Answer Key

POWER PLANT ENGINEERING
Refresher 03

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1

$EP = 12{,}000\ kW$

$Q = 6\ m^3/s$

$Q_L = 2.5\% = 0.15\ m^3/s$

$H_n = 230\ m$

$\eta_g = 95\%$

$\eta_H = 83\%$

Required: Overall turbine efficiency, η_T

$$\eta_T = \frac{BP}{WP} * 100\%$$

$$\eta_H = \frac{H_n}{H_E}$$

$$0.83 = \frac{230\ m}{H_E}$$

$$H_E = 277.1084\ m$$

$$WP = Q\gamma_w H_E = (6\ m^3/s)(9.81\ kN/m^3)(277.1084\ m)$$

$$WP = 16310.6024\ kW$$

and;

$$\eta_g = \frac{EP}{BP}$$

$$0.95 = \frac{12{,}000\ kW}{BP}$$

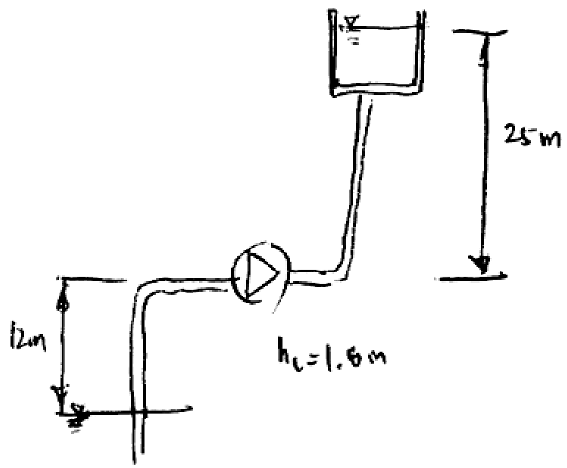
$$BP = 12631.5789\ kW$$

Hence;

$$\eta_T = \frac{12631.5789\ kW}{16310.6024\ kW} * 100\%$$

$$\boxed{\eta_T = 77.44\%}$$

2



$$WP = Q \gamma_w TDH$$

$$TDH = (12 + 25 + 1.8)\ m$$

$$TDH = 38.8\ m$$

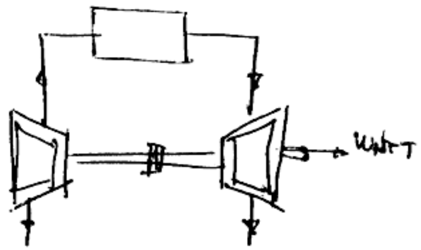
$$\dot{V} = \frac{\dot{m}_w}{\rho_w} = \frac{5\ kg/s}{1000\ kg/m^3} = 5 \times 10^{-3}\ m^3/s$$

Hence;

$$WP = (5 \times 10^{-3}\ m^3/s)(9.81\ kN/m^3)(38.8\ m)$$

$$\boxed{WP = 1.90\ kW}$$

3



$W_c = 280\ kW$ $\quad \eta_c = 85\%$

$W_T = 1200\ kW$ $\quad \eta_T = 90\%$

$$BWR' = \frac{W_c'}{W_T'} \; ; \quad \eta_c = \frac{W_c}{W_c'} = 0.85 = \frac{280\ kW}{W_c'}$$

$$W_c' = 329.4118\ kW$$

$$\eta_T = \frac{W_T'}{W_T} = 0.90 = \frac{W_T'}{1200\ kW}$$

$$W_T' = 1080\ kW$$

Hence;

$$BWR' = \frac{329.4118\ kW}{1080\ kW} * 100\%$$

$$\boxed{BWR' = 30.5\%}$$

4

$$W = (2.5\,hp)\left(\frac{0.746\,kW}{1\,hp}\right)\left(\frac{1\,Btu}{1.055\,kJ}\right)\left(\frac{3600\,s}{1\,hr}\right) = 6363.9810\,Btu/hr$$

$$T_L = -5\,°F + 460 = 455\,°R$$

$$T_H = 110\,°F + 460 = 570\,°R$$

Heat Pump:

$$PF = \frac{Q_R}{W} = \frac{Q_R}{Q_R - Q_A} = \frac{T_L}{T_H - T_L}$$

$$\frac{Q_R}{6363.9810\,Btu/hr} = \frac{455\,°R}{(570 - 455)\,°R}$$

$$\boxed{Q_R = 25179.2292\,Btu/hr}$$

5

impulse turbine

$H_E = 280m$

$d_j = 130mm$

$C_v = 95\%$

Water jet power, P_j

$P_j = Q_j \gamma_w H_E$

$Q_j = A_j v_j = \frac{\pi d_j^2}{4} v_j$

from ideal jet velocity, v_j

$v_j = C_v \sqrt{2 g_o H_E}$

$= 0.95\sqrt{2(9.81 m/s^2)(280m)}$

$v_j = 70.4129\ m/s$

$Q_j = \frac{\pi (0.130\ m)^2}{4}(70.4129\ m/s)$

$Q_j = 0.9346\ m^3/s$

subst;

$P_j = (0.9346\ m^3/s)(9.81\ m/s^2)(280m)$

$\boxed{P_j = 2567.1773\ kW}$

6

5PV

Level of water

8

Conduction

9

Rankine cycle

10

Greater than 1

11

It should be equal

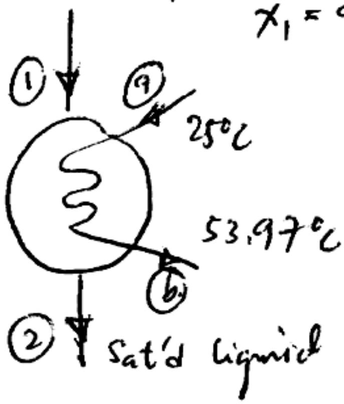
12

Evaporative

13

$m_s = 1.3\ kg/s$, $P_1 = 15\ kPa$

$x_1 = 90\%$



$$m_w C_p \Delta T = m_s (h_1 - h_2)$$

$$h_1 = h_f + x_1 h_{fg} = 225.94\ kJ/kg + (0.90)(2373.1\ kJ/kg)$$

$$h_1 = 2361.73\ kJ/kg$$

Subst;

$$m_w (4.187\ kJ/kg\text{-}K)(53.97 - 25)°C = (1.3\ kg/s)(2361.73 - 225.94)\ kJ/kg$$

$$\boxed{m_w = 17.6079\ kg/s}$$

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$D_1 = 310\,mm$

$H_1 = 60\,m$

$Q_1 = 0.8\,m^3/s$

$N_1 = 600\,rpm$

$Q_2 = ?$

$N_2 = 400\,rpm$

$$\frac{Q_1}{N_1} = \frac{Q_2}{N_2}$$

$$\frac{0.8\,m^3/s}{600\,rpm} = \frac{Q_2}{400\,rpm}$$

$$\boxed{Q_2 = 0.5333\,m^3/s}$$

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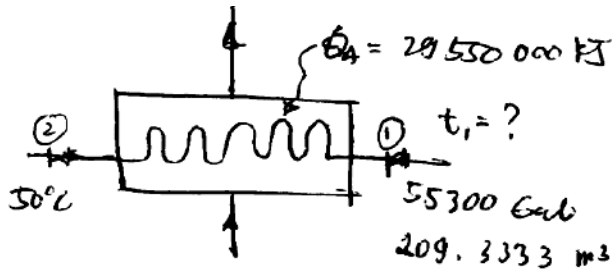

$$\dot{Q}_A = m_w C_{pw} (t_2 - t_1)$$

$$\dot{m}_w = \rho \dot{V} = (1000\ kg/m^3)(209.3333\ m^3)$$

$$\dot{m}_w = 209333\ kg$$

subst;

$$29550000\ kJ = (209333\ kg)(4.187\ kJ/kg\text{-}K)(50 - t_1)$$

$$\boxed{t_1 = 16.2855\ °C}$$

16

$$PF = COP + 1$$

$$= 5.8 + 1$$

$$\boxed{PF = 6.8}$$

17

$x_p = 18\%$

$x_F = 20\%$ $\quad m_F = 28\,000 \text{ kg}$

Det. amount of moisture content extracted, m_m

$$m_m = m_F - m_p$$

$$(1 - x_F)\, m_F = (1 - x_p)\, m_p$$

$$(1 - 0.20)(28000 \text{ kg}) = (1 - 0.18)\, m_p$$

$$m_p = 27\,317.0732 \text{ kg}$$

Hence;

$$m_m = (28\,000 - 27\,317.0732) \text{ kg}$$

$$\boxed{m_m = 682.9268 \text{ kg}}$$

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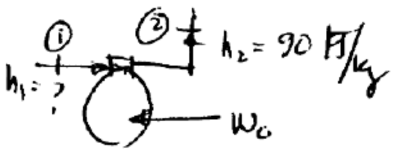
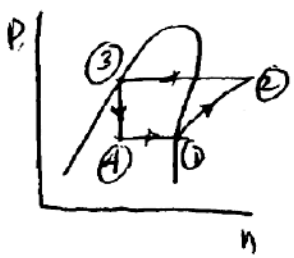
Vapor Compression Refrigeration System

$Q_A = 60\ KJ/kg$

$COP = 7$





$$COP = \frac{Q_A}{Q_R - Q_A}$$

$$7 = \frac{60\ KJ/kg}{Q_R - 60\ KJ/kg}$$

$$Q_R = 68.5714\ KJ/kg$$

and;

$$Q_R = m_R(h_2 - h_3)$$

$$68.5714\ KJ/kg = (90 - h_3)$$

$$h_3 = 21.4286\ KJ/kg = h_4$$

and

$$Q_A = m_R(h_1 - h_4)$$

$$60\ KJ/kg = (h_1 - 21.4286\ KJ/kg)$$

$$\boxed{h_1 = 81.4286\ KJ/kg}$$

19

Regain in the products

$$(1-x_F)m_F = \left[\frac{1}{1+x_P}\right] m_P$$

$$(1-0.35)(30\,MT) = \left[\frac{1}{1+x_P}\right](30\,MT)$$

$$\boxed{x_P = 53.85\%}$$

20

Reversed Carnot cycle

$T_H = 330\ K$

$COP = 7$

$$COP = \frac{T_L}{T_H - T_L}$$

$$7 = \frac{T_L}{330 - T_L}$$

$$\boxed{T_L = 288.75\ K}$$

21

$h_g = 30\,m$

$t_g = 200°C$

Height of stack

$$h_s = \frac{\Delta P}{\gamma_a - \gamma_g} = \frac{\gamma_w h_w}{\gamma_a - \gamma_g}\ ;$$

head of gas:

$$h_g = \frac{\Delta P}{\gamma_g} = \frac{\gamma_w h_w}{\gamma_g}$$

For γ_g;

$$\gamma_g = \rho_g\left(\frac{g_0}{g_c}\right)\ ;\ \rho_g = \frac{P_a}{R_g T_g}$$

$$\rho_g = \frac{101.325\ kPa}{\left(0.287\ \frac{kJ}{kg-K}\right)(200+273)K} = 0.7464\ kg/m^3$$

and;

$$\gamma_g = \left(0.7464\ kg/m^3\right)\left(\frac{9.81\ m/s^2}{1000\ \frac{kg-m}{kN-s^2}}\right) = 7.322\times10^{-3}\ kN/m^3$$

Hence;

$$h_s = \frac{(30\,m)\left(7.322\times10^{-3}\ kN/m^3\right)}{\left(0.0118 - 7.322\times10^{-3}\right)kN/m^3}$$

$$\boxed{h_s = 49.0531\ m}$$

22

At a line to the condenser

Rectifier

24

Blower

25

Air cooled

26

$H_1 + H_2$

27

Decrease the combustion time

28

Refrigerating effect

29

$$PV = mRT$$

$$\frac{V}{m} = \frac{RT}{P} \quad ; \quad k = \frac{C_p}{C_v}$$

$$1.555 = \frac{C_p}{3.0023 \ kJ/kg\text{-}K}$$

$$C_p = 4.6686 \ kJ/kg\text{-}K$$

and;

$$R = C_p - C_v = (4.6686 - 3.0023) \ kJ/kg\text{-}K$$

$$R = 1.6663 \ kJ/kg\text{-}K$$

subst;

$$\frac{V}{m} = \frac{(1.6663 \ kJ/kg\text{-}K)(50 + 273)K}{101.325 \ kPa}$$

$$\boxed{\frac{V}{m} = 5.3117 \ m^3/kg}$$

30

$h_g = 28\,m$

$t_g = 180°C$

$m_g = 5\ kg/s$

$M = 30$

Required: Diameter of Stack

$$Q = \frac{\pi D_s^2}{4} V_{act}$$

Theoretical velocity

$$v = \sqrt{2 g_o h_g}$$

$$= \sqrt{2(9.81\ m/s^2)(28\ m)}$$

$$v = 23.4384\ m/s$$

Actual velocity, v'

$$v' = 0.40\,v = 0.40(23.4384\ m/s)$$

$$v' = 9.3754\ m/s$$

for $Q = \dot{V}$;

$$\rho_g = \frac{\dot{m}_g}{\dot{V}_g};$$

$$PV = mRT$$

$$\rho_g = \frac{V}{m} = \frac{P_{atm}}{R_g T_g}$$

$$R_g = \frac{\bar{R}}{M} = \frac{8.314\ kJ/kg\text{-}K}{30\ kg/kg}$$

$$R_g = 0.2771\ kJ/kg\text{-}K$$

$$\rho_g = \frac{101.325\ kPa}{(0.2771\ kJ/kg\text{-}K)(180+273)K}$$

$$\rho_g = 0.8071\ kg/m^3$$

then;

$$0.8071\ kg/m^3 = \frac{5\ kg/s}{\dot{V}_g}$$

$$\dot{V}_g = 6.1949\ m^3/s$$

Hence; subst;

$$6.1949\ m^3/s = \frac{\pi D_s^2}{4}(9.3754\ m/s)$$

$$\boxed{D_s = 0.9172\ m}$$

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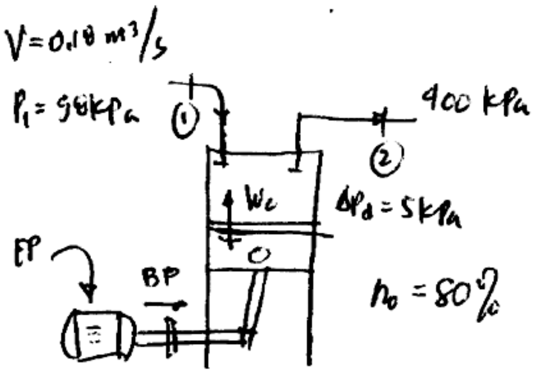


$$\eta_o = \frac{W_c}{BP} * 100\%$$

$$W_c = \frac{k P_1 V_1}{1-k}\left[\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} - 1\right]$$

$$= \frac{1.4(98\ kPa)(0.18\ m^3/s)}{1-1.4}\left[\left(\frac{400\ kPa}{98\ kPa}\right)^{\frac{1.4-1}{1.4}} - 1\right]$$

$$W_c = 30.5364\ kW$$

thus;

$$0.80 = \frac{30.5364\ kW}{BP}$$

$$\boxed{BP = 38.1705\ kW}$$

32

$D = 0.250\ m$

$L = 0.350\ m$

$m_a = 0.80\ kg/s$

$P_1 = 100\ kPa$

$P_2 = 350\ kPa$

$N = 180\ rpm$

Req'd: Piston Speed

$$v_p = \frac{2LN}{60} = \frac{2(0.350\ m)(180\ rpm)}{60}$$

$$\boxed{v_p = 2.1\ m/s}$$

33

$\eta_p = 80\%$

$\eta_T = 85\%$

$W_p = m_s v (P_B - P_c)$

$\eta_p = \frac{W_p}{W_p'}$; $W_p' = \frac{W_p}{\eta_p}$

Hence;

$$W_p' = \frac{(12\ kg/s)(0.001043\ m^3/kg)(4500 - 100)\ kPa}{0.80}$$

$$\boxed{W_p' = 68.838\ kW}$$

34

$$W_c = \frac{3 k m_a R_a T_1}{1-k}\left[\left(\frac{P_x}{P_1}\right)^{\frac{k-1}{k}} - 1\right]$$

$$P_x = \sqrt[3]{P_s^{\,2} P_d} = \sqrt[3]{(101.325\ kPa)^2 (380\ kPa)}$$

$$P_x = 157.4245\ kPa$$

Hence;

$$W_c = \frac{3(1.4)(0.5\ kg/s)(0.287\ kJ/kg\text{-}K)(21+273)K}{1-1.4}\left[\left(\frac{157.4245\ kPa}{101.325\ kPa}\right)^{\frac{1.4-1}{1.4}} - 1\right]$$

$$\boxed{W_c = 59.4293\ kW}$$

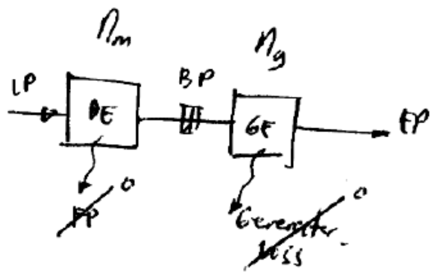
35

$EP = 20\,MW$

$m_F = 1.8\ kg/s$

$LHV = 35000\ kJ/kg$

$\eta_{ME} = 90\%$



$$\eta_{ME} = \frac{EP}{IP} * 100\%$$

$$IP = \frac{EP}{\eta_{ME}} = \frac{20\,MW\left(\frac{1000\,kW}{1\,MW}\right)}{0.90} = 22{,}222.22\,kW$$

Therefore; for indicated thermal efficiency

$$e_{IP} = \frac{(22222.22\,kW)}{(1.8\ kg/s)(35000\ kJ/kg)}$$

$$\boxed{e_{IP} = 35.27\%}$$

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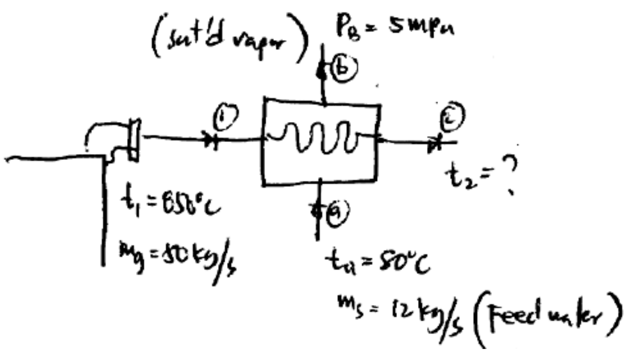


Heat given off = heat absorbed

$$m_g C_{pg}(t_1 - t_2) = m_s h_b - m_s C_{pw} t_a$$

$$(50\ \text{kg/s})(1.0062\ \text{kJ/kg·K})(850 - t_2) = (12\ \text{kg/s})(2794.3\ \text{kJ/kg}) - (12\ \text{kg/s})(4.187\ \text{kJ/kg·K})(80\ \text{K})$$

$$\boxed{t_2 = 263.3953°C}$$

37

$c = 6$

$S = 4$ stroke

$D = 0.220$ m

$L = 0.250$ m

$N = 350$ rpm

$\eta_v = 85\%$

$\rho = \frac{m}{V}$; $\eta_v = \frac{V_1}{V_D} * 100\%$

$$V_D = \frac{\pi D^2}{4} L \left[\frac{c\,a\,(n/60)\,2}{S}\right]$$

$$= \frac{\pi (0.220\ m)^2}{4}(0.250\ m)\left[\frac{(6)(1)(350\ rpm/60)\ 2}{4}\right]$$

$V_D = 0.1663\ m^3/s$

Subst;

$$0.85 = \frac{V_1}{0.1663\ m^3/s}$$

$V_1 = 0.1414\ m^3/s$

Hence;

$$1.2\ kg/m^3 = \frac{m_a}{0.1414\ m^3/s}$$

$$\boxed{m_a = 0.1696\ kg/s}$$

38

Open Brayton Cycle

$r_k = 4.8$

For the pressure ratio, r_p;

$$(r_p)^{\frac{k-1}{k}} = (r_k)^{k-1}$$

$$r_p = r_k^{\,k}$$

$$r_p = (4.8)^{1.4}$$

$$\boxed{r_p = 8.9895}$$

39

DOUBLE SUCTION Centrifugal pump (Single Impeller)

$$N_s = \frac{(51.63, rpm)\sqrt{\frac{Q_T}{2}, m^3/s}}{(TDH, m)^{3/4}}$$

$$380\, rpm = \frac{(51.63 * 1300\, rpm)\sqrt{\frac{Q_T}{2}}}{(12\, m)^{3/4}}$$

$$\boxed{Q_T = 2.6649 \times 10^{-3}\, m^3/s}$$

40

Open Brayton Cycle

$r_k = 6$

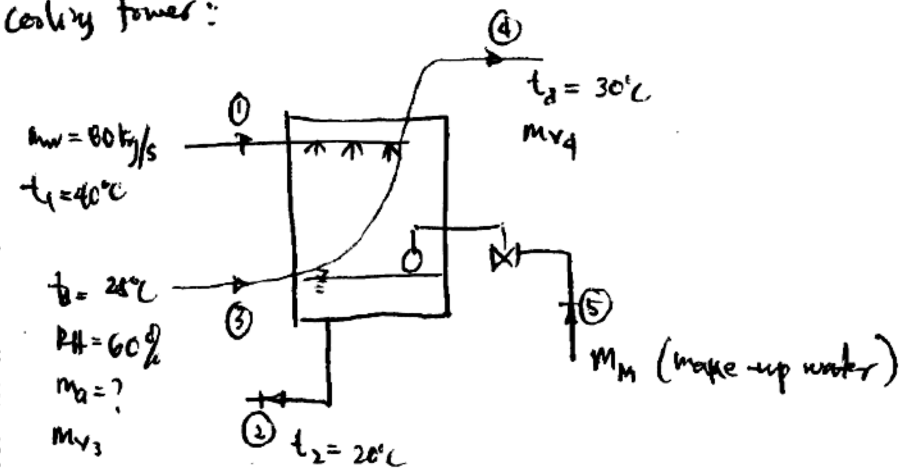
$$\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = r_k^{\,k-1}$$

$$\frac{P_2}{101.325 \text{ kPa}} = (6)^{1.4}$$

$$\boxed{P_2 = 1244.0825 \text{ kPa}}$$

41

cooling tower:



Energy balance

$$m_w C_{pw} t_1 + m_a h_3 + m_w C_{pw} t_5 = m_a h_4 + m_w C_{pw} t_2$$

mass balance, air side

$$\cancel{m_a} + m_{v3} + m_M = \cancel{m_a} + m_{v4}$$

$$m_M = m_{v4} - m_{v3} \quad ; \quad SH = \frac{m_a}{m_v}$$

$$m_M = m_a (SH_4 - SH_3)$$

41 cont…

Solving for SH_3;

$$SH_3 = 0.622\left[\frac{P_v}{P_t - P_v}\right] \quad ; \quad RH_3 = \frac{P_v}{P_{sd}}$$

$RH_3 = 0.60$

$P_{sd} = 3.169$ kPa $\quad P_{sat}$ @ $t_{d3} = 25°C$

Solving simultaneously;

$SH_3 = 0.01190 \ \frac{kg_v}{kg_a}$

Solving for h_3;

$$h_3 = C_{pa} t_3 + SH_3(h_v)$$

$h_v = 2501.3 + 1.82 t_d = 2501.3 + (1.82)(25°C)$

$h_v = 2546.8$ KJ/kg

Solving simultaneously

$h_3 = 55.4619$ KJ/kga

Solving for SH_4;

$$SH_4 = 0.622\left[\frac{P_v}{P_t - P_v}\right] \quad ; \quad RH_4 = 100\% \text{ (IF NOT GIVEN)}$$

$P_{sd} = 4.246$ kPa $\quad P_{sat}$ @ t_{d4}

Solving simultaneously

$SH_4 = 0.0272 \ \frac{kg_v}{kg_a}$

Solving for h_4;

$$h_4 = C_{pa} t_4 + SH_4(h_v)$$

$h_v = 2501.3 + 1.82 t_d = 2501.3 + (1.82)(30°C)$

$h_v = 2555.9$ KJ/kg

Solving simultaneously;

$h_4 = 99.7187$ KJ/kg

41 cont…

Substituting to the original equation

$$m_w C_{pw} t_1 + m_a h_3 + m_a(SH_4 - SH_3)C_{pw} t_5 = m_a h_4 + m_w C_{pw} t_2$$

$$m_a = \frac{m_w C_{pw}(t_2 - t_1)}{(h_3 - h_4) + (SH_4 - SH_3)C_{pw} t_5}$$

$$= \frac{(80\ kg/s)(4.187\ KJ/kg\text{-}K)(20-40)K}{(55.4619 - 99.7187)KJ/kg + (0.0272 - 0.01190)\ kg_v/kg_a\ (4.187\ KJ/kg\text{-}K)(20\ K)}$$

$$m_a = 155.8839\ kg/s$$

Since mass of dry air & water vapor enters the system

from; $m_m = m_a + m_v$

$$m_m = m_a + m_a SH_3 = m_a(1 + SH_3)$$

$$= 155.8839\ kg/s\ (1 + 0.01190)\ kg_v/kg_a$$

$$\boxed{m_m = 157.7389\ kg_m/s}$$

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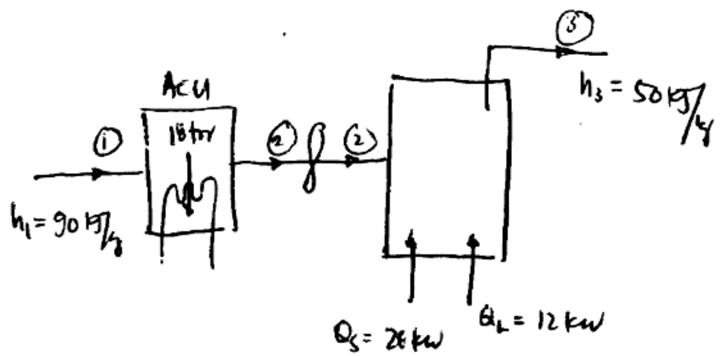

Energy balance at the whole system

$$m_a h_1 + Q_s + Q_L = Q_A + m_a h_3$$

$$m_a (h_1 - h_3) = Q_A - Q_L - Q_s$$

$$m_a (90 - 50)\ \mathrm{kJ/kg} = (18\ \mathrm{tor})\left(\frac{3.517\ \mathrm{kW}}{1\ \mathrm{tor}}\right) - 12\ \mathrm{kW} - 28\ \mathrm{kW}$$

$$\boxed{m_a = 0.5827\ \mathrm{kg/s}}$$

43

$N_1 = 1900\ rpm$

$Q_1 = 0.6\ m^3/s$

$t_1 = 18°C$

$N_2 = 1300\ rpm$

$Q_2 = ?$

$$\frac{Q_1}{N_1} = \frac{Q_2}{N_2}$$

$$\frac{0.6\ m^3/s}{1900\ rpm} = \frac{Q_2}{1300\ rpm}$$

$$\boxed{Q_2 = 0.4105\ m^3/s}$$

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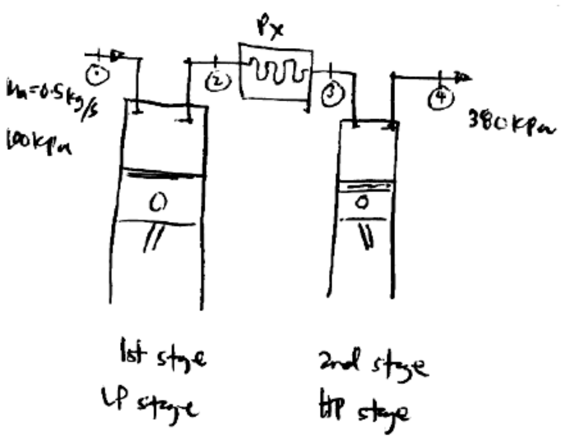

$$W_{1st} = \frac{k\, m_a R_a T_a}{1-1.4}\left[\left(\frac{P_x}{P_s}\right)^{\frac{k-1}{k}} - 1\right]$$

$$P_x = \sqrt{P_s P_d} = \sqrt{(101.325\ \text{kPa})(380\ \text{kPa})}$$

$$P_x = 196.2231\ \text{kPa}$$

$$W_{1st} = \frac{(1.4)(0.5\ \text{kg/s})(0.287\ \text{kJ/kg}\cdot\text{K})(21+273)\text{K}}{1-1.4}\left[\left(\frac{196.2231\ \text{kPa}}{101.325\ \text{kPa}}\right)^{\frac{1.4-1}{1.4}} - 1\right]$$

$$\boxed{W_{1st} = 30.69\ \text{kW}}$$

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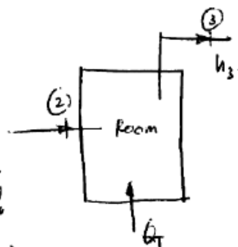

$h_3 = 65$ kJ/kg

$t_2 = 16°C$
RH = 60%
Standard pressure
$\dot{V} = 8 m^3/s$

Total heat load, Q_T

$$Q_T = m_a(h_3 - h_2)$$

for h_2;

$$h_2 = C_{pa} t_2 + SH_2 h_v$$

$$h_v = 2501.3 + 1.82\, t_d = 2501.3 + 1.82(16°C)$$

$$h_v = 2530.42 \text{ kJ/kg}$$

$$SH_2 = 0.622\left[\frac{P_v}{P_B - P_v}\right] \;;\; P_v = 1.83188 \text{ kPa}\ \ P_{sat} @ t_{d_2}$$

$$P_B = 101.325 \text{ kPa}$$

$$SH_2 = 0.017973 \frac{kg_v}{kg_a}$$

Substituting;

$$h_2 = 36.2729 \text{ kJ/kg}_a$$

for m_a;

$$m_a = \frac{\dot{V}_2}{\bar{v}_2} \;;\; \bar{v}_2 = \frac{R_a T_A}{P_B - P_v} \;;\; P_v = 1.83188 \text{ kPa}\ \ P_{sat} @ t_{d_2}$$

$$P_B = 101.325 \text{ kPa}$$

$$\bar{v}_2 = 0.8291 \text{ m}^3/\text{kg}$$

substituting;

$$m_a = \frac{8.0 \text{ m}^3/\text{s}}{0.8291 \text{ m}^3/\text{s}} = 9.6490 \text{ kg/s}$$

Hence;

$$Q_T = (9.6490 \text{ kg/s})(65 - 36.2729) \text{ kJ/kg}_a$$

$$\boxed{Q_T = 277.1883 \text{ kJ/s}}$$

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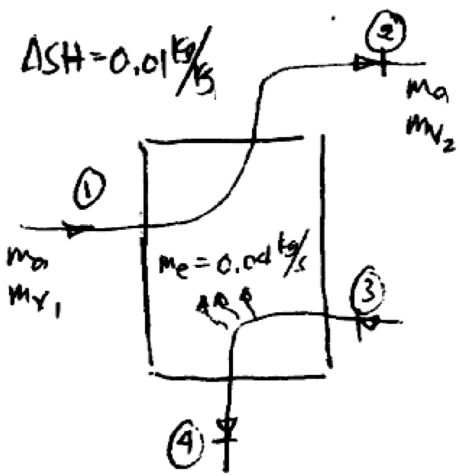


mass balance

$$\cancel{m_a} + m_{v_1} + m_e = \cancel{m_a} + m_{v_2}$$

$$m_e = m_{v_2} - m_{v_1} \quad ; \quad SH = \frac{m_v}{m_a}$$

$$m_e = m_a\left(SH_2 - SH_1\right)$$

subst:

$$0.04\ kg/s = m_a\left(0.01\ kg/kg\right)$$

$$\boxed{m_a = 4\ kg/s}$$

47

Thermal efficiency

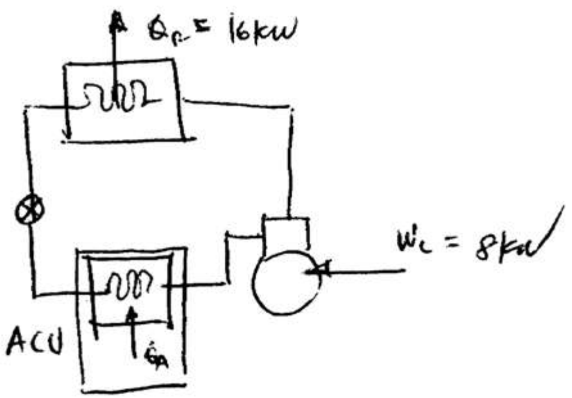
$$e_{oc} = 1 - \frac{1}{r_k^{k-1}} * 100\%$$

Note: for Otto cycle $r_e = r_k$

$$e_{oc} = 1 - \frac{1}{9^{1.4-1}} * 100\%$$

$$\boxed{e_{oc} = 58.48\%}$$

48



$$Q_A = m_a (h_1 - h_2)$$

Heat Balance at whole system

$$Q_A + W_c = Q_R$$

$$Q_A = Q_R - W_c = (16 - 8) kW = 8 kW$$

Subst,

$$8 kW = m_a (48 kJ/kg)$$

$$\boxed{m_a = 0.1667 kg/s}$$

49

Actual Air fuel ratio, $e = 12\%$

$$C_{12}H_{36} + a(1+e)[O_2' + 3.76N_{2Air}'] \rightarrow bCO_2 + cH_2O_F + a(e)O_{2excessair} + a(1+e)N_{2air}$$

For Carbon:

$(1)(12) = b(1)$

$b = 12$ mol

For Hydrogen:

$(1)(36) = c(2)$

$c = 18$ mol

For Oxygen:

$a(1.12)(2) = b(2) + c(1) + a(0.12)(2)$

$a = 21$ mol

balanced molal equation:

$$C_{12}H_{36} + 23.52[O_2' + 3.76N_{2air}'] \rightarrow 12CO_2 + 18H_2O_F + 2.52O_{2exessair} + 23.52N_{2air}$$

For m_a':

$m_a' = (23.52)(16)(2) + (23.52)(3.76)(14)(2)$

$m_a' = 3228.8256\ kg_a'$

For m_F;

$m_F = (1)(12)(12) + (1)(1)(36)$

$m_F = 180\ kg_F$

Hence;

$$A{:}F' = \frac{3228.8256\ kg_a'}{180\ kg_F}$$

$$\boxed{A{:}F = 17.9379\ \frac{kg_a'}{kg_F}}$$

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$$SHF = \frac{Q_s}{Q_T}$$

$$0.90 = \frac{Q_s}{110\ kJ/s}$$

$$\boxed{Q_s = 99\ kJ/s}$$

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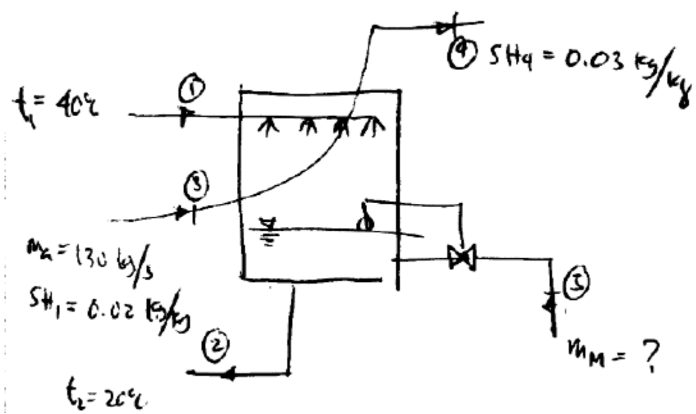
Cooling tower



$$m_M = m_a(SH_4 - SH_3)$$

$$= (130\ \text{kg/s})(0.03 - 0.02)\ \text{kg/kg}$$

$$\boxed{m_M = 1.3\ \text{kg/s}}$$

52

$$W_c = \frac{n P_1 V_1}{1-n}\left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

Solving for V_1

$$\eta_v = \frac{V_1}{V_0} = 1 + c - c\left(\frac{P_2}{P_1}\right)^{1/n}$$

$$V_0 = \frac{\pi D^2}{4} L\left[\frac{c_a n}{60}\right] \;;\; v_p = \frac{2Ln}{60}$$

$$V_0 = \frac{\pi D^2}{4}\frac{v_p}{2} c_a = \frac{\pi (0.33\text{ m})^2}{4}\frac{\left(8/60\ \text{m/s}\right)}{2}(1)(1)$$

$$V_0 = 5.70199 \times 10^{-3}\ \text{m}^3/\text{s}$$

Then;

$$\frac{V_1}{\left(5.70199\times10^{-3}\ \text{m}^3/\text{s}\right)} = 1 + 0.06 - 0.06\left(\frac{380\text{ kPa}}{100\text{ kPa}}\right)^{1/1.29}$$

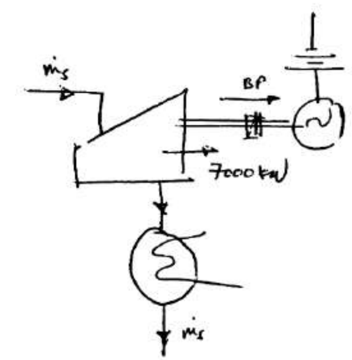
$$V_1 = 5.08112 \times 10^{-3}\ \text{m}^3/\text{s}$$

Hence;

$$W_c = \frac{(1.29)(100\text{ kPa})(5.08112\times10^{-3}\ \text{m}^3/\text{s})}{1-1.29}\left[\left(\frac{380\text{ kPa}}{100\text{ kPa}}\right)^{\frac{1.29-1}{1.29}} - 1\right]$$

$$\boxed{W_c = 0.7911\ \text{kW}}$$

53



Combined Heat Rate, HR_c

$$HR_c = \frac{E_c}{EP}$$

Brake steam rate, BSR

$$BSR = \frac{m_s}{BP}$$

generator efficiency; η_g

$$\eta_g = \frac{EP}{BP}$$

Solving for BP;

$$BSR = \frac{m_s}{BP}$$

$$8 \frac{kg}{kW\text{-}hr} = \frac{m_s}{BP}$$

$$\frac{BP}{m_s} = \frac{1}{8} \frac{kW\text{-}hr}{kg} \left(\frac{3600 s}{1 hr}\right) = 450 \ kJ/kg$$

Solving for EP;

$$\eta_g = \frac{EP}{BP}$$

$$0.95 = \frac{EP}{450 \ kJ/kg}$$

$$EP = 427.5 \ kJ/kg$$

Hence; $HR_c = \frac{E_c}{EP}$

$$\left(11000 \frac{kJ}{kW\text{-}hr}\right)\left(\frac{1 hr}{3600 s}\right) = \frac{E_c}{427.5 \ kJ/kg}$$

$$\boxed{E_c = 1306.25 \ kJ/kg}$$

54

Radiation

55

Uniform

56

Condenser

57

Air density

58

Speed governor

59

At full load only

60

An increase in speed

61

$$V_D = ALN_s = \frac{\pi D^2}{4} L \left[\frac{c\,a\,(n/60)\,2}{s} \right]$$

$\longrightarrow \frac{\text{Power Stroke}}{\text{cylinder-sec}}$

$s = 2$ for reciprocating compressor or reciprocating pump

$$V_D = \frac{\pi D^2}{4} L \left[c\,a\,n/60 \right]$$

For one cylinder:

$$= \frac{\pi (0.320\,m)^2}{4} (0.260\,m) \left[0.6 \frac{\text{power stroke}}{\text{cyl - sec}} \right]$$

$$\boxed{V_D = 0.01255\ m^3/s}$$

62

$$b\,C_8H_{18} + a\left[O_2 + 3.76\,N_{2\,air}\right] \longrightarrow 10.02\,CO_2 + 5.62\,O_2 + 0.88\,CO + 83.48\,N_2 + c\,H_2O_F$$

For carbon:

$$b(8) = (10.02)(1) + (0.88)(1)$$
$$b = 1.3625 \text{ mol}$$

For oxygen:

$$a(2) = (10.02)(2) + (5.62)(2) + (0.88)(1) + (12.2625)(1)$$
$$a = 22.2113 \text{ mol}$$

For Hydrogen:

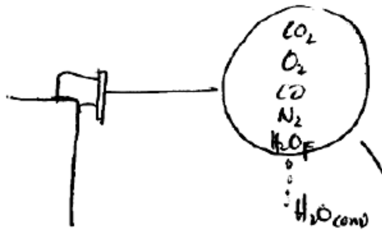
$$(1.3625)(18) = c(2)$$
$$c = 12.2625 \text{ mol}$$

for 1 mol of fuel

$$C_8H_{18} + 16.3019\left[O_2 + 3.76\,N_{2\,air}\right] \longrightarrow 7.3541\,CO_2 + 4.1248\,O_2 + 0.6459\,CO + 61.2697\,N_2 + 9\,H_2O_F$$

62 cont…

For the fraction of H_2O that condences $= \dfrac{n_{H_2O\,cond}}{n_{H_2O}}$



$H_2O_{LEFT} = (H_2O - H_2O_{cond})$

$$P_T = P_{CO_2} + P_{O_2} + P_{CO} + P_{N_2T} + P_{H_2O\,LEFT}$$

$$\frac{P_{H_2O\,LEFT}}{P_T} = \frac{n_{H_2O\,LEFT}}{(n_T - n_{H_2O\,cond})}$$

and;

$$\frac{P_{H_2O\,LEFT}}{P_T} = \frac{n_{H_2O} - H_2O_{cond}}{n_T - n_{H_2O\,cond}}$$

where: $P_{H_2O\,LEFT} = \underline{3.169\ kPa}$ P_{sat} @ $t_{dp} = 25°C$

Subst;

$$\frac{3.169\ kPa}{100\ kPa} = \frac{9 - H_2O_{cond}}{82.3945 - H_2O_{cond}}$$

$$n_{H_2O\,cond} = 6.5980\ mol$$

Hence;

$$\frac{n_{H_2O\,cond}}{n_{H_2O}} = \frac{6.5980\ mol}{9\ mol}$$

$$\boxed{\frac{n_{H_2O\,cond}}{n_{H_2O}} = 0.7331}$$

63

Stoichiometric Air Fuel Ratio

Fuel: Natural Gas

$$(72CH_4 + 9H_2 + 14N_2 + 2O_2 + 3CO_2) + a[O_2 + 3.76N_{2air} + \_\_\_ H_2O_{air}] \rightarrow bCO_2 + cH_2O_P + a(1)(3.76)N_{2air} + 14N_{2F} + \_\_\_ H_2O_{AIR}$$

Required: Dew point of the products:

Balancing

For Carbon:

$$72(1) + 3(1) = b(1)$$

$b = 75$ mols

For Hydrogen:

$$72(4) + 9(2) = c(2)$$

$c = 153$ mols

For Oxygen:

$$2(2) + 3(2) + a(2) = b(2) + c(1)$$

$a = 146.5$ mols

We cannot neglect water vapor content of air because we are given with its conditions

Solving for H_2O (water vapor) on moist or humid air

$$P_{atm} = P_B = P_a + P_v$$

$$\frac{P_v}{P_{atm}} = \frac{n_v}{n_M} = \frac{n_v}{n_a + n_v}$$

63 cont…

Solving for P_v

$$\%RH = \frac{P_v}{P_{sat}}$$

$$0.80 = \frac{P_v}{2.339\ kPa}$$

$$P_v = 1.8712\ kPa$$

Subst;

$$\frac{1.8712\ kPa}{101.325\ kPa} = \frac{n_v}{146.5[1+3.76]+n_v}$$

$$n_v = 13.1203\ mols_{H_2O\ AIR}$$

The balanced molal equation:

$$(72CH_4 + 9H_2 + 14N_2 + 2O_2 + 3CO_2) + 146.5[O_2 + 3.76N_{2air} + \underline{13.1203H_2O_{AIR}}] \longrightarrow 75CO_2 + 153H_2O_P + 550N_{2air} + 14N_{2P} + \underline{13.1203H_2O_{AIR}}$$

Solving for the dew point temperature;

$$t_{dH_2O} = \underline{\qquad\qquad} t_{sat} @ P_{H_2O_P}$$

$$\frac{P_{H_2O_T}}{P_T} = \frac{n_{H_2O_T}}{n_T}$$

$$\frac{P_{H_2O_T}}{101.325\ kPa} = \frac{(153+13.1203)mol}{(75+153+550+14+13.1203)mol}$$

$$P_{H_2O_T} = 20.9064\ kPa$$

Hence;

Using tables attached (by interpolation)

$$\boxed{t_{dp} = 60.9287°C}$$

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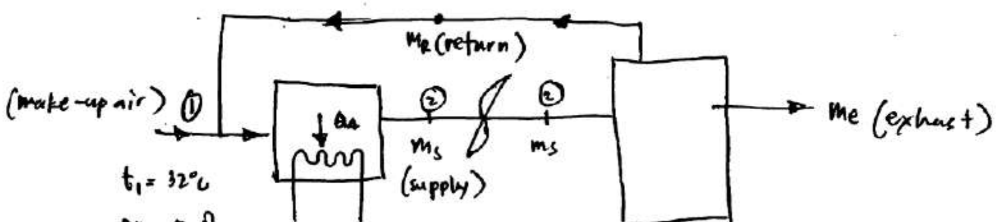

$t_1 = 32°C$

$RH_1 = 80\%$

$h = 95\ kJ/kg$

$v = 0.898\ m^3/kg$

$V_{Room} = 9 \times 8 \times 3\ m = 216\ m^3$

$t_3 = 25°C$

$RH_3 = 50\%$

$Q_T = Q_s + \cancel{Q_L}^{\,0} = 9\ kW$

air changes per hour = 10/hr

$h = 50.5\ kJ/kg$

$v = 0.8575\ m^3/kg$

64 cont…

Required:

$$m_1 h_1 + Q_T = Q_A + m_e h_3$$

$$Q_A = Q_T + m_1 h_1 - m_e h_3$$

Solving for M_{room}

$$\bar{v}_{room} = \frac{V_{room}}{M_{room}}$$

$$0.8575\ m^3/kg = \frac{216\ m^3}{m_{room}}$$

$$m_{room} = 251.8950\ kg$$

Solving for m_1;

$$\text{Air changes per hour} = \frac{\text{mass flow rate of make-up air}}{\text{Room air mass}}$$

$$m_1 = \left(10/hr\right)\left(251.8950\ kg\right)\left(\frac{1\ hr}{3600\ s}\right)$$

$$m_1 = 0.6997\ kg/s$$

Based on mass analysis:

$$m_1 = m_e$$

Hence;

$$Q_A = 9\ kJ/s + \left(0.6997\ kg/s\right)\left(95 - 50.5\right)\ kJ/kg$$

$$Q_A = \left(40.1367\ kJ/s\right)\left(\frac{1\ ton}{3.516\ kJ/s}\right)$$

$$\boxed{Q_A = 11.4154\ ton}$$

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65 to 68

Fuel consumed for 850 kw-hr energy produced

$$\rho_F = \frac{M_F}{V_F}$$

$$°API = \frac{141.5}{SG_{F@15.6°}} - 131.5$$

$$25 = \frac{141.5}{SG_{F@15.6°}} - 131.5$$

$$SG_{F@15.6°} = 0.9042$$

hence;

$$m_F = (0.9042)(1\ kg/L)(1.8\ barrel)\left(\frac{200L}{1 barrel}\right)$$

$$\boxed{m_F = 325.512\ kg}$$

Engine-fuel rate

$$BSFC = \frac{m_F}{BP}\ ; \quad \eta_g = \frac{EP}{BP}$$

$$0.90 = \frac{850\ kW\text{-}hr}{BP}$$

$$BP = 944.44\ kw\text{-}hr$$

$$BSFC = \frac{325.512\ kg}{944.44\ kw\text{-}hr}$$

$$\boxed{BSFC = 0.3447\ kg/kW\text{-}hr}$$

65 to 68 cont…

Brake thermal efficiency

$$e_{BP} = \frac{BP}{m_F\, LHV}$$

$$HHV = 41130 + (139.6 * {}^\circ API) = 41130 + (139.6 * 25)$$

$$HHV = 44620 \text{ KJ/kg}$$

Hence;

$$e_B = \frac{(944.44 \text{ kw-hr})\left(\frac{3600 s}{1 hr}\right)}{(325.512 \text{ kg})(44620 \text{ KJ/kg})} * 100\%$$

$$\boxed{e_B = 23.41\%}$$

Indicated thermal efficiency

$$e_{IP} = \frac{IP}{m_F\, LHV} \; ; \; n_M = \frac{BP}{IP}$$

$$0.80 = \frac{944.44 \text{ kw-hr}}{IP}$$

$$IP = 1180.55 \text{ kw-hr}$$

Hence;

$$e_{IP} = \frac{(1180.55 \text{ kw-hr})\left(\frac{3600 s}{1 hr}\right)}{(325.512 \text{ kg})(44620 \text{ KJ/kg})} * 100\%$$

$$\boxed{e_{IP} = 29.26\%}$$

69

Friction

70

High mean piston speed

71

Single cylinder piston type

72

An increase in speed

73

Thermal radiation

74

Check valve

75 to 76

$V_{milk} = 3800\ gal$

$t_i = 75°F$

$t_F = 40°F$

cooling time = 5 hrs

$\rho_{milk} = 8.8\ lbs/gal$

$SG_{milk} = 1.05$

$Cp_{milk} = 0.946\ Btu/lb-°F$

Required: Brine to be circulated in tons;

$$Q = mC_p(t_i - t_F)$$

$$= \left(\frac{3800\ gal}{5\ hrs}\right)\left(8.8\frac{lbs}{gal}\right)\left(0.946\ Btu/lb\text{-}°F\right)(75-40)°F$$

$$Q_A = \left(221439.68\ Btu/hr\right)\left(\frac{1\ ton}{12000\ Btu/hr}\right)$$

$$\boxed{Q_A = 18.4533\ tons}$$

Brine to be circulated

$$Q_A = m_{brine} Cp_{brine} \Delta T$$

$$221439.68\ Btu/hr = m_{brine}\left(0.715\ Btu/lb\text{-}°F\right)(16\ °F)$$

$$m_{brine} = \left(19356.6163\frac{lb}{hr}\right)\left(\frac{1hr}{60\ min}\right) = 322.6103\ lb/min$$

Hence;

$$\rho = \frac{m_{brine}}{V_{brine}}$$

$$(1.173)\left(62.4\frac{lb}{ft^3}\right)\left(\frac{1\ ft^3}{7.48\ gal}\right) = \frac{322.6103\ lb/min}{V_{brine}}$$

$$\boxed{V_{brine} = 32.0868\ gal/min}$$

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77 to 78

$P_1 = 70$ bar
$t_1 = 65°C$
$v_1 = ?$

$P_2 = 50$ bar
$T_2 = 700$ K
$v_2 = 110$ m/s

From Continuity Equation;

$\dot{m}_1 = \dot{m}_2$; $\rho = \frac{\dot{m}}{\dot{V}}$ and $\dot{V} = Av$

$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$

$\frac{1}{\bar{v}_1} \cancel{A_1} v_1 = \frac{1}{\bar{v}_2} \cancel{A_2} v_2$

$$\frac{1}{(0.001017\ m^3/kg)} v_1 = \frac{1}{(0.06081\ m^3/kg)} (110\ m/s)$$

$$\boxed{v_1 = 1.8397\ m/s}$$

Volume flow

$\dot{V} = Q = A_1 v_1$

$$Q = \frac{\pi (0.03\ m)^2}{4} (1.8397\ m/s)\left(\frac{1000\ L}{1\ m^3}\right)$$

$$\boxed{Q = 1.3\ L/s}$$

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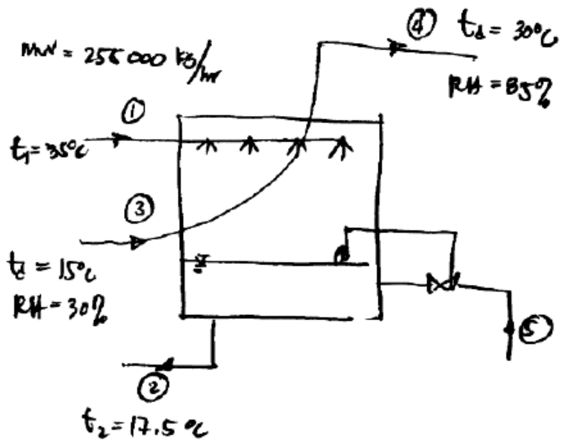
79 to 82



Tower Range, R

$R = t_1 - t_2$

$R = (35 - 17.5)°C$

$\boxed{R = 17.5°C}$

mass flow rate of air required

$Q_w = Q_a$

$m C_p \Delta T = m_a (h_4 - h_3)$

$(255000\ kg/hr)(4.187\ kJ/kg\text{-}K)(17.5°C) = m_a (89 - 23)\ kJ/kg$

$\boxed{m_a = 283\ 098.2955\ kg/hr}$

make-up water

$m_m = m_a (SH_4 - SH_3)$

$= (283\ 098.2955\ kg/hr)(0.0232 - 0.0032)\ kg/kg$

$\boxed{m_m = 5661.9659\ kg/hr}$

percentage of make-up water to the cooling water flow

$\frac{m_m}{m_w} = \frac{5661.9659\ kg/hr}{255000\ kg/hr} \times 100\%$

$\boxed{\frac{m_m}{m_w} = 2.22\%}$

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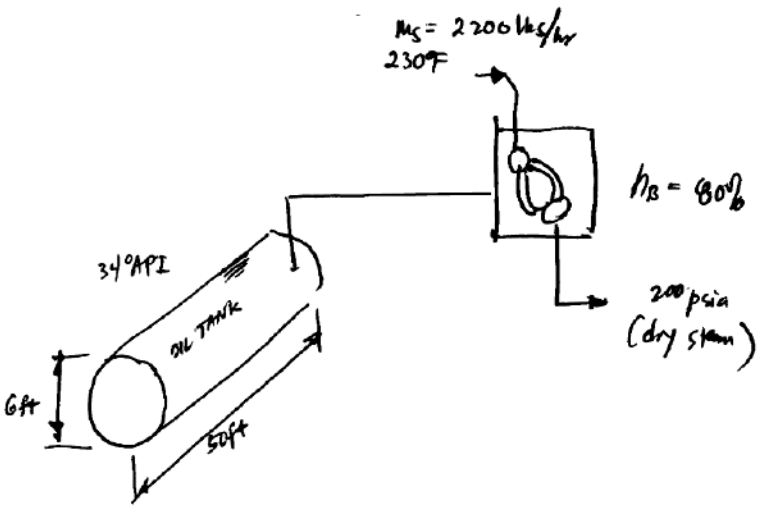
83 to 85



Flow rate of fuel in kg/hr

$$\eta_{BO} = \frac{m_s(h_s - h_f)}{m_F\,HHV} * 100\%$$

$$HHV = 41130 + (139.6 * {}^\circ API)$$

$$HHV = 41130 + (139.6 * 34) = 45876.4\ kJ/kg$$

subst:

$$0.80 = \frac{(2200\ lbs/hr)\left(\frac{1kg}{2.2lb}\right)(2789.6 - 461.3)\ kJ/kg}{m_F\,(45876.4\ kJ/kg)}$$

$$\boxed{m_F = 63.4395\ kg/hr}$$

83 to 85 cont…

Density of fuel

$$\rho_{F@60F} = \rho_w (SG_{F@60F})$$

$$34 = API = \frac{141.5}{SG_{F@60F}} - 131.5$$

$$SG_{F@60F} = 0.8550$$

Hence;

$$\rho_{F@60F} = (1000\ kg/m^3)(0.8550)$$

$$\boxed{\rho_{F@60F} = 855\ kg/m^3}$$

Number of days the supply tank can have for continuous operation

$$V_T = \frac{\pi}{4}(6ft)^2(50ft)\left(\frac{1m}{3.28ft}\right)^3 = 40.0628\ m^3$$

$$\rho_F = \frac{m_T}{V_T}$$

$$855\ kg/m^3 = \frac{m_T}{40.0628\ m^3}$$

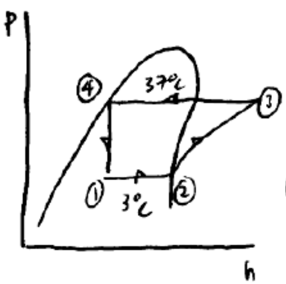
$$m_T = 34253.694\ kg$$

for the number of days:

$$\#\ of\ days = \frac{34253.694\ kg}{(63.4395\ kg/hr)\left(\frac{24\ hrs}{1\ day}\right)}$$

$$\boxed{\#\ of\ days = 22.49\ days}$$

86 to 88



$Q_A = 450\ \text{kW}$

The mass of flash gas per kg of refrigerant circulated

$$x_1 = \frac{m_F}{m_R} \quad \text{or} \quad h_1 = h_f + x_1 h_{fg}$$

$$235.503\ \text{kJ/kg} = (202.70\ \text{kJ/kg}) + x_1 (149.975\ \text{kJ/kg})$$

$$\boxed{x_1 = 0.2182}$$

mass of R12 that must be circulated

$$Q_A = m_R (h_2 - h_1)$$

$$450\ \text{kW} = m_R (352.755 - 235.503)\ \text{kJ/kg}$$

$$\boxed{m_R = 3.8379\ \text{kg/s}}$$

Volume at the suction

$$\dot{V}_2 = m_R \bar{v}_2$$

$$= (3.83792\ \text{kg/s})\left(50.47\ \frac{\text{L}}{\text{kg}}\right)\left(\frac{1\ \text{m}^3}{1000\ \text{L}}\right)$$

$$\boxed{\dot{V}_2 = 0.1937\ \text{m}^3/\text{s}}$$

89 to 94

$P_x = 32\ psig$

$= 321.8964\ kPaa$

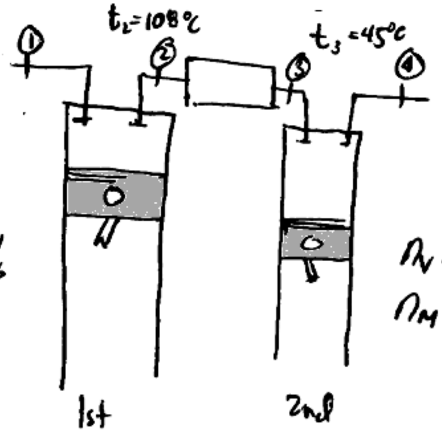
$t_1 = 23°C$

$P_1 = 14.58\ psia$

$= 100.4974\ kPa$

$t_2 = 108°C$

$t_3 = 45°C$



$P_4 = 110\ psig$

$= 859.5393\ kPaa$

$V_{D_1} = 95200\ cm^3/s$

$BP = 35\ hp$

$\eta_v = 88\%$

$\eta_M = 96\%$

Volume Flow rate at the suction, m^3/s

$$\eta_v = \frac{V_1'}{V_D} * 100\%$$

$$0.88 = \frac{V_1'}{\left(95200\ cm^3/s\right)\left(\frac{1m}{100cm}\right)^3}$$

$$\boxed{V_1' = 0.08378\ m^3/s}$$

mass flow rate at the suction, kg/s

$$P_1 V_1 = m R T_1$$

$$\left(14.58\ \frac{lb}{in^2}\right)\left(\frac{101.325\ kPa}{14.7\ psi}\right)\left(0.08378\ m^3/s\right) = m_1\left(0.287\ \frac{kJ}{kg \cdot K}\right)(23+273)K$$

$$\boxed{m_1 = 0.09911\ kg/s}$$

89 to 94 cont…

Air Power in the first Stage

$$W_{c_{1st}} = \frac{n\, m_a R_a T_1}{n-1}\left[\left(\frac{P_x}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

Since it is not a perfect intercooling, the process is polytropic, $PV^n = C$

$$\frac{T_1}{T_2} = \left(\frac{P_1}{P_2}\right)^{\frac{n-1}{n}} = \left(\frac{V_2}{V_1}\right)^{n-1}$$

$$\frac{296\ K}{381\ K} = \left(\frac{100.4979\ kPa}{321.8964\ kPa}\right)^{\frac{n-1}{n}}$$

$$0.7769 = 0.3122^{\frac{n-1}{n}}$$

$$\frac{n-1}{n} = \frac{\ln(0.7769)}{\ln(0.3122)}$$

$$n = 1.2769$$

Hence;

$$W_{c_{1st}} = \frac{(1.2769)(0.09911\ kg/s)(0.287\ kJ/kg\text{-}K)(296\ K)}{1.2769-1}\left[\left(\frac{321.8964\ kPa}{100.4979\ kPa}\right)^{\frac{1.2769-1}{1.2769}} - 1\right]$$

$$\boxed{W_{c_{1st}} = 11.1493\ kW}$$

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89 to 94 cont…

Compressor efficiency

$$\eta_c = \frac{W_c}{IP} \quad ; \quad \eta_m = \frac{IP}{BP}$$

$$0.96 = \frac{IP}{(35\ hp)\left(\frac{0.746\ kW}{1\ hp}\right)}$$

$$IP = 25.0656\ kW$$

Hence;

$$\eta_c = \frac{(11.1493 + 9.9011)\ kW}{25.0656\ kW} * 100\%$$

$$\boxed{\eta_c = 83.98\%}$$

89 to 94 cont…

Power Saved by intercooling

$$\text{Power Saved} = W_{1-2}' - W_{1-2}$$

Work w/o intercooler (2nd stage)

$$W_{2nd}' = \frac{n\, m_a R_a T_2}{n-1}\left[\left(\frac{P_d}{P_x}\right)^{\frac{n-1}{n}} - 1\right]$$

$$= \frac{(1.2769)(0.09911\ kg/s)(0.287\ kJ/kg\text{-}K)(381\ K)}{1.2769-1}\left[\left(\frac{859.5393\ kPa}{321.8964\ kPa}\right)^{\frac{1.2769-1}{1.2769}} - 1\right]$$

$$W_{2nd}' = 11.8625\ kW$$

then;

$$W_{1-2}' = (11.8625 + 11.1493)\ kW$$

$$W_{1-2}' = 23.0119\ kW$$

Hence;

$$\text{Power Saved} = (23.0119 - 21.0504)\ kW$$

$$\boxed{\text{Power Saved} = 1.9615\ kW}$$

89 to 94 cont…

Heat rejected in intercooler

$$Q_{IC} = m_a C_{pa} (T_2 - T_3)$$

$$= (0.09911\ kg/s)(1.0062\ kJ/kg\text{-}K)(108 - 45)^\circ C$$

$$\boxed{Q_{IC} = 6.2826\ kW}$$

95

Carnot cycle

96

Ka/Ki

97

Internal combustion engines

98

No change in PE

99

2

100

Reheating