ cfm, $h_{1G} = 173.7$ BTU/hr, $h_{2G} = 109$ BTU/lbm,

$R = 53.3$ ft-lbm/lbm-oR, and $T_{1G} = 725$ oR

$hp_G = 114.4$ hp, Answer for (a).

- b. To calculate the cooling capacity, with flow given in cfm and the capacity required in BTU/hr, refer to refrigeration equation (80) **CFM** (PCYCL/REFRI/ENG/CAPAC/BTU.H)

For $p = 16560$ psfa, $cfm = 175$ cfm, $cp = .24$ BTU/lbm-oF, $t_1 = 79$ oF (given), $t_2 = -75.4$ oF (step 1),

$R = 53.3$ ft-lbm/lbm-oR, and $T = 725$ oR

$q = 166,741$ BTU/hr, Answer for (b).

POWER CYCLE EXAMPLES

30. 1150 oF exhaust gas from a gas turbine runs through a waste heat boiler and generates 950 oF at 890 psia super heated steam. The gas temperature drops to 700 oF, when leaving the boiler. The generated steam enters to a turbine, in which it expands to 2.5 psia. The condensed steam is pumped back to the waste heat boiler.

Considering the following information:

Gas flow quantity: 9.5 lbm/sec

Efficiencies: Boiler: 85% Pump: 65% Turbine: 86%

- a. Determine the amount of generated steam in lbm/sec.
 - b. Determine the generated power in the steam turbine.
- a. To determine the mass flow of the steam, the enthalpies at the entrance and the exit of the waste heat boiler must be calculated first.

Step 1 Determine the inlet enthalpy of the gas to the boiler (h1G):

From CHOTKEH's AIR table, for $T = 1150 + 460 = 1610$ oR

$$h1G = 398.5 \text{ BTU/lbm}$$

Step 2 Determine the enthalpy of the gas at the exit of the boiler (h2G):

From CHOTKEH's AIR table, for $T = 700 + 460 = 1160$ oR

$$h2G = 281 \text{ BTU/lbm}$$

Step 3 Determine the enthalpy of feed water to the boiler (h1B):

This will be the enthalpy of condensed water after the feed pump (h2P).

1. Determine the enthalpy of condensed water:

From the CHOTKEH's SAT.P table, for $P = 2.5$ psia

$$h1P (hf) = 103.5 \text{ BTU/lbm}$$

2. Determine the enthalpy of condensed water after the pump:

2.1 Determine the Specific Volume (SPC.V) of condensed water (vf1P):

From the CHOTKEH's SAT.P table, for $P = 2.5$ psia

$$vf1P (vf) = .01628 \text{ cf/lbm}$$

2.2 Calculate the enthalpy:

For English system, refer to pump enthalpy equation (105) **ENTH**
(PCYCL/S.TURB/PUMP/ENG)

for $h1P = 103.5 \text{ BTU/lbm}$, $vf1P = .01628 \text{ cf/lbm}$, $p2P$ (steam pressure) $= 890 * 144 = 128,160$
psfa, $p1P = 2.5 * 144 = 360$ psfa, and $\eta_p = .65$

$$h1B = h2P = 107.6 \text{ BTU/lbm}$$

POWER CYCLE EXAMPLES

Step 4 Determine the enthalpy of steam, leaving the boiler (h_{2B}):

From the CHOTKEH's SUPHT table, for **P=890** psia and **t=950** oF

$$\underline{h_{2B} = 1480.8 \text{ BTU/lbm}}$$

Step 5 Calculate the mass flow of steam (MS):

Refer to waste heat boiler/heat exchanger heat balance equation (92) **HTEXC**
(PCYCL/S.TURB/BOILR)

MG=9.5 lbm/sec, **h_{1G}=398.5** BTU/lbm, **h_{2G}=281** BTU/lbm, **η_s= .85** ,

h_{2B}=1480.8 BTU/lbm, and **h_{1B}=107.6** BTU/lbm

$$\text{MS} = .691 \text{ lbm/sec, Answer for (a).}$$

b. To calculate the turbine's power, determine the enthalpies first, use the Mollier diagram.

Step 1 Find the inlet enthalpy (h_{1S}):

Mark **P=890** psia and **t=950** oF on the chart. Read the enthalpy

$$\underline{h_{1S} = 1477 \text{ BTU/lbm}}$$

Step 2 Find the ideal enthalpy at the exit (h_{2SI}):

From the marked point draw a vertical line to intersect the constant pressure line at **P=2.5** psia. Read the enthalpy

$$\underline{h_{2SI} = 971 \text{ BTU/lbm}}$$

Step 3 Find the actual enthalpy at the exit (h_{2S}):

For exit enthalpy, refer to equation (93) **EXIT** (PCYCL/S.TURB/ENTH)

For **h_{1S}=1477** BTU/lbm, **h_{2SI}=971** BTU/lbm, and **η_s= .86** $\underline{h_{2S} = 1041.8 \text{ BTU/lbm}}$

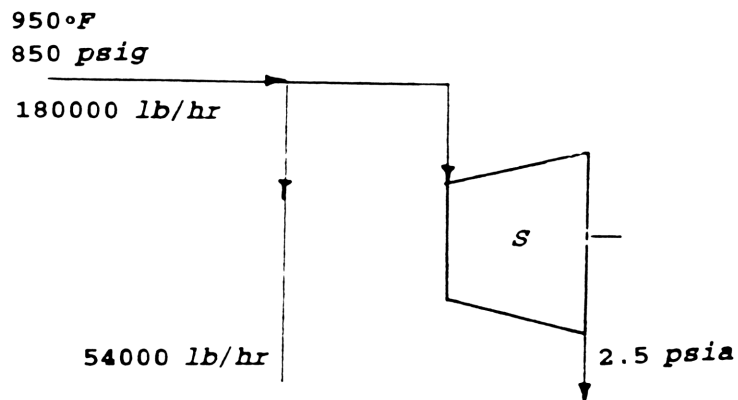
For English system and single path turbine, refer to power equation (96) **SINGL**
(PCYCL/G.TURB/POWR/ENG/HP)

For **MS=.691** lbm/sec, **h_{1S}=1477** BTU/lbm, and **h_{2S}=1041.8**

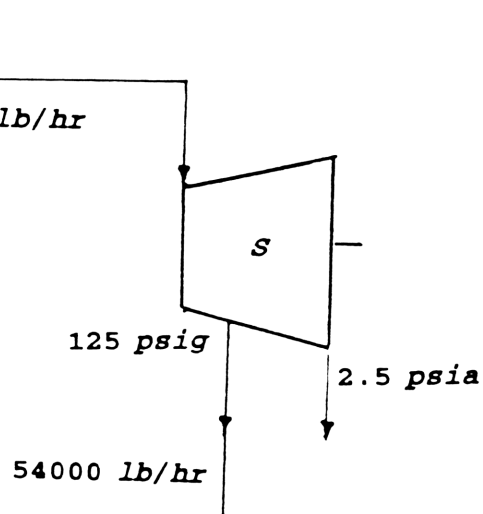
$$\text{hpS} = 425.4 \text{ hp, Answer for (b)}$$

POWER CYCLE EXAMPLES

31. A steam plant generates 950 oF at 850 psig super heated steam. Out of 180,000 lbm/hr of the produced steam, 30% is the process steam and the balance expands through a steam turbine and generates electric power. If the turbine's thermal efficiency is 82% and the generator's efficiency is 98%, determine:
- The enthalpy of the steam at the turbine's exit.
 - The electric power generated by the turbine.
 - The electric power generated by the turbine, if the entire steam enters to the turbine and the process steam is extracted from the turbine at 125 psig.



(b)



(c)

POWER CYCLE EXAMPLES

Solution:

- a. To find the actual outlet enthalpy, take the following steps. Use the steam tables.

Step 1 Find the inlet enthalpy (h_{1S}):

From CHOTKEH's SUPHT table, for $P=850+14.7=864.7$ psia and $t=950$ oF

$$h_{1S} = 1481.6 \text{ BTU/lbm}$$

Step 2 Find the ideal enthalpy at the exit (h_{2SI}):

1. Determine the entropy at the inlet (s_{1S}):

From CHOTKEH SUPHT table, for $P=864.7$ psia and $t=950$ oF

$$s_{1S} = 1.6518 \text{ BTU/lbm-oR}$$

For an isentropic process this is the ideal entropy at the exit.

2. Determine the state of the steam at the exit:

Find the entropy of saturated gas (sg_{2S}) at the exit

From CHOTKEH SAT.P table, for $P=2.5$

$$sg_{2S} = 1.9014 \text{ BTU/lbm-oR}$$

Since $sg_{2S} > s_{1S}$, therefore the steam is sub-liquid.

3. Determine the quality of steam:

From CHOTKEH SAT.P table, for $P=2.5$ psia: $sg=1.9014$ BTU/lbm-oR, $sf=.1901$ BTU/lbm-oR, and for $s=1.6518$ BTU/lbm-oR.

$$X = .8541$$

4. Calculate the ideal enthalpy (h_{2SI}):

From CHOTKEH SAT.P table, for $P=2.5$ psia: $hf=103.5$ BTU/lbm, $hg=1120.1$ BTU/lbm, and for $X=.8541$

$$h_{2SI} = 971.8 \text{ BTU/lbm}$$

Step 3 Find the actual enthalpy at the exit (h_{2S}):

For enthalpy at the exit, refer to equation (93) EXIT (PCYCL/S.TURB/ENTH)

For $h_{1S}=1481.6$ BTU/lbm, $h_{2SI}=971.8$ BTU/lbm, and $\eta_g = .82$

$$h_{2S} = 1063.6 \text{ BTU/lbm, Answer for (a).}$$

- b. In English system, to find the generators power in kW for a single path turbine, refer to equation (98) SINGL (PCYCL/S.TURB/POWR/ENG/KW)

For MS= key in '180000*(1-.3)/3600 EVAL=35 lbm/sec, $h_{1S}=1481.6$ BTU/hr, $h_{2S}=1063.6$ BTU/lbm, and $\eta_{gen}=.98$

$$kWS = 15,123.1 \text{ kw, Answer for (b).}$$

POWER CYCLE EXAMPLES

c. To find the generator's power, under the new condition, follow the steps in "a" and "b" above.

Step 1 Find the inlet enthalpy (h_{1S}):

From step 1 above

$$\underline{h_{1S} = 1481.6 \text{ BTU/lbm}}$$

Step 2 Find the ideal enthalpy at the exit (h_{2SI}):

1. Determine the entropy at the inlet (s_{1S}):

From step 2.1 above

$$\underline{s_{1S} = 1.6518 \text{ BTU/lbm-oR}}$$

2. Determine the state of the steam at the Bleeding point:

Find the entropy of saturated gas (sg_{2S}) at the bleeding point

From CHOTKEH SAT.P table, for $P=125+14.7=139.7$ $\underline{sg_{BL} = 1.5768 \text{ BTU/lbm-oR}}$

Since $sg_{BL} < s_{1S}$, therefore the steam is super heated

3. Calculate the ideal temperature (T_{2BL}):

- From CHOTKEH SUPHT table, for $P=139.7$ psia and $s=1.6518 \text{ BTU/lbm-oR}$

$$\underline{T_{BLI} = 474.2 \text{ oF}}$$

- From the same table, for $P=139.7$ psia and $T=474.2$ oF $\underline{h_{BLI} = 1259 \text{ BTU/lbm}}$

Step 3 Find the actual enthalpy at the bleeding point (h_{BL}):

For a turbine with bleeding process, refer to equation (94) **BLID** (PCYCL/S.TURB/ENTH)

For $h_{1S}=1481.6 \text{ BTU/lbm}$, $h_{BLI}=1259 \text{ BTU/lbm}$, and $\eta_s = .82$

$$\underline{h_{BL} = 1299.1 \text{ BTU/lbm}}$$

Step 4 Calculate the power:

For English system. to find the generator's power in kW with bleeding process, refer to power equation (97) **BLID** (PCYCL/S.TURB/POWR/ENG/KW)

For $MS = \text{key in '180000/3600 EVAL} = 50 \text{ lbm/sec}$, $h_{1S}=1481.6 \text{ BTU/hr}$, $h_{BL}=1299.1 \text{ BTU/lbm}$, $MBL = .3*180000/3600 = 15 \text{ lbm/sec}$, $h_{2S}=1063.6 \text{ BTU/lbm}$, and $\eta_{GEN} = .98$

$\text{kWS} = 17,953 \text{ kw, Answer for (c).}$

POWER CYCLE EXAMPLES

Problems 32 - 35

In a power plant the atmospheric air is compressed by a compressor, then is heated in a combustor. The heated air is expanded in a gas turbine, which generates the electrical energy. The exhausted gas, from the turbine, enters into a waste heat boiler which produces the super heated steam. The steam also expands in a steam turbine and generates the electrical energy while the condensed steam is pumped back to the waste heat boiler.

Following are the characteristics of the plant equipment.

Compressor:

Intake air: 60 F, 14.7 psia
 Air mass flow: 110 lbm/sec
 Compression Ratio: 12
 Efficiency: 82%

Combustor:

Fuel mass flow: 8200 lbm/hr
 Fuel heat value: 18,200 BTU/lbm

Gas turbine/Generator:

Intake air: 2300 oR
 Exhaust air: 17 psia
 Turbine efficiency: 72%
 Generator efficiency: 98%

Steam turbine/Generator:

Inlet: 980 oF, 320 psia
 Outlet: 5 psia
 Turbine's efficiency 78%

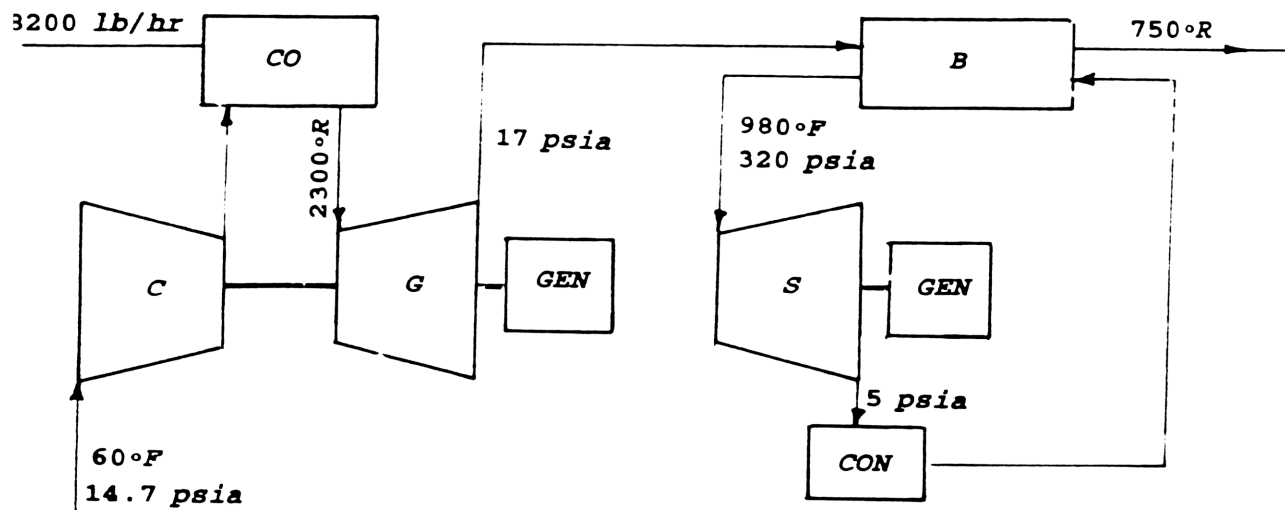
Waste heat boiler:

Air temperature at exit 750 oR

Others:

Waste heat boiler eff.: 84%
 Feed pump efficiency: 67%

Based on the above information, solve the following problems:



POWER CYCLE EXAMPLES

32. Determine the Combustor's efficiency:

Solution:

To calculate the combustor's efficiency, determine the intake and outlet enthalpy of the air.

Step 1 Determine the enthalpy of the compressed air entering the combustor (h_{1CO}):

Given the compressor's inlet temperature and compression ratio, use the AIR Table to find the relevant pressures, then the outlet temperature, and finally the compressed air enthalpy.

1. Find the enthalpy and reduced pressure (Pr) of the air entering the compressor:

From CHOTKEH's AIR table, for $T = 60 + 460 = 520$ oR $h_{1C} = 124.3$ BTU/lbm

From the same AIR table, for $T = 520$ oR $Pr_1 = 1.2$

2. Find the ideal enthalpy of the air exiting the compressor (h_{2CI}):

2.1 Determine the reduced pressure at the exit:

From $Pr_2 = Pr_1 \times \text{compression ratio}$: $Pr_2 = 1.2 \times 11$ $Pr_2 = 13.2$

2.2 By knowing the Pr_2 , determine the ideal temperature:

From CHOTKEH's AIR table, for $Pr = 13.2$ (Assume $T > 850$ oR)

$T_{2CI} = 1019.3$ oR

2.3 By knowing the temperature, determine the ideal enthalpy:

From CHOTKEH's AIR table, for $T = 1019.3$ oR $h_{2CI} = 245.9$ BTU/lbm

2.4 Determine the actual enthalpy of the air exiting the compressor (h_{2C}):

Refer to compressor's enthalpy equation (15) **ENTH (PCYCL/COMP)**

For $h_{1C} = 124.3$ BTU/lbm, $h_{2CI} = 245.9$ BTU/lbm, and $\eta_c = .82$

$h_{2C} = 272.6$ BTU/lbm

This is the enthalpy of air entering the combustor: $h_{1CO} = 272.6$ BTU/lbm

Step 2 Determine the enthalpy of the air at the exit of the combustor (h_{2CO}):

From CHOTKEH's AIR table, for $T = 2300$ oR $h_{2CO} = 588.9$ BTU/lbm

Step 3 Determine the efficiency of the combustor:

Refer to combustor's heat balance equation (47) **HTBAL (PCYCL/G.TURB/CMBS)**

For $MG = 110$ lbm/sec (given), $h_{2CO} = 588.9$ BTU/lbm, $h_{1CO} = 272.6$ BTU/lbm,

$MFU = 8200/3600 = 2.2778$ lbm/sec, and $HV = 18200$ BTU/lbm

$\eta_{co} = .839 = 83.9\%$, Answer for (a).

POWER CYCLE EXAMPLES

33. Determine the power generated by gas turbine's generator

Solution:

To calculate the generated power, determine the gas turbine's intake and outlet enthalpy:

Step 1 Determine the enthalpy of the air entering the gas turbine (h_{1G}):

This is the same as enthalpy at the combustor's exit (h_{2CO}) $h_{1G} = 588.9 \text{ BTU/lbm}$

Step 2 Determine the enthalpy of the gas at the exit of turbine (h_{2G}):

1. Find the relevant pressure (P_r) of the air entering the turbine:

From CHOTKEH's AIR table, for $T = 2300 \text{ oR}$ $P_{r1G} = 308.5$

2. Find the relevant pressure at the exit of the turbine (P_{r2G}):

Refer to relevant pressure equation (57) P_r (PCYCL/G.TURB)

From $P_{2G} = 17 \text{ psia}$ (given), $P_{1G} = 14.7 \times 12 = 176.4 \text{ psia}$ (Compressor's intake pressure * compression Ratio), and $P_{r1G} = 308.5$ $P_{r2G} = 29.7$

3. By knowing the P_{r2G} , determine the exit ideal temperate (T_{2IG}):

From CHOTKEH's AIR table, for $P_r = 29.7$ (Assume $T > 1150 \text{ oR}$) $T_{2IG} = 1269.9 \text{ oR}$

4. Also by knowing the temperature, determine the ideal enthalpy (h_{2GI}):

From CHOTKEH's AIR table, for $T = 1269.9 \text{ oR}$ $h_{2GI} = 309.3 \text{ BTU/lbm}$

5. Determine the actual enthalpy of the air exiting the turbine (h_{2G}):

Refer to turbine's enthalpy equation (48) $ENTH$ (PCYCL/G.TURB)

For $h_{1G} = 588.9 \text{ BTU/lbm}$, $h_{2GI} = 309.3 \text{ BTU/lbm}$, and $\eta_o = .72$ $h_{2G} = 387.6 \text{ BTU/lbm}$

Step 3 Determine the power of generator:

NOTE: As it shows in the figure above, the gas turbine is powering both the compressor and electric generator.

For English system with the flow lbps , refer to gas turbines power equation (51) $LBPS$ (PCYCL/G.TURB/POWER/ENG/KW)

For $M_G = 110 \text{ lbm/sec}$ (given), $h_{1G} = 588.9 \text{ BTU/lbm}$, $h_{2G} = 387.6 \text{ BTU/lbm}$, $h_{2C} = 272.6 \text{ BTU/lbm}$ (compressor's outlet enthalpy), $h_{1C} = 124.3 \text{ BTU/lbm}$ (compressor's intake enthalpy) and, $\eta_{GEN} = .98$

$kWG = 6026.5 \text{ kw, Answer.}$

POWER CYCLE EXAMPLES

34. Determine the power generated by the steam turbine's generator

Solution:

To calculate the generated power, determine the mass flow of steam.

Step 1 Determine the inlet enthalpy of the gas entering the boiler (h1G):

This is enthalpy of the gas at the gas turbine's exit:

$$\underline{h1G = 387.6 \text{ BTU/lbm}}$$

Step 2 Determine the enthalpy of the gas at the exit of the boiler (h2G):

From CHOTKEH's AIR table, for **T=750 oR**

$$\underline{h2G = 179.7 \text{ BTU/lbm}}$$

Step 3 Determine the enthalpy of feed water to the boiler (h1B):

This will be the enthalpy of condensed water after the feed pump (h2P).

1. Determine the enthalpy of condensed water:

From the CHOTKEH's SAT.P table, for **P=5 psia** h1P (hf) = 129.9 BTU/lbm

2. Determine the enthalpy of condensed water after the pump:

2.1 Determine the Specific Volume (SPC.V) of condensed water (vf1P)

From the CHOTKEH's SAT.P table, for **P=5 psia** vf1P (vf) = .01642 cf/lbm

2.2 Calculate the enthalpy

For English system, refer to pump enthalpy equation (105) **ENTH**
(PCYCL/S.TURB/PUMP/ENG)

for **h1P=129.9 BTU/lbm**, **vf1P=.01642 cf/lbm**, **p2P (steam pressure)=320*144=46,080**

psfa, **p1P=5*144=720 psfa**, and **$\eta_p = .67$**

$$\underline{h1B = h2P = 131.3 \text{ BTU/lbm}}$$

Step 4 Determine the enthalpy of steam, leaving the boiler (h2B):

From the CHOTKEH's SUPHT table, for **P=320 psia** and **t=980 oF**

$$\underline{h2B = 1515.4 \text{ BTU/lbm}}$$

Step 5 Calculate the mass flow of steam (MS):

Refer to waste heat boiler/heat exchanger heat balance equation (92) **HTEXC**
(PCYCL/S.TURB/BOILR)

MG=110 lbm/sec, **h1G=387.6 BTU/lbm**, **h2G=179.7 BTU/lbm**, **$\eta_s=.84$** ,

h2B=1515.4 BTU/lbm, and **h1B=131.3 BTU/lbm**

$$\underline{MS = 13.88 \text{ lbm/sec}}$$

POWER CYCLE EXAMPLES

Step 6 Determine the power of generator:

1. Determine the enthalpy of steam entering the turbine:

Use the Mollier diagram,

For **P=320** psia, and **t=980** oF

$$\underline{h_{1S} = 1514 \text{ BTU/lbm}}$$

2. Determine the ideal enthalpy of the steam leaving the turbine:

For **P=5** psia (Moullier diagram)

$$\underline{h_{2SI} = 1089 \text{ BTU/lbm}}$$

3. Calculate the actual enthalpy of the steam leaving the turbine:

For enthalpy at the exit, refer to equation (93) **EXIT** (PCYCL/S.TURB/ENTH)

For $h_{1S}=1514$ BTU/lbm, $h_{2SI}=1089$ BTU/lbm, and $\eta_s=.78$

$$h_{2S} = 1182.5 \text{ BTU/lbm}$$

4. For a single pass turbine in English system, refer to gas turbine's power equation (98)
SINGL (PCYCL/S.TURB/POWR/ENG/KW)

For **MS=13.88 lbm/sec** (step 5), **h1S=1514 BTU/lbm**, **h2S=1182.5 BTU/lbm**,
and **$\eta_{\text{comp}}=.98$**

kw=4756.3 kw, Answer.

35. Determine the system's overall efficiency

Solution:

For English system with the known amount of input heat, refer to system's efficiency equation (36)

QIN (PCYCL/EFFI/SYST/ENG)

For $kW=6026.5+4756.3=10782.8$ kw, $kWin=0$ (neglected the pump's consumed power), and $qin=8200*18200=149,240,000$ BTU/hr (fuel heat equivalent)

$$\eta_{sys} = .247 = 24.7\% \text{ , Answer.}$$

* * * * *

36. A walk-in refrigerator/freezer, as shown in the system sketch below, has the following characteristics:

Heat removal: 18,000 BTU/hr Refrigerant: R-12

Compressor:

Condenser:

Exit pressure: 120 psia

Inlet pressure: 120 psia

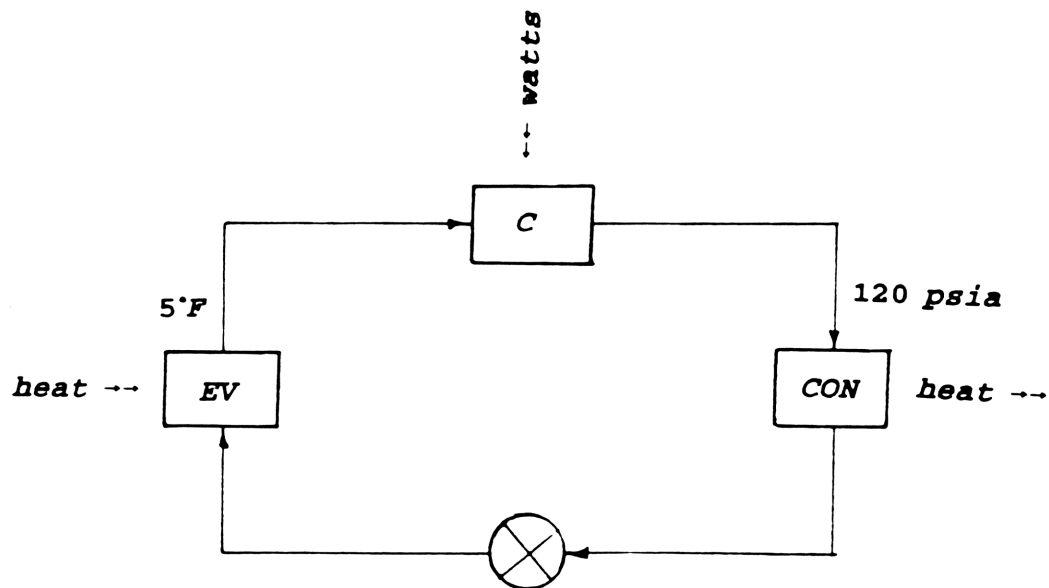
Thermal efficiency: 79%

State of R-12 at exit: saturated liquid

POWER CYCLE EXAMPLES

Evaporator:

Exit temperature: 5 oF



Based on the above information, determine:

- a. The R-12's temperature at compressor's exit.
- b. The mass flow of R-12 in lbm/hr.
- c. The compressor's motor horsepower. Assume 86% and 92% mechanical and electrical efficiency
- d. The system's Coefficient Of Performance (COP).
- e. The system's Energy Efficiency Ratio (EER).

Solution:

Use the Freon-12 gas tables to solve this problem.

- a. To find the R-12's temperature at the compressor's exit, find the inlet and exit enthalpy.

Step 1 Determine the inlet enthalpy (h_{1C}):

From saturated gas, by pressure, table

For t=5 oF

$$h_{1C} = h_g(5 \text{ oF}) = 78.79 \text{ BTU/lbm}$$

$$s_{1C} = s_g(5 \text{ oF}) = .17052 \text{ BTU/lbm-oR}$$

POWER CYCLE EXAMPLES

Step 2 Find the ideal enthalpy at the exit (h_{2CI}):

From saturated gas, by pressure, table

For $P=120$ psia $s_{2C} = s_g(120 \text{ psi}) = .1661 \text{ BTU/lbm-oR}$

Since $s_{2C} < s_{1C}$, therefore R-12 is super heated at the compressor's exit.

(Looked up for s_{2C} only to determine the state of the gas at the exit)

From super heated table

For $P=120$ psia and $s_g=.17052 \text{ BTU/lbm-oR}$ (interpolation) $h_{2CI} = 90.58 \text{ BTU/lbm}$

Step 3 Determine the actual enthalpy at the exit (h_{2C}):

Refer to compressor's enthalpy equation (15) **ENTH (PCYCL/COMP)**

For $h_{1C}=78.79 \text{ BTU/lbm}$, $h_{2CI}=90.58 \text{ BTU/lbm}$, and $\eta_C=.79$

$h_{2C} = 93.71 \text{ BTU/lbm}$.

Step 4 Determine the actual temperature at the exit (t_{2C}):

From super heated table

For $P=120$ psia and $h=93.71 \text{ BTU/lbm}$ (interpolation) $t_{2C} = 128 \text{ oF}$

$t_{2C} = 128 \text{ oF}$, Answer for (a).

- b. To find the mass flow, with the input heat in BTUH, refer to refrigeration evaporator's heat balance equation (89) **BTUH (PCYCL/REFRI/ENG/EVAP/HTBAL)**

For $q_{in}=18,000 \text{ BTU/hr}$, $h_{2EV}=h_g(5 \text{ oF})=78.79 \text{ BTU/lbm}$, $h_{1EV}=h_f(120 \text{ psia})=29.53 \text{ BTU/lbm}$

$MG = .1015 \text{ lbm/sec}$.

$m = 365.4 \text{ lbm/hr}$, Answer for (b).

- c. To find the **hp** in ENG system refer to compressor's equation (17) **HP (PCYCL/COMP/POWR/ENG)**

For $MG=.1015 \text{ lbm/sec}$, $h_{2C}=93.71 \text{ BTU/lbm}$, $h_{1C}=78.79 \text{ BTU/lbm}$ $hp_C = 2.143 \text{ hp}$

For motor's horsepower, considering the efficiencies, type 0.86 press ÷ and 0.92 press ÷

$hp = 2.71 \text{ hp}$, Answer for (c).

- d. To find the COP, with the given q_{in} , refer to refrigeration COP equation (83) **QIN (PCYCL/REFRI/ENG/COP)**

For $q_{in}=18000 \text{ BTU/hr}$, and $hp=2.71 \text{ hp}$

$COP = 2.61$, Answer for (d).

POWER CYCLE EXAMPLES

- e. To find the EER, with the calculated **hp**, refer to refrigeration EER equation (87) **HP**
(PCYCL/REFRI/ENG/EER)

For $\text{tonR} = 18000/12000 = 1.5$ ton and $\text{hp} = 2.71$ hp

$$\text{EER} = 8.91, \text{ Answer for (e).}$$

* * * * *

37. A refrigeration system, as shown below, works under the following conditions:

Heat removal: 50,000 BTU/hr

Refrigerant: R-12

Compressor:

Condenser:

Exit pressure: 120 psia

Exit temperature: 90 oF

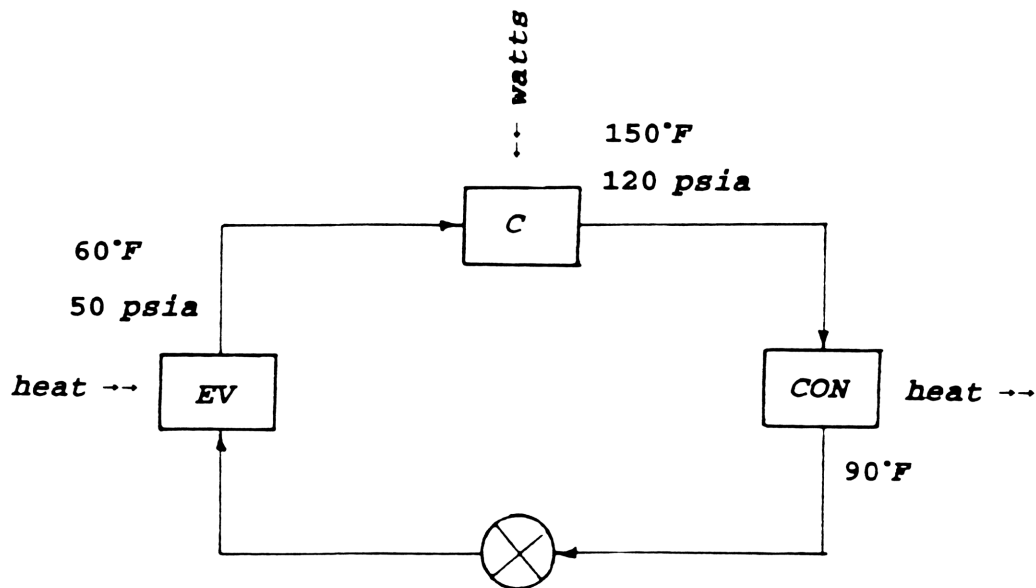
Exit temperature: 150 oF

State of R-12 at exit: saturated liquid

Evaporator:

Exit temperature: 60 oF

Exit pressure: 50 psia.



POWER CYCLE EXAMPLES

Based on the above information, determine:

- a. The mass flow of refrigerant in lbm/hr.
- b. If the evaporator's condition changed to 35 psia and 40 oF, determine the new cooling capacity of the system. Assume constant displacement constant speed compressor.
- c. The COP for condition (a). Assume isentropic process.
- d. The COP for condition (b). Assume isentropic process.

Solution:

To solve this problem use the R-12 tables.

- a. To find the mass flow, with the capacity in **BTUh**, refer to refrigeration evaporator's heat balance equation (89) **BTUH** (PCYCL/REFRI/ENG/EVAP/HTBAL)

For $q_{in}=50,000$ BTU/hr, $h_{2EV}=h(50 \text{ psi}, 60 \text{ oF})=85.72$ BTU/lbm, and

$h_{1EV}=h_f(90 \text{ oF})=28.70$ BTU/lbm.

$MG = .24358$ lbm/sec.

$$m = 876.9 \text{ lbm/hr, Answer for (a).}$$

- b. For a constant displacement compressor, since the displaced volume remains constant, under both conditions "a" and "b", therefore the following equation pertains:

$$m_a * v_a = m_b * v_b$$

For $m_a=876.9$ lbm/hr, $v_a=.863$ cf/lbm (specific volume at 50 psia and 60 oF), and $v_b=1.273$ cf/lbm (specific volume at 35 psia and 40 oF)

$m_b = \text{key in } 876.9 * .863 / 1.273 \text{ EVAL}$

$m_b = 594.5$ lbm/hr

To find the new cooling capacity, refer evaporator's heat balance equation (89) **BTUH** (PCYCL/REFRI/ENG/EVAP/HTBAL)

For $MG=594.5$ lbm/hr=.16514 lbm/sec, $h_{2EV}=h(35 \text{ psi}, 40 \text{ oF})=83.40$ BTU/lbm,

$h_{1EV}=28.70$ BTU/lbm (no change)

$$q_{in} = \text{capacity} = 32,519 \text{ BTU/hr, Answer for (b).}$$

- c. Step 1: Under the isentropic process ($\eta_c=1$), find the compressor's horsepower.

For English system, refer to equation (17) **HP** (PCYCL/COMP/POWR/ENG)

For $MG=.24358$ lbm/sec, $h_{2C}=h_{2CI}=97.3$ BTU/lbm (at 120 psia, and 150 oF),

$h_{1C}=85.72$ BTU/lbm

$hp_C = 3.99$

Step 2: To find the COP, with the q_{in} is known, Refer to refrigeration COP equation (83) **QIN** (PCYCL/REFRI/ENG/COP)

For $q_{in}=50,000$ BTU/hr, and $hp=3.99$

$$\text{COP} = 4.92, \text{ Answer for (c).}$$

POWER CYCLE EXAMPLES

- d. Step 1: Like question "c", refer to compressor equation (17) **HP** (PCYCL/COMP/POWR/ENG)
 For **MG** = .16514 lbm/sec, **h_{2C}** = **h_{2CI}** = 97.3 BTU/lbm (at 120 psi, and 150 oF),
h_{1C} = **h**(35 psi, 40 oF) = 83.4 BTU/lbm hp_C = 3.25 hp

- Step 2: To find the COP, with the **q_{in}** is known, Refer to registration COP equation (83) **QIN**
 (PCYCL/REFRI/ENG/COP)
 For **q_{in}** = 32,519 BTU/hr, and **hp** = 3.25

COP = 3.93, Answer for (d).

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38. A refrigeration system, as shown in the sketch below, has the following characteristics:

Refrigeration capacity: 8 tons

Refrigerant: R-12

Compressor:

Condenser:

rpm: 130

exit pressure: 120 psia

Thermal efficiency: 65%

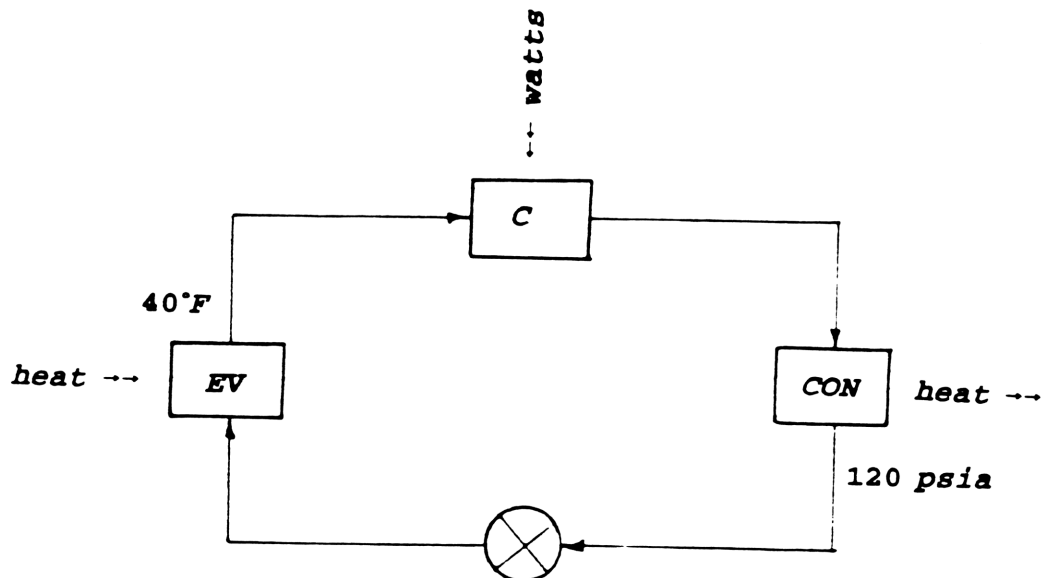
State of R-12 at exit: saturated liquid

Polytropic exponent: 1.25

volumetric clearance: 5.5%

Evaporator:

Exit temperature 40 oF



POWER CYCLE EXAMPLES

Based on the above information, determine:

- a. The piston's displacement.
- b. The input power.

Solution:

- a. To find the piston's displacement:

Step 1: Determine the R-12's mass flow. With the capacity in **tonR**, refer to refrigeration evaporator's heat balance equation (90) **TONR** (PCYCL/REFRI/ENG/EVAP/HTBAL)
For **tonR=8 ton**, **h2EV=hg(40 oF)=82.71 BTU/lbm**, and
h1EV=hf(120 psia)=29.53 BTU/lbm MG = .50144 lbm/sec.

Step 2: To determine the compressor's per stroke displacement, find the compressor's volume efficiency first. Refer to compressor's volumetric equation (24) **VOLM** (PCYCL/EFFI/COMP)
For **P2=120 psi**, **P1=P(40 oF)=51.68 psi**, **n=1.25** (given), and **clr%=5.5**.
 $\eta V = .9471$

Find the displacement. For English system, with the given mass flow, refer to compressor's piston displacement equation (02) **MASS** (PCYCL/COMP/DISP/PISTN/ENG)
For **MG=.51044 lbm/sec**, **vG=vg(40 oF)=.792 cf/lmb**, **$\eta V=.9471$** , and **RPM=130**

$$\text{disp} = 340.4 \text{ ci} = .197 \text{ cf (unit conversion), Answer for (a).}$$

- b. To find the compressor's power in kw, take the following steps:

Step 1 Determine the inlet enthalpy (h1C):
This is equal to evaporator's enthalpy at the exit h1C = 82.71 BTU/lbm

Step 2 Determine the ideal enthalpy at the exit (h2CI):
For the isentropic process:
1. Find the entropy at the entrance (**40 oF**) s1g = .16833 BTU/lbm-oR

2. The gas at the exit is super-heated. For **P=120 psi**, and the entropy remains the same, or
s2g=.16833 BTU/lbm-oR (Interpolation) t2 = 101.07 oF

3. From the same table, for **P=120 psia**, and **t=101.7 oF** h2CI = 89.3 BTU/lbm

POWER CYCLE EXAMPLES

Step 3 Determine the actual enthalpy at the exit (h_{2C}):

Refer to compressor's equation (15) **ENTH** (PCYCL/COMP)

For $h_{1C}=82.71$ BTU/lbm, $h_{2CI}=89.3$ BTU/lbm, and $\eta_C=.65$

$$h_{2C} = 92.85 \text{ BTU/lbm.}$$

Step 4 Determine the power in kW:

For English system, refer to compressor's power equation (18) **KW** (PCYCL/COMP/POWR/ENG)

For $MG=.51044$ lbm/sec, $h_{2C}=92.85$ BTU/lbm, and $h_{1C}=82.71$

$$kW_C = 5.46 \text{ kw, Answer for (b).}$$

* * * * *

39. A walk-in freezer, as shown in the sketch below, has the following characteristics:

Refrigeration capacity: 2 tons

Refrigerant: R-12

Compressor:

Condenser:

rpm: 300

exit pressure: 100 psia

Thermal efficiency: 70%

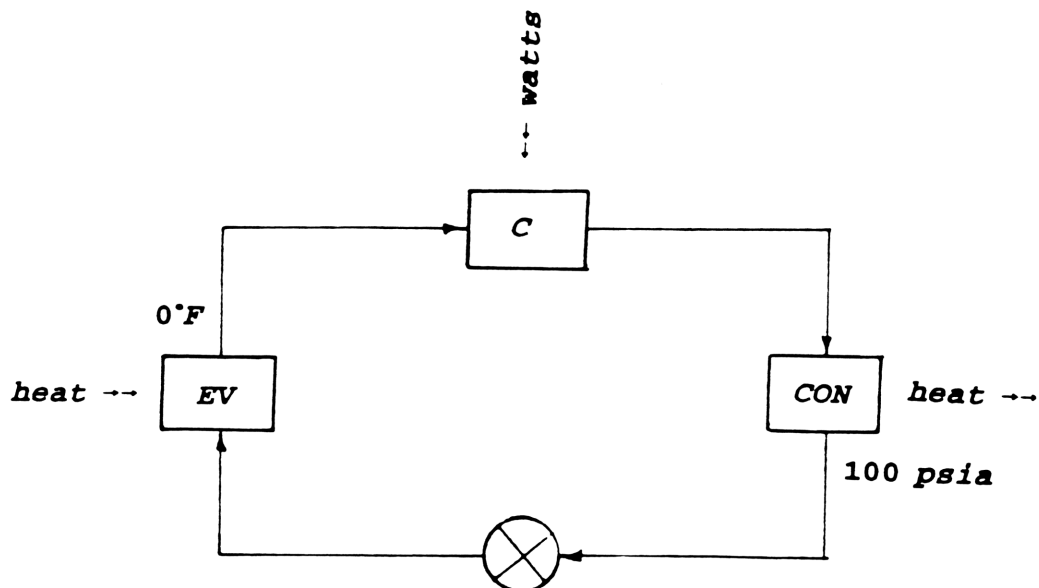
State of R-12 at exit: saturated liquid

Polytropic exponent: 1.2

volumetric efficiency: 78%

Evaporator:

Exit temperature: 0 oF



POWER CYCLE EXAMPLES

Based on the above information, determine:

- a. The piston's displacement.
- b. The input power.

Solution:

- a. To find the piston's displacement:

Step 1: Determine the R-12's mass flow. With the capacity in **tonR**, refer to refrigeration evaporator's heat balance equation (90) **TONR** (PCYCL/REFRI/ENG/EVAP/HTBAL)
 For **tonR=2 ton**, **$h_{2EV}=h_g(0\text{ oF})=78.21\text{ BTU/lbm}$** , and
 $h_{1EV}=h_f(100\text{ psia})=26.49\text{ BTU/lbm}$ $MG = .1289\text{ lbm/sec.}$

Step 2: For English system, to determine the compressor's per stroke displacement, with the volumetric efficiency and mass flow are given, refer to compressor's displacement equation (02) **MASS** (PCYCL/COMP/DISP/PISTN/ENG)
 For **$MG=.1289\text{ lbm/sec}$** , **$v_g=v_g(0\text{ oF})=1.637\text{ cf/lbm}$** , **$\eta_v=.78$** , and **$RPM=300\text{ rpm}$**

$\text{disp} = 93.5\text{ ci} = .0541\text{ cf (unit conversion), Answer for (a).}$

- b. To find the compressor's power in kw, take the following steps:

Step 1 Determine the inlet enthalpy (**h_{1C}**):

This is equal to evaporator's enthalpy at the exit $h_{1C} = 78.21\text{ BTU/lbm}$

Step 2 Determine the ideal enthalpy at the exit (**h_{2CI}**):

For the isentropic process:

1. Find the entropy at the entrance (**0 oF**) $s_{1g} = .17091\text{ BTU/lbm-oR}$

2. The gas at the exit is super-heated. For **$P=100\text{ psi}$** , and the entropy remains the same, or
 $s_{2g}=.17091\text{ BTU/lbm-oR}$ (Interpolation) $t_2 = 95.7\text{ oF}$

3. From the same table, for **$P=100\text{ psia}$** , and **$t=95.7\text{ oF}$** $h_{2CI} = 89.2\text{ BTU/lbm}$

Step 3 Determine the actual enthalpy at the exit (**h_{2C}**):

Refer to compressor's equation (15) **ENTH** (PCYCL/COMP)

For **$h_{1C}=78.21\text{ BTU/lbm}$** , **$h_{2CI}=89.2\text{ BTU/lbm}$** , and **$\eta_C=.7$**

$$\text{h2C} = 93.9\text{ BTU/lbm.}$$

POWER CYCLE EXAMPLES

Step 4 Determine the power in kw:

For English system, refer to compressor's power equation (18) KW
(PCYCL/COMP/POWR/ENG)

For $MG = .1289$ lbm/sec, $h2C = 93.9$ BTU/lbm, and $h1C = 78.21$

$$kW_C = 2.13 \text{ kw, Answer for (b).}$$

* * * * *

40. A refrigerator system, as shown in the sketch below, has the following characteristics:

Compressor:

Bore: 6 in.

Stroke: 10 in.

Type: double action

Polytropic exponent: 1.2

rpm: 210

Refrigerant: Ammonia

Condenser:

Inlet temperature: 110 oF

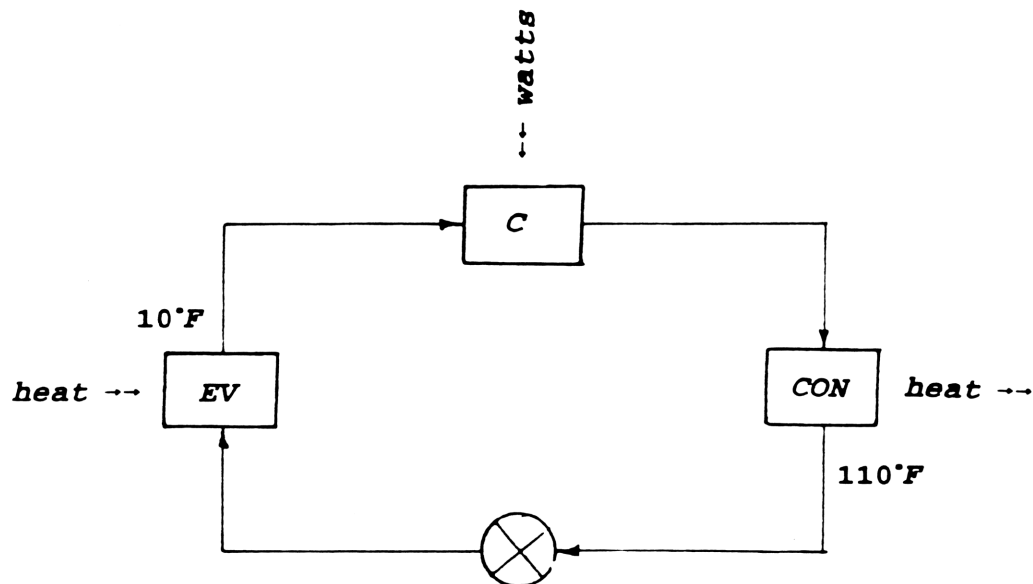
State at inlet: Saturated gas

State at exit: Saturated liquid

Evaporator:

Exit temperature: 10 oF

Ammonia at exit: Saturated gas



POWER CYCLE EXAMPLES

Based on the above information, determine:

The system's cooling capacity.

Solution:

Use the Ammonia property tables for this problem.

To find the cooling capacity, calculate the mass flow of the ammonia first:

Step 1: Determine the volumetric efficiency of the compressor. Refer to compressor's volumetric efficiency (24) **VOLM** (PCYCL/EFFI/COMP)

For **P2**=P(saturated ammonia at 110 oF)=**247.7** psia, **P1**=P(saturated ammonia at 10 oF)=**38.51** psia, **n**=**1.2**, and **clr**%=**6** $\eta_v = .777$

Step 2: Find the mass flow quantity of the gas. For English system with the given bore and stroke of the compressor, refer to compressor's gas displacement equation (07) **B&S** (PCYCL/COMP/DISP/GAS/ENG/MASS)

For **bore**=**6** in., **strk**=**10** in., **RPM**=**210** rpm, **η_v** =**.777** ,

and **vG**=**vg(110 oF)**=**1.217** cf/lbm.

MG = .36563 lbm/sec

or for double action:

MG = .73126 lbm/sec.

Now by knowing the mass flow rate, to find the system's cooling tonnage, refer to refrigeration evaporator's equation (90) **TONR** (PCYCL/REFRI/ENG/EVAP/HTBAL)

For **MG**=**.73126** lbm/sec, **h2EV**=**hg(10 oF)**=**614.9** BTU/lbm,

h1EV=**hf(110 oF)**=**167** BTU/lbm.

tonR = **98.26** ton, Answer.

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41. An internal combustion engine is working under the following condition/characteristics:

Intake air:

Pressure: 14.7 psia

Temperature: 75 oF

Characteristics:

a. bhp: 180 hp

b. air/fuel ratio: 20

c. SFC: .44 lbm/hp-hr

d. mechanical efficiency: 88%

If the intake air's conditions change to 12 psia and 58 oF, determine:

The new characteristics (a thru d) of the engine.

POWER CYCLE EXAMPLES

Solution:

- a. To find the new horsepower, determine the new indicated horsepower and deduct the friction horsepower, which is assumed to be the same for both conditions.
Considering the similar intake air volume, for both conditions, the following equation pertains:

$$ihp2 = ihp1 * P2 * T1 / P1 * T2$$

For $ihp1 = 180 / .88 = 204.55$ hp, $P2 = 12$ psia, $T1 = 75 + 460 = 535$ oR, $P1 = 14.7$ psia, and $T2 = 58 + 460 = 518$ oR

key in ' $204.55 * 12 * 535 / (14.7 * 518)$ EVAL

$$ihp2 = 172.5 \text{ hp}$$

From $bhp2 = ihp2 - (ihp1 - bhp1)$

Key in ' $172.5 - (204.55 - 180)$ EVAL

$$bhp (2) = 147.95 \text{ hp, Answer for (a).}$$

- b. To find the new air/fuel ratio (AFR), use the following equation:

$$AFR2 = AFR1 * P2 * T1 / P1 * T2$$

For $AFR1 = 20$, $P2 = 12$ psia, $T1 = 75 + 460 = 535$ oR, $P1 = 14.7$ psia, and $T2 = 58 + 460 = 518$ oR

key in ' $20 * 12 * 535 / (14.7 * 518)$ EVAL

$$\text{air/fuel ratio (2)} = 16.86, \text{ Answer for (b).}$$

- c. To find the new air/fuel Specific Fuel Consumption (SFC), use the following equation:

$$SFC2 = SFC1 * ihp1 / ihp2$$

For $SFC1 = .44$ lbm/hp-hr, $ihp1 = 204.55$ hp, and $ihp2 = 172.5$

key in ' $.44 * 204.55 / 172.5$ EVAL

$$SFC (2) = .52 \text{ lbm/hp-hr, Answer for (c).}$$

- d. For the new mechanical efficiency, which is $bhp2 / ihp2$

For $bhp2 = 147.95$ hp, and $ihp2 = 172.5$

key in ' $147.95 / 172.5$ EVAL

$$\eta_m (2) = .86 = 86\%, \text{ Answer for (d).}$$

POWER CYCLE EXAMPLES

42. An internal combustion engine works under the following conditions:

rpm: 4800 Number of stroke: 4 Number of cylinders: 8 Fuel: gasoline

If the work performed (thru expansion) and the work required (for compression) are 1600 ft-lbf and 1250 ft-lbf per cylinder per cycle, determine:

- a. The indicated horsepower.
- b. Thermal efficiency of the engine. Assume an input energy of 1.4 BTU/cylinder/cycle.
- c. The amount of gasoline consumed in gallon/hr. Assume the specific gravity and the heat value of gasoline are equal to .75 and 19,000 BTU/lbm, respectively.
- d. The specific fuel consumption.

Solution:

- a. To find the indicated horsepower, in English system, with the given effective mean work (W_m), refer to engine's indicated horsepower equation (71) W_m (PCYCL/ENG/IHP/ENG)
For $W_m = 1600 - 1250 = 350$ ft-lbf/cylinder/cycle, $RPM = 4800$ rpm, $NCYL = 8$ cylinder, and $NSTR = 4$ stroke/cycle.

$$ihp = 203.64 \text{ hp, Answer for (a).}$$

- b. To find the thermal efficiency, in English system, with the given input energy (q_{in}), refer to thermal efficiency of engine equation (26) Q_{IN} (PCYCL/EFFI/ENG/THRM/ENG).
For $W_{out} = 350$ ft-lbf = $350/778 = .45$ BTU/cylinder/cycle and $q_{in} = 1.4$ BTU/cylinder/cycle.

$$\eta_{th} = .321 = 32.1\%, \text{ Answer for (b).}$$

- c. To find the fuel consumption, in Eng. system, refer to equation (68) ENG (PCYCL/ENG/FC).
For $hp = 203.64$ hp, $HV = 19,000$ BTU/lbm, and $\eta_{th} = .321$
 $FC = 84.98 \text{ lbm/hr} = 84.98 / (.75 * 62.4) = 1.82 \text{ cf/hr.}$ or by unit conversion

$$FC = 13.61 \text{ gallons/hr, Answer for (c).}$$

- d. For specific fuel consumption, in English system, refer to equation (76) ENG (PCYCL/ENG/SFC).
For $HV = 19,000$ BTU/hr and $\eta_{th} = .321$

$$SFC = .417 \text{ lbm/hp-hr, Answer for (d).}$$

POWER CYCLE EXAMPLES

43. A passenger car requires 40 brake horsepower to run at 65 mph on a horizontal road (condition "a"). The characteristics of the car and engine are as follows:

Engine (gasoline):

stroke: 4/cycle

displacement: 370 ci/cycle

Car:

Wheel diameter: 26 in.

rpm transmission ratio: 3/1

Under a different condition ("b"), when the car runs at the same 65 mph, the following data are measured:

mean effective pressure: 140 psi Mechanical efficiency: 84%

Brake specific fuel consumption (BSFC): .48 lbm/hp-hr.

Assuming that the thermal and mechanical efficiency, for both conditions, remains the same, determine:

The mile/gallon of the car for condition "a" (65 mph, level road).

Solution:

To solve this problem determine the friction horsepower for condition "b" and add it to **bhp** of condition "a" to find the **ihp** of condition "a" and finally find the fuel consumption.

Step 1 Find the engines rpm:

For English system, refer to engine **RPM** of car equation (60) **RPM**
(PCYCL/ENGN/CAR/ENG)

For **mph=65**, **TR**=(Transmission Ratio)=3, and **WIL.d**=(Wheel diameter)=26 in.

$$\underline{\text{RPM} = 2521}$$

Step 2 Find the indicator horsepower:

For English system, with the given engine's displacement, refer to engine's indicated horsepower equation (72) **DISP** (PCYCL/ENGN/IHP/ENG)

For **Pm=140 psi**, **disp=370 ci/cycle**, **RPM=2521 rpm**, and **NSTR=4 stroke/cycle**.

$$\underline{\text{ihp}(b) = 165}$$

Step 3 Determine the friction horsepower:

From **fhp=ihp(1- η_M)**, key in '165*(1-.84) **EVAL** **fhp = 26.4 hp**

Now by having the friction loss: **ihp (a)=40+26.4** **ihp (a) = 66.4 hp**

For English system, to find the mile/gallon, **MPG**, refer to car equation (61) **MPG**
(PCYCL/ENGN/CAR/ENG)

For **SGF=.75** (assumed Specific Gravity of Fuel as .75), **mph=65**, **SFC=.48 lbm/ihp-hr**,
and **hp=ihp(a)=66.4 hp**

$$\text{MPG} = 12.76 \text{ mile/gallon Answer.}$$

POWER CYCLE EXAMPLES

44. A 12 cylinder, 4 stroke, 1200 rpm, and 18:1 air/fuel ratio diesel engine, drives a 600 kw generator. The generator's efficiency is 90% and the brake specific fuel consumption is .42 lbm/bhp-hr. Also the intake air has a temperature of 97 oF and 25 inHg pressure. If the stroke of the piston is 1.25 times of the bore, determine:
- The bore and stroke of each cylinder. Assume 82% volumetric efficiency.
 - The volumetric clearance of each cylinder. Assume compression ratio equals to 16.

Solution:

- a. To find the bore and stroke, calculate the engine's displacement first.

Step 1 Find the brake fuel consumption (BFC):

From $BFC = BSFC \cdot bhp$

For $BSFC = .42 \text{ lbm/bhp-hr}$ and $bhp = 600 \text{ kw}/(.7457 \cdot .9)$

Key in $.42 \cdot 600 / (.7457 \cdot .9)$ EVAL

$$BFC = 375.5 \text{ lbm/hr}$$

Step 2 Find the volume of intake air based on BFC, air/fuel ratio, and intake air condition:

1. mass of the air = $BFC \cdot \text{air/fuel ratio} = 375.5 \cdot 18$ mair = 6795 lbm/hr = 113.25 lbm/min

2. To find the volume of air, use the ideal gas equation (39) **IDEAL** (PCYCL/GAS)

For $p = 25 \text{ inHG} = 1768.2 \text{ psf}$ (unit conversion), $m = 113.25 \text{ lbm/min}$, $R = 53.3 \text{ ft-lbf/lbm-oR}$, and $T = 97 + 460 = 557 \text{ oR}$

$$\text{cfmG} = 1901.5 \text{ cfm}$$

Step 3 Determine the engines displacement:

For English system with the given total volume, refer to engine's displacement equation (65) **VOLM** (PCYCL/ENG/ENG/ENG)

For $\text{cfmG} = 1901.5 \text{ cfm}$, $\eta_v = .82$, $RPM = 1200 \text{ rpm}$ disp = 6678 ci

Step 4 Calculate the bore and stroke of a cylinder:

For the **B&S** to be calculated, in English system, refer to engine displacement equation (64) **B&S** (PCYCL/ENG/ENG/ENG)

For $\text{disp} = 6678 \text{ ci/cycle}$, $\text{strk} =$ key in 1.25 press soft key under BORE (you should see $1.25 \cdot \text{bore}$ ENTER , press STRK, and $NCYL = 12$ cylinder

Press $\leftarrow$ BORE, Press $\leftarrow$ STRK (solve for bore first)

$$\text{bore} = 8.3 \text{ in.}, \text{stroke} = 10.3 \text{ in.}, \text{Answers for (a).}$$

- b. To find the volumetric clearance, refer to engine equation (76) **VCLR** (PCYCL/ENG/ENG)
- For $\text{disp} = 6678 \text{ ci}$, $CR = (\text{compression ratio}) = 16$, and $NCYL = 12$ cylinder

$$VC = \text{volume clearance} = 37.1 \text{ ci.}, \text{Answers for (b).}$$

POWER CYCLE EXAMPLES

45. Determine the entropy of .85 MPaa steam if its quality is equal to 0.9.

Solution:

To find the entropy of steam, the entropy of saturated liquid (sf) and saturated steam (sg) must be calculated first.

Step 1 Find sf:

At LIBRARY press $\leftarrow$ PREV SAT.P ENTR SI SF NXT .8 <MPa< 1.7
For P=.85 MPaa sf = 2.071 kJ/kg.K

Step 2 Find sg:

At LIBRARY press $\leftarrow$ PREV SAT.P ENTR SI SG NXT .8 <MPa< 1.7
For P=.85 MPaa sg = 6.643 kJ/kg.K

Step 3 Find the quality, x:

At LIBRARY press $\leftarrow$ PREV SAT.P ENTR SI S
For x=.9 and the stored calculated values for sf and sg (you may check by pressing $\rightarrow$ and the associated soft key for hf and hg.)

$s = 6.186 \text{ kJ/kg.K, Answer}$

* * * * *

46. Determine the quality of 145 oC steam if its enthalpy equals to 2500 kJ/kg.

Solution:

To find the quality of steam, the enthalpy of saturated liquid (hf) and saturated steam (hg) must be calculated first.

Step 1 Find hf:

At LIBRARY press $\leftarrow$ PREV SAT.T ENTH SI HF 100C <T< 150C
For T=145 oC hf = 610.5 kJ/kg

Step 2 Find hg:

At LIBRARY press $\leftarrow$ PREV SAT.T ENTH SI HG 100C <T< 150C
For T=145 oC hg = 2739.2 kJ/kg

Step 3 Find the quality, x:

At LIBRARY press $\leftarrow$ PREV SAT.T ENTH SI X
For h=2500 kJ/kg and the stored calculated values for hf and hg (you may check by pressing $\rightarrow$ and the associated soft key for hf and hg.)

$x = .8867, \text{ Answer}$

POWER CYCLE EXAMPLES

47. Determine (a) the enthalpy and (b) the specific volume of 510 oC super-heated steam at 700 kPaa pressure. Assume atmospheric pressure equals to 100 kPaa.

Solution:

Reminder: Pressure in tables is the absolute pressure. Therefore, $P = 100 + 700 = 800$ kPaa.

- a. At LIBRARY press ↩ PREV SUPHT ENTH SI NXT **.47<MPa<.9 400C<T<650C**
For $T = 510$ oC and $P = .8$ MPa

$$h = 3503.7 \text{ kJ/kg, Answer for (a)}$$

- b. At LIBRARY press ↩ PREV SUPHT SPC.V SI NXT **.47<MPa<.9 400C<T<650C**
For $T = 510$ oC and $P = .8$ MPa

$$v = .4496 \text{ m}^3/\text{kg, Answer for (b)}$$

* * * * *

48. Determine (a) the enthalpy and (b) the entropy of air at 197 oC.

Solution:

Reminder: Temperature in Air Table is in Kelvin (K) scale. Therefore, $T = 197 + 273 = 470$ K

- a. At LIBRARY press ↩ PREV AIR SI ENTH **300K<T<470K**
For $T = 470$ K

$$h = 472 \text{ kJ/kg, Answer for (a)}$$

- b. At LIBRARY press ↩ PREV AIR SI ENTR **300K<T<470K**
For $T = 470$ K

$$\phi = 2.969 \text{ kJ/kg.K, Answer for (b)}$$

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49. Determine the temperature of air (in oC) if its Pressure Ratio (Pr) equals to 26.

SOLUTION:

At LIBRARY press ↩ PREV AIR SI PR. Since the temperature is not known, select the middle range, i.e. NXT **470K<T<640K**

For $Pr = 26$

$$T = 682.7 \text{ K}$$

POWER CYCLE EXAMPLES

Since the calculated temperature (682.7 K) is out of the selected range (470K - 640K), press prev. MENU key and select the proper range (640 - 800K)

For **Pr=26**

$T = 681 \text{ K} = 408 \text{ }^{\circ}\text{C}, \text{ Answer}$

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50. Determine the thermal efficiency of a jet engine compressor with the intake at -25 °C and 48 kPaa with the exhaust at 165 °C and 270 kPaa. Assume $k=1.4$.

Solution:

To find the efficiency of the compressor, take the following steps:

Step 1 Determine the enthalpy of air at the intake (**h1C**):

Refer to CHOTKEH's AIR table. For $T = -25 + 273 = 248 \text{ K}$

$$h1C = 248 \text{ kJ/kg}$$

Step 2 Determine the actual enthalpy of air at the exhaust (**h2C**):

From the same AIR table. For $T = 165 + 273 = 438 \text{ K}$

$$h2C = 439.6 \text{ kJ/kg}$$

Step 3 Determine the ideal enthalpy of air at the exhaust (**h2CI**):

Considering air as an ideal gas, for isentropic process, refer to gas equation (41)

$\delta P / \delta T$ (PCYCL/GAS/ISENT)

For $p2=270 \text{ kPaa}$, $p1=48 \text{ kPaa}$, $T1=248 \text{ K}$, and $k=1.4$ $T2 = 406.2 \text{ K}$

Refer to CHOTKEH's AIR table. For $T=406.2 \text{ K}$

$$h2CI = 407.4 \text{ kJ/kg}$$

Step 4 Calculate the compressor's efficiency (**η_c**):

Refer to thermal efficiency of compressor equation (23) **THRM** (PCYCL/EFFI/COMP)

For $h2CI=407.4 \text{ kJ/kg}$, $h1C=248 \text{ kJ/kg}$, and $h2C=439.6 \text{ kJ/kg}$

$\eta_c = .832 = 83.2\%, \text{ Answer}$

* * * * *

51. Determine the efficiency of a steam power plant, generating 425 MW electric power with the condensate load equals to 6.5EE5 kW. Neglect the power for auxiliary equipment.

Solution:

To find the system's efficiency, in SI system, with the given output heat, refer to efficiency of system equation (35) **QOUT** (PCYCL/EFFI/SYST/SI)

For $kW=425,000$, $kWin=0$, and $qout=6.5EE8 \text{ W (J/s)}$

$\eta_{SYS} = .395 = 39.5\% \text{ Answer}$

POWER CYCLE EXAMPLES

52. Determine the thermal efficiency of a steam turbine with the following characteristics:

Inlet:

Pressure: 5860 kPa

Temperature: 420 °C

Outlet:

Pressure: 1240 kPa

Actual enthalpy: 2900 kJ/kg

Solution:

By knowing the actual outlet enthalpy, to find the efficiency, determine the inlet and ideal outlet enthalpies first, then calculate the efficiency.:

Step 1 Find the inlet enthalpy (h_{1S}):

Refer to CHOTKEH's SUPHT table. For t=420 °C and P=5.86 MPa

$$h_{1S} = 3234.6 \text{ kJ/kg}$$

Step 2 Find the outlet ideal enthalpy (h_{2SI}), where s₁=s₂:

1. Find the entropy at the inlet (s_{1S}):

From CHOTKEH's SUPHT table. For t=420 °C and P=5.86 MPa

$$s_{1S} = 6.6359 \text{ kJ/kg} \cdot ^\circ\text{C}$$

2. Determine the outlet temperature (t_{2SI}):

For isentropic process (ds=0) for outlet pressure P=1.24 MPa

s=6.6359 kJ/kg·°C

$$t_{2SI} = 213.76 \text{ } ^\circ\text{C}$$

3. Assuming the super heated steam, from CHOTKEH's SUPHT table. For t=213.76 °C and P=1.24 MPa

$$h_{2SI} = 2849.5 \text{ kJ/kg}$$

Step 3 Find the efficiency:

Refer to efficiency of steam turbine equation (34) S.TURB (PCYCL/EFFI)

For h_{1S}=3234.6 kJ/kg, h_{2S}=2900 kJ/kg (given), and h_{2SI}=2849.5 kJ/kg

$$\eta_s = .869 = 86.9\%, \text{ Answer}$$

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Problems 53- 54

A process gas at 5700 kPag and 125 °C with the flow rate of 6 lps expands in a gas turbine. The pressure of the gas at the turbine's exhaust is 655 kPag:

Based on the above information solve the following problems.

53. Determine, the temperature of the gas at the turbine's exit. Assume efficiency=79% and k=1.4.

Solution:

To calculate the exit temperature, find the enthalpies first.

Step 1 Find the ideal temperature at the exit:

For an isentropic process, refer to gas equation (41) $\delta P / \delta T$ (PCYCL/GAS/ISENT)

For P₂=655000+101353=756353 Pa, P₁=5700000+101353=5801353 Pa,

T₁=125+273=398 K, and k=1.4

$$T_{2GI} = 222.4 \text{ K}$$

POWER CYCLE EXAMPLES

Step 2 Find the ideal enthalpy at the exit (h2GI):

From CHOTKEH's AIR table, for $T=222.4$ K

$$\underline{h_{2GI} = 222.4 \text{ kJ/kg}}$$

Step 3 Find the inlet enthalpy (h1G):

From CHOTKEH's AIR table, for $T=398$ K

$$\underline{h_{1G} = 399.1 \text{ kJ/kg}}$$

Step 4 Find the actual enthalpy at the exit (h2G):

Refer to gas turbine enthalpy equation (48) **ENTH** (PCYCL/G.TURB)

For $h_{1G}=399.1$ kJ/kg, $h_{2GI}=222.4$ kJ/kg and $\eta_g = .79$

$$\underline{h_{2G} = 259.5 \text{ kJ/kg}}$$

Step 5 Find the actual temperate at the exit (T2G):

From CHOTKEH's AIR table, for $h=259.5$ kJ/kg

$T_{2G} = 260.2 \text{ K} = -12.95 \text{ oC, Answer}$
--

54. Determine the amount of heat that must be added to exhaust gas to raise its temperature to 13 oC.

To find the additional heat, find the mass of the flow first.

For air as an ideal gas, refer to gas equation (39) **IDEAL** (PCYCL/GAS)

For $P=5801353$ Pa, $V=6$ lps = .006 m³/s, $R=286.75$ J/kg.K (equivalent of 53.3 in ENG), and $T=398$ K

$$\underline{m = .305 \text{ kg/s}}$$

Calculate the added heat:

From $q=m \cdot c_p \cdot (t_2 - t_1)$

Key in $'.305 \cdot 1005 \cdot (13 + 12.95)$ **EVAL**

$q = 7954 \text{ W (J/s), Answer.}$

* * * * *

55. Waste steam is used to heat the cold water. The characteristics of the system is as follows:

Steam: Temperature=230 oC Pressure= 800 kPa

Cold water: " = 25 oC " = 500 kPa

Hot water: " = 80 oC " = 150 kPa

Mass flow of hot water=.23 kg/s

Based on the above, determine:

The mass flow rate of the steam, in kg/s.

POWER CYCLE EXAMPLES

Solution:

To find the mass flow find the enthalpies first:

Steam enthalpy: **HS=2906 kJ/kg**, SUPHT table for **P=.8 MPa** and **t=230 oC**

Cold water " : **HW=hf(25 oC)=104.7 kJ/kg**, SAT.T table for **T=25 oC**

Hot water " : **HMIX=hf(80 oC)=334.9 kJ/kg**, SAT.T table for **T=80 oF**

Refer to steam/water mixture heat balance equation (95) **HTBAL** (PCYCL/S.TURB/MIXT)

For **HS=2906 kJ/kg**, **MW=** key in '**.23-MS ENTER** press **MW**, **HW=104.7 kJ/kg**, **MMIX=.23 kJ/kg**, and **HMIX=334.9 kJ/kg**.

Press ↩ MS

MS (steam flow rate) = .019 kg/s

Press ↩ MW

MW (water flow rate) = .211 kg/s

m (steam)= .019 kg/s, Answer.

NOTE: Ensure to solve for MS first, then for MW

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56. Steam at 290 oC and 830 kPa is throttled through a pressure reducing valve, to 220 kPa, and used in a heating plant. If the heating load and the condensate temperature are 7.5 EE6 W and 85 oC respectively, determine:

The mass flow of the steam in kg/s.

Solution:

Assuming $dh=0$ at pressure reducing valve, use the following equation to calculate the mass:

$m=q/(h_1-h_2)$. For:

$q=7.5EE6$ W (given)

$h_1=3032900$ J/kg (From CHOTKEH's SUPHT table, for **P=.83 kPa** and **T=290 oC**)

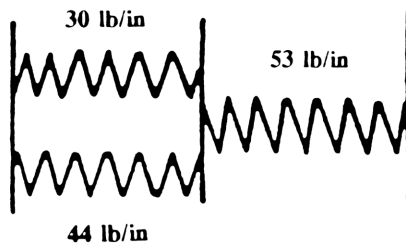
$h_2=hf(85 oC)=355878$ J/kg (From CHOTKEH's SAT.T table, for **T=85 oC**)

key in '**7.5EE6/(3032900-355878) EVAL**

m = 2.8 kg/s, Answer

SPRINGS EXAMPLES

1. For a spring assembly, shown below, determine:
The equivalent spring constant.



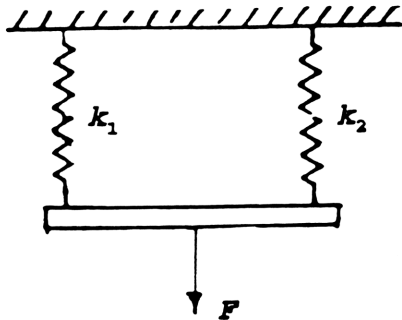
Solution:

- Step 1 Determine the equivalent spring constant for the two in parallel
Refer to parallel spring equation (11) **PARAL** (SPRIN/EQUIV)
For $k_1 = 30$ lb/in, $k_2 = 44$ lb/in, and $k_3 = 0$ $k_e = 74$ lb/in.
- Step 1 Determine the equivalent spring constant for the two in series (modified system)
Refer to series spring equation (12) **TWO** (SPRIN/EQUIV/SERIS)
For $k_1 = 74$ lb/in (k_e , step 1) and $k_2 = 53$ lb/in.

$k_e = 30.9$ lb/in, Answer.

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2. For a spring assembly, shown below, if k_1 is not equal to k_2 , determine:
The equivalent spring constant equation. Assume the load is hung at the middle of the beam.



SPRINGS EXAMPLES

Solution:

Step 1 Write the deflection equation at two ends:

1. For k1 side:

$$y_1 = \frac{F/2}{k_1}$$

2. For k2 side:

$$y_2 = \frac{F/2}{k_2}$$

Step 2 Write the deflection equation at mid point:

$$y = \frac{F}{k_e} = \frac{d_1 + d_2}{2}$$

Step 3 Substitute the y values:

$$\frac{F}{k_e} = \frac{F/2k_1 + F/2k_2}{2} = \frac{F}{4k_1} + \frac{F}{4k_2}$$

$$k_e = \frac{4k_1k_2}{k_1 + k_2}, \text{ Answer.}$$

* * * * *

3. If a three (3) lb weight drops 14 ft on a spring with k=22 lb/in, determine:
The deflection of the spring.

Solution:

Refer to dynamic section (DYNA), example equations (77) **DROP** (DYNA/XMPL/SPRG)

For w=3 lb, k=22 lb/in, and h=14 ft.

$$dy = .58' = 6.9" \text{ Answer.}$$

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4. A spring is initially compressed from its free length of 10" to 8". If the spring is compressed 4" more, determine:
The additional work performed for the second compression. Assume k=22 in/lb.

SPRINGS EXAMPLES

Solution:

Refer to spring's work equation (22) **WORK (SPRIN)**

For $k=22$ lb/in, $y_2=6$ " (final deflection), and $y_1=2$ " (initial deflection).

$$\text{work} = 352 \text{ in-lb, Answer.}$$

* * * * *

5. A cylindrical coil spring has the following characteristics:
- | | |
|-------------------------|------------------------------------|
| Number of coils: 12 | Deflection: 6.5" |
| Wire diameter: 1" | Modulus of shear stress: 12EE6 psi |
| Carrying load: 5800 lb. | Squared and grounded |
- Based on the above information, determine:
- a. The coils mean diameter.
 - b. The stress on the coil.

Solution:

- a. Refer to coil diameter equation (04) **DIAM (SPRIN/COIL)**
For $y=6.5$ ", $G=12\text{EE}6$ psi, $d=1$ ", $F=5800$ lb, and $N=12-2=10$

$$D_m = 5.52", \text{ Answer for (a).}$$

- b. With the given diameters refer to stress equation (15) **DIAM (SPRIN/SHEAR/COREC)**
For $D_m=5.52$ ", $d=1$ ", and $F=5800$ lb

$$\tau = 104139 \text{ psi, Answer for (b).}$$

* * * * *

6. A cylindrical coil spring has the following characteristics:
- | | |
|------------------------|----------------------|
| Number of coils: 18 | Free length: 2.5" |
| Wire diameter: .07" | Squared and grounded |
| Coil mean diameter: 1" | |

Based on the above information, determine:

- a. Spring constant (rate).
- b. Stress at solid length.
- c. Shear stress and load at .6" deflection

SPRINGS EXAMPLES

Solution:

- a. Refer to spring constant/rate equation (14) **RATE** (SPRIN/CONS)
For $d = .07"$, $G = 12 \times 10^6$ psi, $D_m = 1"$, and $N = 18 - 2 = 16$

$k = 2.25 \text{ lb/in, Answer for (a).}$

- b. To determine the stress at solid length:

Step 1 Calculate the amount of load required to make the solid length.

Refer to free length equation (05) **FREE** (SPRIN/COIL/LNTH)

For $L_f = 2.5"$, $k = 2.25 \text{ lb/in}$, $N_t = 18$, and $d = .07"$ $F = 2.79 \text{ lb}$

Step 2 Calculate the shear stress:

With the given diameters refer to stress equation (15) **DIAM** (SPRIN/SHEAR/COREC)

For $D_m = 1"$, $d = .07"$, and $F = 2.79 \text{ lb}$.

$\tau = 22774 \text{ psi, Answer for (b).}$

- c. Stay with the same equation

For $D_m = 1"$, $d = .07"$, and $F = y \cdot k = .6 \cdot 2.25 = 1.35 \text{ lb}$.

$\tau = 11020 \text{ psi, Answer for (c).}$

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7. A cylindrical coil spring has the following characteristics:

Number of coils: 6

Coil outside diameter: 2"

Wire diameter: .3"

Clamped at both ends.

Based on the above information, determine:

The lowest critical frequency. Assume the specific weight of the steel equals to .281 pci.

Solution:

To calculate critical frequency, by equation (02), the spring constant and the weight of the spring must be calculated first.

Step 1 Calculate the spring constant (rate):

Refer to spring's rate equation (14) **RATE** (SPRIN/CONS)

SPRINGS EXAMPLES

For $d = .3"$, $G = 12 \text{EE}6$ psi (assumed), $D_m = 2 - .3 = 1.7"$, and $N = 6 - .5 = 5.5$ (clamped at both end.)
 $k = 449.6 \text{ lb/in}$

Step 1 Calculate the weight of the spring (W):

$$\text{From } W = \frac{\pi * d^2}{4} (\pi * D_m * N) * \rho$$

For $d = .3"$, $D_m = 1.7"$, $N = 6 - .5 = 5.5$, and $\rho = .281$ pci.

Key in ' $W = \pi * .3^2 / 4 * \pi * 1.7 * 5.5 * .281$ NUM $W = .583 \text{ lb.}$

Step 3 Calculate the critical frequency:

Refer to coil critical frequency equation (02) **FREQ** (SPRIN/COIL/CRTIC)

For $m = 1$ (harmonic value for minimum frequency), $k = 449.6 \text{ lb/in}$, and $W = .583 \text{ lb}$

$f_{cr} = 273 \text{ cps, Answer.}$
