PROBLEM SET 3

A

A DH

① ⓐ $\eta = \dfrac{P_{max}}{\left.\frac{dE}{dt}\right|_{max}} \times 100\%$

$P_{max} = 1000\,HP \cdot \dfrac{745\,W}{1\,HP} = 745\,kW$

$\left.\dfrac{dE}{dt}\right|_{max} = 3.68 \times 10^6\,W$

ALL VALUES FROM HW 1 (VALUES I FOUND)

$\eta = \dfrac{745 \times 10^{3}\,W}{3.68 \times 10^{6}\,W} \times 100\%$

$\approx 200 \times 10^{-3} \times 10^{2}\,\%$

$\boxed{\eta \approx 20\%}$ EFFICIENCY

ⓑ ASSUME: CARNOT EFFICIENCY

T_{max} OF GAS COMBUSTION $= 1026\,°C = 1299\,K$

$T_{ambient} = 26°C$

$\eta|_{max} = \eta_{carnot} = \dfrac{T_H - T_C}{T_H} = \dfrac{T_{max} - T_{amb}}{T_{max}} \times 100\%$

$\eta_{max} = \dfrac{1026°C - 26°C}{1299\,K} \times 100\% = \dfrac{1000}{1299} \times 100\% \approx \dfrac{10}{13} \times 100\%$

$\boxed{\eta_{max} \approx 80\%}$

ALTERNATIVELY: ASSUME OTTO CYCLE

T_{max} OF OTTO CYCLE = 1089 K

$T_{AMBIENT}$ 294 K

$\eta_{max} = \eta_{carnot} = 1 - \dfrac{T_{Amb}}{T_{max}} = 1 - \dfrac{294\,K}{1089\,K} \approx 1 - \dfrac{300}{1100} \approx (1 - .27) \times 100\%$

$\boxed{\eta_{carnot} \approx 73\%}$ EFFICENT

ⓒ SINCE $\eta_{actual} \approx 20\%$, AND $\eta_{carnot} \approx 73\%$, THE VEYRON ACHIEVES ~30% OF IT'S THEORETICAL MAXIMUM EFFICIENCY.

(d) THE KEY FACTOR IN OTTO CYCLE EFFICIENCY IS THE COMPRESSION RATIO, THE RATIO OF INITIAL AND FINAL VOLUMES. DIESEL ENGINES ARE MORE EFFIENT BECAUSE FUEL IS ONLY INJECTED UNTIL AFTER THE COMPRESSION STROKE. SO THE COMPRESSION RATIO IS NOT LIMITED BY THE NEED TO KEEP THE AIR AT A TEMPERATURE THAT DOES NOT CAUSE THE FUEL TO PREMATURELY EXPLODE. THIS ALLOWS FOR MORE COMPRESSION, HIGHER COMPRESSION RATIO, AND HIGHER EFFICIENCY.

(e) FOR VEYRON

COMPRESSION RATIO: $r = 9$

$\gamma = 1.3$

$$\eta_{otto} = 1 - \frac{1}{r^{(\gamma-1)}} = 1 - \frac{1}{9^{1.3-1}} = 1 - \frac{1}{9^{.3}}$$

$$\approx 1 - \frac{1}{\sqrt[3]{9}} \approx 1 - \frac{1}{2.1} \approx .52 = 52\%$$

$\boxed{\eta_{otto} \approx 52\%}$

(f) $\eta_{max\ otto} \approx 52\%$, WHILE $\eta_{actual} \approx 20\%$, SO THE VEYRON ACHIEVES ~40% OF MAXIMUM OTTO EFFICIENCY.

(2) (a) NGCC STANDS FOR NATURAL GAS COMBINED CYCLES

(b) BURNING COAL EMITS MORE TOXINS BECAUSE IT CONTAINS MORE CHEMICALS DUE TO BEING A SOLID COMPOSED OF BIOLOGICAL REMAINS. NATURAL GAS CONTAINS FEWER OF THESE CHEMICALS BECAUSE THESE SUBSTANCES ARE IN A SOLID STATE, WHILE THE METHANE IN THE REMAINS ESCAPES AND BECOMES NATURAL GAS. *is filtered in the earth!*

(c) NATURAL GAS EMITS 117.0 lb CO_2 FOR EACH BTU
COAL EMITS 228.6 lb CO_2 FOR EACH BTU
THUS COAL EMITS ABOUT 2 TIMES THE CO_2 AS NATURAL GAS.

(d) COAL HAS A HIGHER CARBON CONTENT THAN NATURAL GAS, AND
IT IS NOT AS EFFICIENT AS NATURAL GAS FOR ELECTRICITY GENERATION, *because can't be used in Brayton Cycle, so no CC, so $\eta \approx 35\%$ instead of NGCC ~ 60%*
THESE TWO FACTORS COMBINE AND CAUSE COAL TO EMIT MORE CO_2 THAN NATURAL GAS.

(e) $\Sigma C_{\text{...}} = 146.823$ Quad/year ?

$C_{US} = 17.339 \rightarrow \%C_{US} = \frac{17.339}{146.823} \approx \frac{20}{150} \approx \boxed{14\%}$

$C_{CHINA} = 69.72 \rightarrow \%C_{CHINA} = \frac{69.72}{146.823} \approx \frac{70}{150} \approx \boxed{48\%}$

$\Sigma NG = 123.998$ Quad/year ?

$NG_{US} = 26.095 \rightarrow \%NG_{US} = \frac{26.095}{123.998} \approx \frac{30}{120} \approx \boxed{25\%}$

$NG_{CHINA} = 5.323 \rightarrow \%NG_{CHINA} = \frac{5.323}{123.998} \approx \frac{5}{120} \approx \boxed{4\%}$

$$\begin{array}{r} 365 \\ \times\ 24 \\ \hline 1460 \\ 7300 \\ \hline 8760 \end{array}$$

(3) $P = 100\,W$

$t = 1yr \cdot \frac{365 day}{1yr} \cdot \frac{24hr}{1day} \approx 8760\ hr$

$E = P \cdot t$

$= 100W \cdot \frac{1kW}{1000W} \cdot 8760hr = 876 kWh$

(a) 876kWh IN A NGCC PLANT:

$\frac{dCO_2}{dE} = 1.21\ lbCO_2/kWh$ ← RATE OF CO_2 EMISSION

TOTAL CO_2 PRODUCED IS

$\Sigma CO_2 = E \cdot \frac{dCO_2}{dE} = 876kWH \cdot 1.21 \frac{lbCO_2}{kWH}$

$\approx \boxed{1000\ lb\ CO_2 \text{ EMITTED IN NGCC PLANT}}$

(b) $E = 876\ kWh$

FOR COAL PLANT, CO_2 EMISSION IS

$\frac{dCO_2}{dE} = 1886\ lbCO_2/MWH = 1.886\ lbCO_2/kWH$

THUS, THE TOTAL CO_2 PRODUCED IS

$\Sigma CO_2 = E \cdot \frac{dCO_2}{dE} = 876kWH \cdot 1.886\ lbCO_2/kWH$

$\approx 1700\ lbCO_2$

(c) $E = 876\ kWH$

NGCC PLANT FUEL PER ENERGY OUTPUT IS

$\frac{dF}{dE} = 1000 ft^3/kWh$?

CONSUMPTION IS

~20 tonnes

$$E \cdot \frac{dF}{dE} = 876\,kWH \cdot 1000\,ft^3/kWh = \boxed{876\,000\,ft^3 \text{ of NG}}$$

(d) $E = 876\,kWH$

what about $10^3\,lb\ CO_2/\text{year}$ $\left(\frac{16\,g\ (\text{methane})}{44\,g\ CO_2}\right) = \approx 300\,lb$ methane

RANKINE CYCLE: ENERGY OUTPUT FOR FUEL INPUT IS

$\frac{dF}{dE} = 1.05\,lb/kWh$ where did you get this?

THUS, CONSUMPTION IS

$$E \cdot \frac{dF}{dE} = 876\,kWH \cdot 1.05\,lb/kWH \approx \boxed{900\,lb\ \text{COAL}}$$

4 (a)
- ELECTRICAL CURRENT INCREASES
- TORQUE INCREASES DRAMATICALLY
- SPINNING FREQUENCY DECREASES
- VOLTAGE DECREASES

(b) INCREASE FLOW OF NG TO THE TURBINE

(c)
- CURRENT IS CONSTANT
- TORQUE IS CONSTANT
- SPINNING FREQUENCY INCREASES
- VOLTAGE INCREASES

(d)
- CURRENT IS GREATER
- TORQUE IS GREATER
- FREQUENCY IS THE SAME
- VOLTAGE IS THE SAME

5 (a) POWER LOSS THROUGH TRANSMISSION LINES IS REDUCED DRAMATICALLY IF THE VOLTAGE IS VERY HIGH. THIS IS BECAUSE POWER LOSS BEHAVES ACCORDING TO THE EQUATION $P_{LOST} = I^2R$, AND $P_{DELIVERED} = IV$. SO INCREASING V DECREASES I, WHICH DRAMATICALLY REDUCES P_{LOST} (RESISTIVE HEAT LOSS) IN TRANSMISSION WIRES.

HOWEVER, THE VOLTAGE AT THE GENERATION AND CONSUMPTION ENDS MUST BE MUCH LOWER THAN TRANSMISSION VOLTAGE, SO WE USE TRANSFORMERS TO SWITCH THE VOLTAGES BETWEEN GENERATION, TRANSMISSION, AND CONSUMPTION. THESE TRANSFORMERS UTILIZE THE MAGNETIC FIELD CHANGES THROUGH SOLENOIDS CAUSED BY AC AND PROPERTIES OF INDUCTION TO CHANGE THE VOLTAGE IN WIRES. THIS WOULD NOT WORK IN DC SINCE THE MAGNETIC FIELD IN THE SOLENOID WILL NOT CHANGE.

(b) IF POWER USE DOUBLES, AND VOLTAGE IS CONSTANT, THEN CURRENT DOUBLES SINCE $P_{USED} = IU$.
$2P \rightarrow 2IU$

IF I DOUBLES, AND TRANSMISSION RESISTANCE IS CONSTANT, THEN RESISTIVE HEAT LOSS QUADRUPLES SINCE $P_{LOST} = I^2R$

$$2I \rightarrow (2I)^2R \rightarrow 4P_{LOST}$$

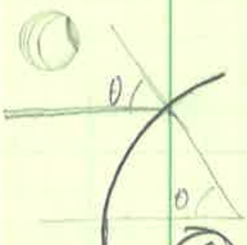
(c) SINCE $R \propto T$, RESISTANCE INCREASES. MORE POWER IS LOST ON HOT DAYS BECAUSE WIRES BECOME MORE RESISTIVE AS THEY HEAT UP.

(d) HAVING HIGH INDUCTANCE AND CAPACITANCE DECREASES THE CURRENT THROUGH THE WIRE, THUS DECREASING THE RESISTIVE HEAT LOSS.

why is this? I think this is wrong.

(e) $U_{new} = U_{old} 5$, $P_{new} = P_{old} \rightarrow I_{new} = I_{old} \cdot \frac{1}{5}$

$$\rightarrow I^2 = I_{old} \frac{1}{25} \rightarrow P_{LOST\,new} = I^2R = I_{old} \frac{1}{25} R = \frac{P_{LOST\,old}}{25}$$



TRANSMISSION LOSS REDUCED BY A FACTOR OF 25 SINCE INCREASING THE VOLTAGE BY x5 REDUCES CURRENT TO $\frac{1}{5}$ OF ITS PREVIOUS VALUE, WHICH IS SQUARED AND REDUCES P_{LOST} TO $\frac{1}{25}$ OF ITS FORMER VALUE

(6) 12.1
L = 52°N

(a) $\theta_{12/21} = 52°N + 23.4° = 75.4°$ FROM NORMAL (OK)

$\theta_{3/20} = 52°N$

$\theta_{6/21} = 52°N - 23.4° = 28.6°$ FROM NORMAL (OK)

(b) $AM_{12/21\ 1200} = \frac{1}{\cos\theta_{12/21}} = \frac{1}{\cos(75.4°)} \approx 4$

$AM_{12/21\ 1500} = \frac{1}{\cos(\theta_{12/21\ 1500})} = \frac{1}{\cos(81.87°)} \approx 6$

$AM_{3/20\ 1200} = \frac{1}{\cos\theta_{3/20}} = \frac{1}{\cos 52°} \approx 1.5$

$AM_{3/20\ 1500} = \frac{1}{\cos\theta_{3/20,\ 1500}} = \frac{1}{\cos 60.03°} \approx 2$

$AM_{6/21\ 1200} = \frac{1}{\cos 28.6°} \approx 1.10$

ok

A

$AM_{6/21\,1500} = \frac{1}{\cos 49.4} \approx 1.5$

(c) S_0 = SOLAR FLUX AT EARTH = 1.37 kW/m²

FROM GRAPH IN BOOK, EXTRAPOLATE

HORIZONTAL:	VERTICAL
$S_{0\,12/21\,1200} \approx .25$	$S_{0\,12/21\,1200} \approx .81$
$S_{0\,12/21\,1500} \approx .10$	$S_{0\,12/21\,1500} \approx .27$
$S_{0\,3/20\,1200} \approx .65$	$S_{0\,3/20\,1200} \approx .81$
$S_{0\,3/20\,1500} \approx .42$	$S_{0\,3/20\,1500} \approx .53$
$S_{0\,6/21\,1200} \approx .90$	$S_{0\,6/21\,1200} \approx .53$
$S_{0\,6/21\,1500} \approx .75$	$S_{0\,6/21\,1500} \approx .25$

OK

A

(7) 12.6

$t = 10\,h$ $\quad n = 20\%$ $\quad T_p = 65°F$ $\quad T_a = 20°F$

$U = 0.5$ $\quad \tau = 0.9$ double-glaze

$Q_{loss}/A = U_L\,(T_p - T_a)\,t$

$Q_{gain}/A = I\tau\alpha$

$I = S_0 \sin(\theta_{...})\left(e^{-\frac{1}{3\cos(\theta)}}\right) \cdot (1-n)$

$I = (435 \sin(65)\, e^{-\frac{1}{3\cos 65}}) \cdot (.8)$ e per hour at noon

$I \approx 140$ Btu/ft² day

$Q_{gain}/A = 140\,\text{Btu/ft}^2 \cdot 0.9 \cdot (.8)$

$\boxed{Q_{gain}/A \approx 100\,\text{Btu/ft}^2}$ per day ~~[illegible]~~ $\times \frac{S_0 T}{\pi}$ A⁻

$Q_{loss}/A = (0.5)(65°F - 20°F) \cdot 10\,h = 225\,\text{Btu/ft}^2$

$\boxed{Q_{loss}/A = 225\,\text{Btu/ft}^2}$ per

THE GAIN IS LESS THAN HALF THE LOSS. $\left(\frac{100}{225} \approx .4\right)$

7

$A = 60\,ft^2$

(8) 12.14

GIVEN

$V = 80\,gal$

$S_o = 270\,Btu/h\,ft^2$

$t = 12h$

$A = 40\,ft^2$

$\eta = 50\%$

$h = 5ft$

$R = 1.5ft$

$I_{ns} = R\text{-}6$

$T_{Avg} = 60°F$

ASSUME LATITUDE OF 30°, ANGLED 45° COLLECTOR

SO

$I = 1950\,Btu/ft^2$

$a = .05$ (SINCE MOST HEAT IS RADIATED AWAY

FIND A_{tank}

$$A_{tank} = 2\pi r^2 + 2\pi r h = 2\pi(1.5ft)^2 + 2\pi(1.5ft)(5ft)$$

$$= 60\,ft^2$$

FIND τ

$$\tau = \frac{mC}{AU_{tot}} = \frac{\pi(1.5ft)^2 \cdot (5ft) \cdot \frac{60\,lb}{1ft^3} \cdot \frac{1kg}{2.2lb} \cdot \frac{1000g}{1kg} \cdot \frac{4.184J}{g}}{20\,ft^2 \cdot \frac{1}{6}}$$

$$\tau = 120{,}000\ J/K\,ft^2 \cdot \frac{1\,Btu}{1055\,J} \cdot \frac{1K}{1.8°F} = 63.7\ BTU/°F\,ft^2$$

(I) $Q_{net} = mC\Delta T = mC(T_p - T_A)$ REARRANGE

$$A(I\tau a - U_L(T_p - T_A))t = mC(T_p - T_A)$$

$$AI\tau a = (T_p - T_A)(mC + U_L t A)$$

$$\frac{\eta A I \tau a}{mC + U_L t A_{tank}} + T_a = T_p$$

$$T_p = \frac{40ft^2(.05)(1950\,btu/ft^2)(3200\,BTU/ft^2°F)(.2)}{\left(303200g \cdot \frac{4.184J/g \cdot Btu}{1055J}\right) + \left(\frac{1}{6} \cdot 24h \cdot 60ft^2\right)}$$

$$\boxed{T_p \approx 108°F}$$

? $T_p - T_A =$
$108 - 60 = 48\,°F$

A-

9 12.15

GIVEN

$Q_{loss}/\Delta T = 500\,\Delta T$ Btu/h ≈ [illegible] kJ/s

$Q_{loss}/\Delta T = 2000\,\Delta T$ Btu/h ≈ 0.58 kJ/s

$T_{out} = 45°F$

$T_{in} = 65°F$ 20

$\alpha = .5$

✓

ASSUME:

WINDOW IS VERTICAL PLATE, SO $I = S_{ov} = .85\ kJ/m^2s$

TIME IS NOON

$U = \frac{1}{R} = \frac{1}{2}$

HOUSE IS 10 m × 10 m × 10 m

SO $m_{air} = 1225\ kg$

$C = 1.01\ J/°C$

$Q_{loss} = Q_{gain}$

I $\frac{Q_{loss}}{\Delta t} = U_L (T_p - T_a)$

II $Q_{gain} = I_T \alpha = \frac{mC}{AU_{tot}} I\alpha$

A

USE II TO SOLVE PROBLEM

ISOLATE A

$$A = \frac{mCI\alpha}{Q_{gain}}$$

$$A = \frac{(1225\,kg)\cdot(0.001\ kJ/1.8°F)\cdot(.85\,kJ/m^2s)(.5)}{Q_{gain}}$$

FOR $Q_{loss} = 500$ BTU/h:

$$A = \frac{.533}{.14} = \boxed{3.8\ m^2}$$

FOR $Q_{loss} = 2000$ BTU/h

$$A = \frac{.533}{.58} = \boxed{.92\ m^2}$$