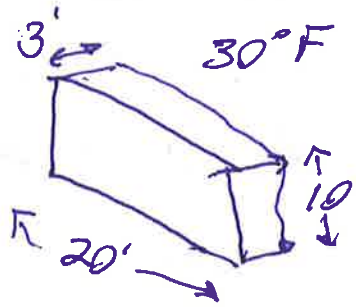
PS #7 Heat Engines.

1) a) $\frac{dT}{dx} = \frac{40°F}{3'}$

70°F



$\Delta(100°C) = (212°F - 32°F)$

$100°C = 180°F$

$\frac{5}{9}°C = °F$

$3' \sim .9\,m$

$\frac{dT}{dx} \approx \frac{40°F}{3'}\left(\frac{\cancel{3'}}{.9m}\right)\left(\frac{5}{9}\frac{°C}{\cancel{°F}}\right)$

$\approx \boxed{25\,°C/m}$

b) $P = (\text{Area})\,\text{conductivity} \cdot \frac{dT}{dx}$ $K_{adobe} \sim \frac{0.57W}{mK}$

$= \underbrace{(20' \times 10')}_{200\,ft^2} \cdot \frac{0.57W}{mK} \cdot \frac{25°K}{m}$

$200\,ft^2 \cancel{\left(\frac{3ft}{.9m}\right)^2} \left(\frac{.9m}{3ft}\right)^2$

although
~~B~~ Kelvin = °C + 273
$\Delta T_{kelvin} = \Delta T_{°C}$

$\approx 18\,\cancel{m^2} \cdot \frac{0.57W}{\cancel{m}\cancel{K}} \times \frac{25\cancel{K}}{\cancel{m}}$

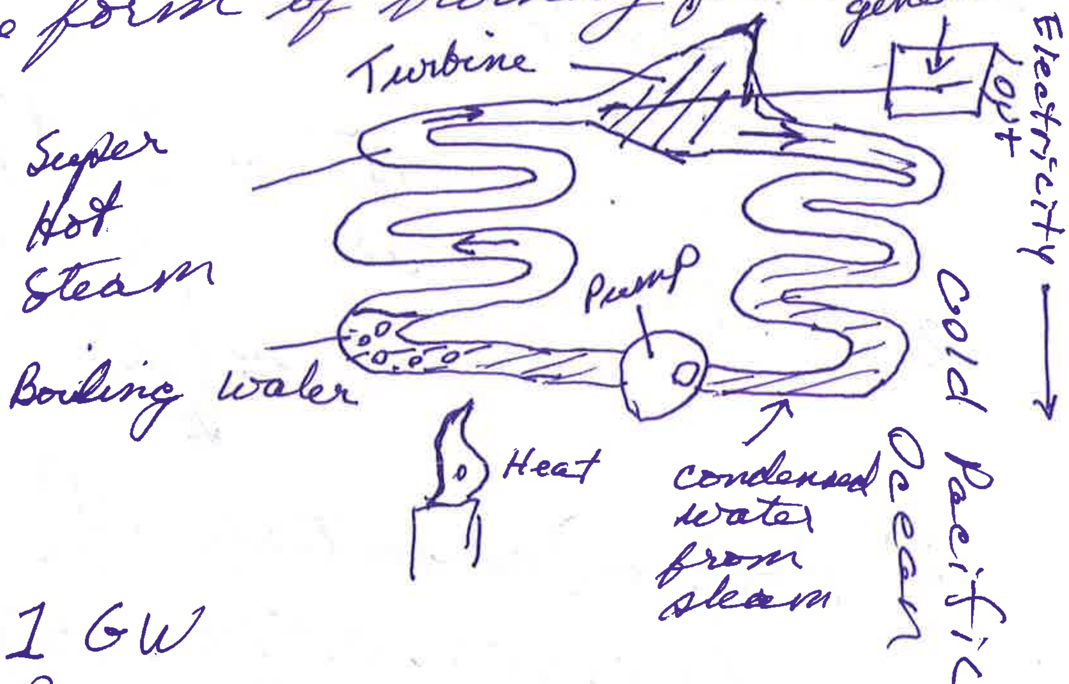
$\approx 260\,W = 260\frac{J}{s}\left(\frac{BTU}{1055J}\right)\left(\frac{3600s}{hr}\right)$

$\approx 880\,\frac{BTU}{hr}$

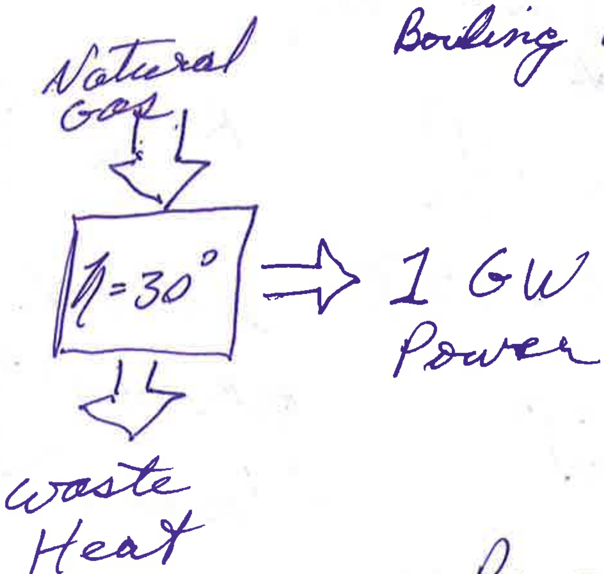
2) we put work in when we compress the gas; we get work out, when the gas expands (Pushing the piston or turbine).

$W_{out} > W_{in}$ because we put in <u>heat</u> (often in the form of burning fuel.

3) a) $\eta \approx 30\%$ Rankine



b)



$$P_{out} = P_{in}\,\eta$$

$$\text{Heat}_{in} = P_{in} = P_{\text{Natural gas}} = \frac{P_{out}}{\eta} \approx \underline{\underline{3.3\ GW}}$$

c) Heat in $(P_{\underline{\underline{in}}})$ = Power Out + Heat out

d) Heat out = Heat in − Power out $\approx \underline{2.3\,GW}$

Energy density of N.G. $\approx 53\ MJ/kg$

rate of NG use $= 3.3 \times 10^{9} \frac{J}{s} \left(\frac{kg}{53\,MJ}\right) \approx 62 \frac{kg}{s}$

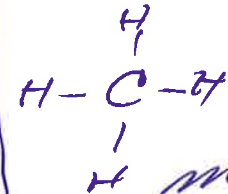
$\approx 62\ kg/s$

#

e) ~~M~~ ~~mass~~ rate of emmission =

$$\left(62\,\frac{kg}{s}\text{ methane}\right)\left(\frac{44g\ CO_2}{16g\text{ methane}}\right)$$

$$\approx 171\,\frac{kg(CO_2)}{s}$$



methane
$m = 16$ AMU

O=C=O
CO_2 mass = 44 Amu

f) waste heat is 2.3 GW or in 1 second
2.3×10^9 J of heat $\quad \Delta T \approx 20°F\left(\frac{5°C}{9°F}\right)\approx 11°C$

$$Q = mc\Delta T$$

$$m = \frac{Q}{c\Delta T} = \frac{2.3\times10^9\,J}{4.2\frac{J}{g°C}\cdot 11°C} \approx 50\,Mg \approx 50\text{ Tons}$$

rate of flow $\approx \frac{50\,m^3}{s}$ or $\frac{50\text{ tons}}{s}$

g) look at part a) - if you lower the temperature of the cold side, the pressure drops, so there is a greater ΔP across the turbine $\Rightarrow$ more power!
Carnot would say $\eta_{max} = 1 - \frac{T_C}{T_H}$
so we want cold to be really cold!

h) $T_H = 2273K \quad T_C \approx 283K \quad \eta_{Carnot} \approx 1 - \frac{283}{2270} \approx 88\%$

I But the pipes can't handle super hot temperatures, so $T_H < 2000K \approx 500°C = 773K$

I) $\eta_c = 1 - \frac{283}{773} = 63\%$, but we still don't reach this because of imperfect mechanisms, $\eta_{Thermal} \approx 30\% - 35\%$ for Rankine.

J) Combined cycle provides efficiencies close to 65% - this would cut fuel use + emissions in half!