Energy cloud – Written exam 1

Energy Cloud: Engineering Localized, Digitized, Sustainable Networks.

DIS Stockholm

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Please submit your answers by March 18th 16:00.
You may choose your favorite support to report the answers (word, pdf, jupyter notebook, etc.) as long the answers are motivated and provided in a structured manner. For calculation questions, please explain your calculation procedure and assumptions made (if any). Making a drawing/schematics of the problems is usually a good aid in solving them.
The answer to the quiz (multiple choice questions) may be directly answered in Canvas.

The written exam is open book. You could use any information provided by the book, or search information from the internet. **This exam is to be performed individually**.

1. Discuss the role that renewable energy technologies will play in future energy systems, and why, as well as potential obstacles to their implementation

See typed_submission.pdf

2. In this troubled geopolitical context, one of your friends comes up with the idea of generating power in a house by plugging a small water turbine to the pressurized cold tap water network and letting water expand to ambient pressure. This could be used to generate power in case of a blackout. The absolute pressure in the tap water network is 8 bar and is maintained through water towers (so it can be maintained over short periods). Assume that water is incompressible and has a density of 1000 kg/m^3. Using the first law of thermodynamics and making necessary assumptions, determine:
   2.1. the maximum (ideal) amount of specific work in Nm/kg that could be produced from such a setup
   2.2. the maximum power that could be generated assuming a constant flow rate of 1 kg/s
   2.3. the actual power that could be generated for a turbine efficiency of 80% and a generator efficiency of 90%
   2.4. give a feedback on your friend's idea based on the numerical value found in the previous question. Use reference values of power usage from common domestic appliances as comparison.

Energy is obtained from the pressure drop of water from 8 bars to 1 bar.

atmospheric, ambient pressure.

$$\cancel{q} - w = \Delta h + \cancel{\Delta \frac{v^2}{2}} + \cancel{\Delta g z}$$

no heat transfered into the system

$$\Delta h = \Delta(u + pv) = u_f + (pv)_f - u_i - (pv)_i$$

$$= (pv)_f - (pv_i)$$

$$pv = \frac{pV}{m} = \frac{p}{\rho} \rightarrow \Delta h = \Delta(pv) = \Delta\left(\frac{p}{\rho}\right)$$

$$= \frac{1}{\rho}\Delta p = \left(\frac{m^3}{1000\,kg}\right)(8\text{ bar} - 1\text{ bar})\left|\frac{10^5\text{ Pa}}{1\text{ bar}}\right|\left|\frac{1\text{ N/m}^2}{1\text{ Pa}}\right|$$

$$= \boxed{700\text{ Nm/kg}}$$

$$\left(700\,\frac{Nm}{kg}\right)\left(1\,\frac{kg}{s}\right) = 700\,\frac{Nm}{s} = \boxed{700\text{ J/s}}$$

→ generator η

$$\left(700\,\frac{J}{s}\right)(0.80)(0.90) = \boxed{504\text{ J/s}} = 504\text{ W}$$

↳ turbine $\left(\frac{1}{\rho}\Delta p\right)$

<504W ?

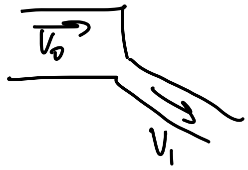
fridge	150-200W	✓
A/C	500-1500W	✓ (barely)
Television	90-250 W	✓
Washing Machine	300-500 W	✓
Clothes Dryer	1800-5000W	✗
Dishwasher	1200-2400 W	✗
Microwave Oven	700-1200 W	✗
Toaster	800-1200 W	✗
Electric Kettle	1500-3000 W	✗
Coffee Maker	800-1500W	✗

Can operate fridge so useful but can't really do anything else!

$$A_1 \dot{x}_1 v_1^2 = A_2 \dot{x}_2 v_2^2$$

SEE SEPARATE FILE

$\frac{1}{2}mv_1^2 = \frac{1}{2}mv_2^2$



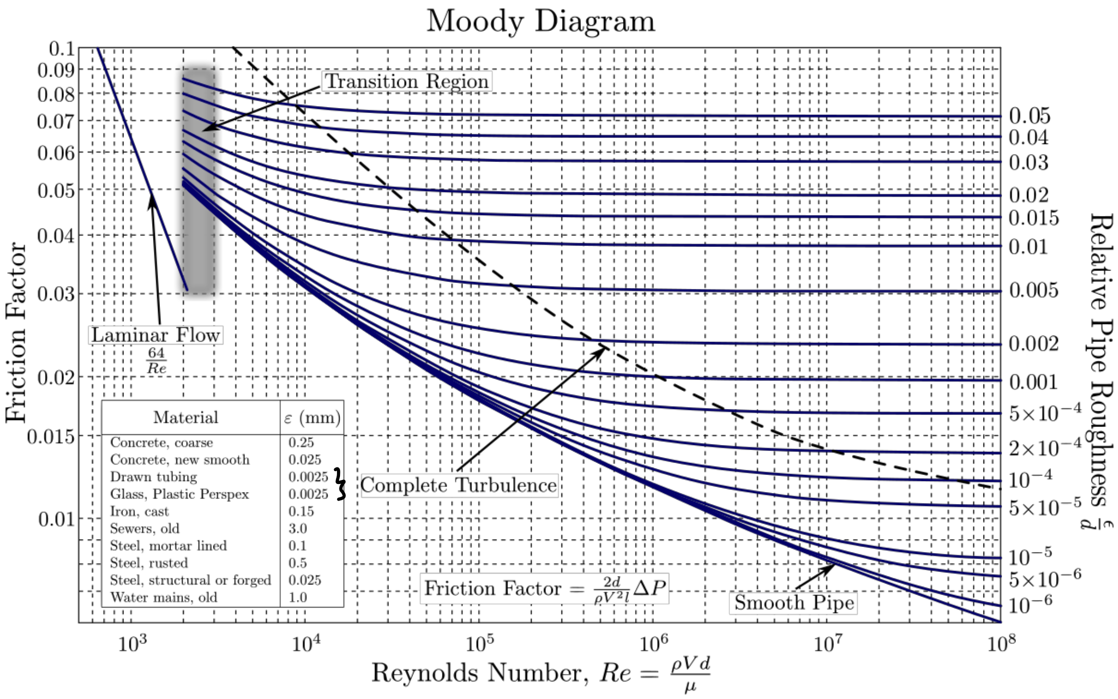
$\dot{m} = \frac{d}{dt}(\rho V)$
$= \rho \dot{V} = \rho (Ax)'$
$= \rho A x'$

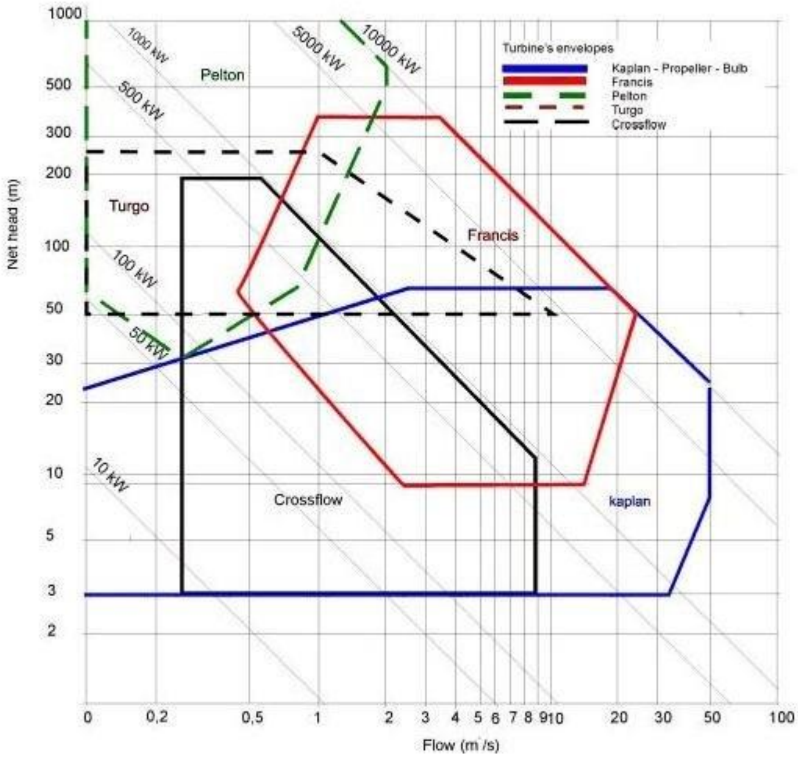
3. A river with the nominal flow of 0.37 m^3/s throughout the year passes nearby a village in Nepal. Assume that you have been hired as a consultant to help the village for developing a run-of-river hydropower plant. There is a requirement to keep 15% of the water flow in the river for downstream irrigation and some other environmental reasons. The length of the penstock required is 300 m and gross head is 35m. Assume that the turbine efficiency is 80% and generator efficiency is 90%. In addition, there is a 10% loss in transmission and distribution of electricity from the powerhouse to the village. Water has a density of 1000 kg/m^3 and a dynamic viscosity of 0,001 Pa·s.

   The daily power demand per household has two peaks: the first one at 0.5 kW between 06:00 and 09:00 and the second one at 1.5 kW between 17:00 and 19:00. The rest of the time the power demand is constant at 0.1 kW. The total number of households in the village is 600. The velocity of water in the cylindrical stainless steel (roughness 0.0025 mm) penstock is 1.8 m/s. Assume minor losses (pressure drop in bends, diameter reduction, etc.) are negligible.

   Do we assume a smooth pipe?

   Determine:
   3.1. the diameter of the penstock pipe kinetic energy at turbine region (in pipe) = reservoir potential with gross head.
   3.2. the net head of the project (i.e. accounting for pressure drop in the penstock). Use the Moody diagram provided below or the Colebrook equation.
   3.3. the power output of the plant. Can the daily energy demand of the village be met with the available head and flow?
   3.4. can the power demand be met? Suggest some ways to possibly mitigate this.
   3.5. what turbine types are suitable for this application? Use the turbine selection chart below (suitable areas are indicated by the area enclosed by color curves for each respective turbine type)




Turbine's envelopes
Kaplan - Propeller - Bulb
Francis
Pelton
Turgo
Crossflow
Pelton
Turgo
Francis
Crossflow
kaplan
1000 kW
500 kW
5000 kW
10000 kW
100 kW
50 kW
10 kW
Net head (m)
Flow (m³/s)

Scratch

(1.1) Assuming the gross head gives the potential energy of water, we can say (potential energy in reservoir/river) = (kinetic energy with which it moves through the pipe) to obtain the diameter of the pipe with assuming no irreversibilities. Then,

$$mgh = \frac{1}{2}mv^2 \Rightarrow gh = \frac{1}{2}v^2$$

where $v = \frac{dx}{dt} = \frac{d}{dt}\left(\frac{V}{A}\right) = \frac{1}{A}\frac{dV}{dt} = \frac{1}{A}\dot{V}$

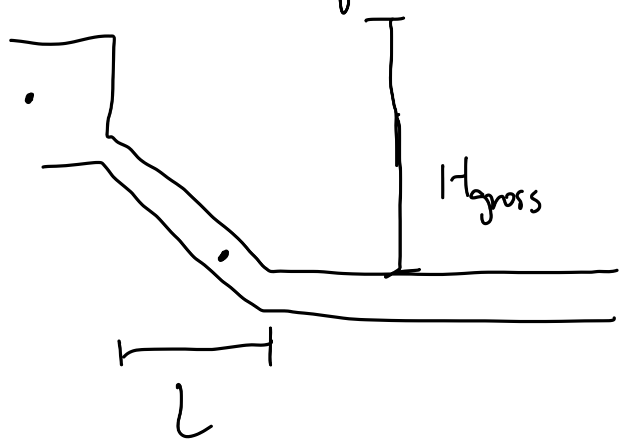
$v = 18$ m/s

$Av = A\frac{dx}{dt} = \frac{d}{dt}V$

We are given $h = 35$ m, $\dot{V} = ?$

$$v = \sqrt{2gh} \rightarrow Av = A\sqrt{2gh} = \frac{d}{dt}V$$

$\dot{W}_{max} = \rho g \dot{V} H_{gross}$ $\qquad$ $\dot{W}_{max} = \dot{m}gh$



Initial
- some KE
- Some PE

Penstock
- known KE $\cancel{\frac{1}{2}mv^2 = \frac{1}{2}\rho V v^2 = \frac{1}{2}\rho A v^3}$

$$\dot{W}_{max} = (\text{initial power}) = \dot{K}_0 + \dot{P}_0 = \frac{1}{2}\dot{m}v^2 + \dot{m}gh$$

$$\dot{m} = \frac{d}{dt}(\rho V) = \rho \frac{dV}{dt} \quad , \quad \frac{dV}{dt} = 0.37 \frac{m^3}{s} \quad \text{(river)}$$

$$\dot{W}_{max} = \rho g \dot{V}_p H_{gross} \quad , \quad \dot{V}_p \text{ is for penstock}$$

$$\frac{1}{2}\rho \dot{V}_r v_r^2 + \rho \dot{V}_r g h = \rho g \dot{V}_p H_{gross} \, ,$$

$$\dot{V}_r = 0.37 \text{ m}^3/\text{s} \quad \text{and} \quad \dot{V}_p = ? \quad \text{and} \quad v_r = ???$$

$$\frac{1}{2}\dot{V}_r v_r^2$$

$$K = \frac{1}{2} m v^2 = \frac{1}{2}\rho V v^2 = \frac{1}{2}\rho A x v^2$$

$$\dot{K} = \frac{1}{2}\rho A v^3$$

$$A_{river} \to \infty \Rightarrow \quad \underbrace{\frac{1}{2}\rho \dot{V}_r v_r^2}_{0} + \rho \dot{V}_r g h = \rho g \dot{V}_p H_{gross}$$

$$\dot{V}_r h = \dot{V}_p H_{gross}$$

$$\dot{V}_p = \frac{\dot{V}_r h}{H_{gross}} =$$

Start

$$P_0 = K \quad \text{(write some justifications)}$$

$$\dot{m} g h = \frac{1}{2}\dot{m} v^2 \quad , \quad \dot{m} = \rho \dot{V}$$

$$\dot{V}_r g h = \frac{1}{2}\dot{V}_p v^2$$

15% loss of river flow

↱ adjusted from new

$0.37 \rightarrow 0.31$

$$\dot V_p = \frac{2\dot V_r g h}{v^2} = \frac{2(0.37\ m^3/s)(9.8\ m/s^2)(35\ m)}{(1.8\ m/s)^2} = \cancel{78}\ 65\ m^3/s$$

$$\frac{m^3}{s}\ \frac{\cancel{m}}{\cancel{s^2}}\ \cancel{m}\ \frac{\cancel{s^2}}{\cancel{m^2}}\ \checkmark$$

$$\dot V_p = \frac{d}{dt} V_p = \frac{d}{dt} A_p x_p = A_p \frac{dx_p}{dt} \Rightarrow A_p = \frac{\dot V_p}{v_p} = \cancel{43}\ 36\ m^2$$

$$\frac{m^{\cancel{3}}/\cancel{s}}{\cancel{m}/\cancel{s}}\ \checkmark$$

$$A_p = \pi r_p^2 = \cancel{43}\ 36\ m^2 \Rightarrow r_p = \cancel{3.7}\ 3.4\ m \Rightarrow \boxed{d = \cancel{7.4}\ 6.8\ m}$$

1.2

$$\frac{\epsilon}{d} = \frac{0.0025\ mm}{\cancel{7.4}\ 6.8\ m}\left|\frac{1\ m}{10^3\ mm}\right| = 3.\cancel{4}7 \times 10^{-7}$$

↓

more or less a smooth pipe from Moody.

$$Re = \frac{\rho v d}{\mu} = \frac{(1000\ kg/m^3)(1.8\ m/s)(\cancel{7.4}\ 6.8\ m)}{(0.001\ Pa\cdot s)} = \cancel{13}\ 12 \cdot 10^6 = 1.\cancel{3}2 \cdot 10^7$$

$$\frac{kg}{m^3}\ \frac{m}{s}\ m\ \frac{1}{Pa\cdot s} = \frac{kg\ \cancel{m^3}}{\cancel{m^3}\ s}\ \frac{m^2}{N}\ \frac{1}{s} = \frac{\cancel{kg}\ \cancel{m^2}}{\cancel{m}\ \cancel{s^2}}\ \frac{\cancel{s^2}}{\cancel{kg}\ \cancel{m}}\ \checkmark$$

$Re \sim 10^7$ and $\frac{\epsilon}{d} \sim$ smooth

$\Big\downarrow$ Moody

$f = 0.005$

$$\Delta p = f \frac{L}{D} \frac{\rho v^2}{2} = (0.005) \frac{(300 m)}{(\cancel{7.4} m)_{6.8}} \frac{(1000 kg/m^3)(1.8 m/s)^2}{2}$$

$$\frac{kg}{m^{\cancel{3}}} \frac{\cancel{m^2}}{s^2} = \frac{kg}{m s^2} = \frac{kg\, m}{s^2} \cdot m^{-2} = \frac{N}{m^2} = Pa$$

$$\boxed{\Delta p = \cancel{328}\ 357\ Pa}$$

(p drop in penstock — no irreversibilities)

3.3 $\dot{W}_{output} = \eta_{transm} \eta_{generator} \eta_{turbine} \dot{W}_{turbine}$

$= (0.90)(0.90)(0.80)(\dot{W}_{max} - \Delta p)$

$\downarrow$

what is max pressure w/o irreversibilities in penstock?

$\dot{P}_o = \dot{m} g h = \rho \dot{V} g h = (1000 \frac{kg}{m^3})(0.31 m^3/s)(9.8 m/s^2)(35 m)$

$=$

$$\frac{kg}{\cancel{m^3}} \; \frac{\cancel{m^3}}{s} \; \frac{m}{s^2} \; m \qquad \frac{kg\,m^2}{s^3} \qquad Pa = \frac{N}{m^2} = \frac{kg\,m}{m^2 s^2} = \frac{kg}{m s^2}$$

$$= J/s$$

$v_p = 1.8\ m/s$

Multiply Δp by velocity to obtain J/s

$$P_{max} - P_{drop} = \dot{P}_o - \Delta p\, v_p = 106\,330\ J/s - 642.6\ J/s$$
$$= 105\ kJ/s = 105\ kW$$

$$\dot{W}_{output} = (0.90)(0.90)(0.80)(105\ kW)$$
$$= 68\ kW$$

Assuming this is run all day (24 hrs) and starts from midnight (00:00),

		demand per house	total demand (600 houses)
6h	00:00 - 06:00	0.1 kW	60
* 3h	06:00 - 09:00	0.5	300
8h	09:00 - 17:00	0.1	60
* 2h	17:00 - 19:00	1.5	900
5h	19:00 - 00:00	0.1	60

(daily E needed) = 60 kW · 6h + 300 kW · 3h + 60 kW · 8h + 900 kW · 2h
+ 60 kW · 5h
= 3840 kWh

(daily E provided) = 68 kW · 24h = 1632 kWh

$\boxed{3840 > 1632 \Rightarrow \text{Daily E cannot be met}}$

3.4

68 > 60 so for normal hrs req is met but peak times we need 4-13 times more efficient ones.

Possible mitigation: store energy somewhere to use it for peak hours.

Extra E (0-6): (68 kW − 60 kW)(6 hr) = 48 kWh

Lacking E (6-9): (300 kW − 68 kW)(3 hr) = 696 kWh

So even if we store all residue E from 0-6 we still cannot last the morning peak.

Extra E (9-17): 64 kWh

Lacking E (17-19): 1664 kWh

Extra E (19-24): 40 kWh

Every day:

Debt : 696 + 1664 = 2360 kWh

Extra Earning: 48 + 64 + 40 = 152 kWh

Debt is ~ 15 times more even if we store all unused energy so you should not move forward with this plant. Design better-performing power plants or use less.

Miscalculation of Head: ΔE b/t before and after turbine. This is

$$\dot{E}_{before} = \dot{W}_{max} - \dot{W}_{\text{lost by penstock}}$$

$$\dot{E}_{after} = 0.15 \text{ of original flow?}$$ ← come back to it!

4. Solar radiation is incident on a flat-plate collector at a rate of 750 W/m^2. The glazing has a transmittivity of 0.86 and the absorptivity of the absorber plate is 0.95. The heat loss coefficient of the collector is 3 W/(m^2 K). The collector is at average temperature of 45°C and the ambient temperature is 23°C. Determine the efficiency of this collector.

$G = 750\ W/m^2$

$\tau = 0.86$

$\alpha = 0.95$

$K = 3$

$T_{avg} = 45°C$

$T_{amb} = 23°C$

$\eta = ?$

$\dot{Q}_{abs} = \tau\alpha A G$

$\eta = \frac{\dot{W}_{out}}{AG}$

$$\eta = \tau\alpha - U\frac{T_c - T_a}{G}$$

U ↓ overall heat transfer coefficient

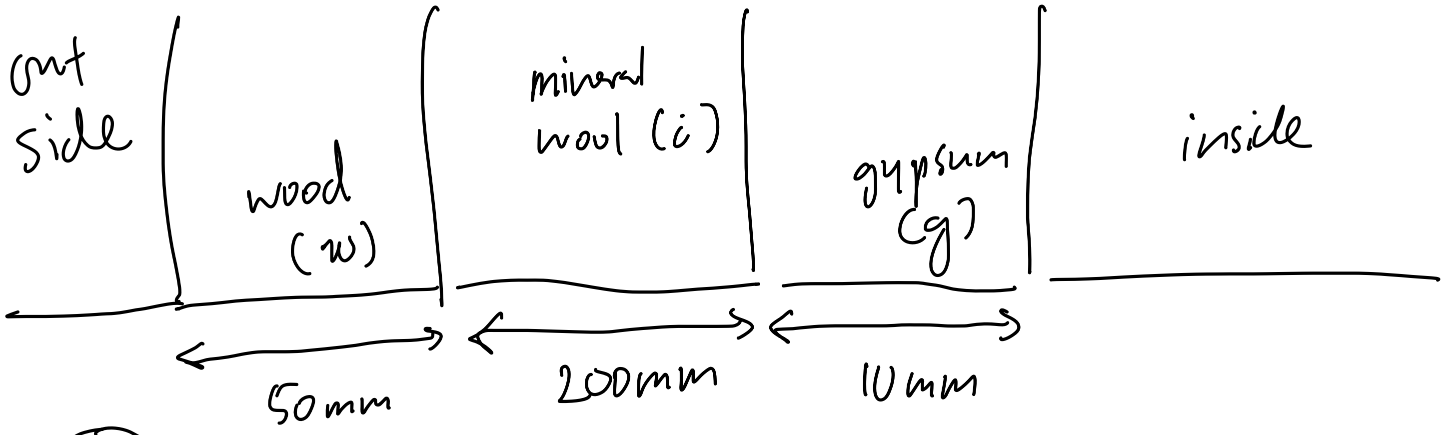
Assume "heat loss coefficient" means "heat transfer coefficient"

$\rightarrow U = 3\ \frac{W}{m^2K}$

$$\eta = \tau\alpha - U\frac{T_c - T_a}{G} = 0.729$$

5. The outer walls of a Swedish house consist of a 50 mm wood layer ($\lambda_w = 0.2\ W\ m^{-1}\ K^{-1}$), a 200 mm layer of insulation (mineral wool, $\lambda_i = 0.04\ W\ m^{-1}\ K^{-1}$), and an inner board of gypsum, 10 mm thick ($\lambda_g = 0.5\ W\ m^{-1}\ K^{-1}$). The heat transfer coefficient (accounting for convection and radiation) on the outside is assumed to be 15 W/(m^2 K) and on the inside 10 W/(m^2 K).
   5.1. Calculate the overall heat transfer coefficient U and the heat losses per m^2 for this wall for design conditions of -18°C for the outdoor temperature and +15°C inside.
   5.2. The house can be assumed to have a rectangular shape (box) with dimensions of 7.5 m x 20 m. The house is one-story house with story height 2.5 m. The windows account for about 40% of the façade area and have a U-value of 1.2 W/(m^2 K) while the flat roof and concrete slab have U-values of 0.2 and 0.5 W/(m^2 K). Calculate the heat lost through each type of component (wall, slab, roof, window) and sum it up to obtain the total heat losses (use the same temperature conditions as in 4.1).[1]
   5.3. Using the U-values found in the previous questions and the csv file containing hourly temperatures in Stockholm provided in Canvas, calculate the hourly heat demand for a balance temperature of 15°C (i.e. when the outdoor temperature exceeds 15°C no heating is needed).
   5.4. Aggregate the hourly heat demand to determine the yearly heating needs in MWh. What would be the electricity bill for heating if a heat pump with a COP of 3 was used? Assume an electricity price of 0.15$/kWh.

[1] Usually cold bridges, heat gains (internal and solar) and ventilation heat losses have to be accounted for but they can be neglected here. Heat gains are indirectly accounted for in the balance temperature of 15°C (i.e. the temperature at which heat gains fully compensate heat losses).



5.1

$$R_{tot} = R_w + R_i + R_g = \frac{L_w}{\lambda_w} + \frac{L_i}{\lambda_i} + \frac{L_g}{\lambda_g}$$

$$= \left(\frac{50}{0.02} + \frac{200}{0.04} + \frac{10}{0.5}\right) \frac{\cancel{mm}\ m K}{W} \left| \frac{1\ m}{10^3\ \cancel{mm}} \right|$$

$$= 7.52 \ \frac{m^2 K}{W}$$

$U = \frac{1}{R} = 0.133 \ \frac{W}{m^2 K}$. But adding U for inside and outside: $U_{tot} = (0.133 + 15 + 10) \frac{W}{m^2 K}$

$$= \boxed{25.133 \ \frac{W}{m^2 K}}$$

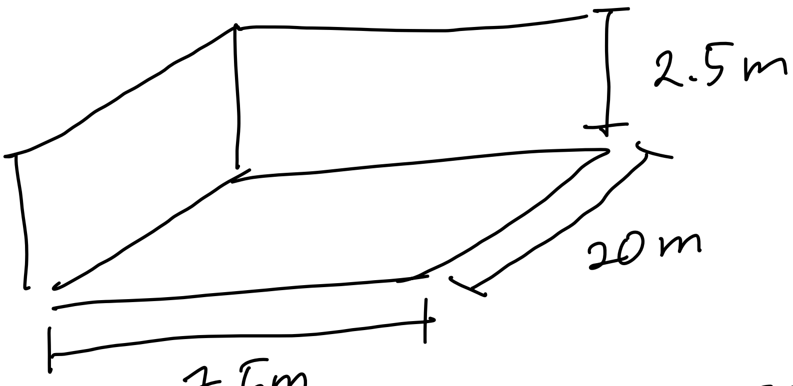
~~* But strictly for conductive formula $Q = hA\Delta T$ you shouldn't include losses thru other modes.~~ → really?

$Q = K \frac{\Delta T}{L} \Rightarrow \frac{Q}{A} = U \Delta T$, $\Delta T = 15 + 18$
$= 33 (°C)$

$\ddot{K}$

$$\frac{Q}{A} = \left(25.133 \ \frac{W}{m^2 K}\right)(33 K) = \boxed{829 \ \frac{W}{m^2}}$$

5.2



$\Delta T = 33\ K$

window $U_w = 1.2\ (W/m^2K)$

roof $U_r = 0.2$

slab $U_s = 0.5$

* Assume slab is floor

Sides are 60% walls and 40% windows

$$\frac{Q}{A} = U\Delta T \rightarrow Q = AU\Delta T \rightarrow \Sigma Q = \Sigma AU\Delta T$$
$$= \Delta T \Sigma AU$$

$$Q_{wall} = A_w U_w \Delta T = (0.6\, A_{sides}) U_w \Delta T$$

$$= (0.6[7.5 \cdot 2.5 \cdot 2 + 20 \cdot 2.5 \cdot 2]\ m^2)\left(0.133 \frac{W}{m^2K}\right)(33\,K)$$

$$= 362\ W$$

$$Q_{window} =$$

$$(0.4[7.5 \cdot 2.5 \cdot 2 + 20 \cdot 2.5 \cdot 2]\ m^2)\left(1.2 \frac{W}{m^2K}\right)(33\,K)$$

$$= 2178\ W$$

$$Q_{roof} = (7.5\,m \times 20\,m)\left(0.2\,\frac{W}{m^2 K}\right)(33\,K) = 990\,W$$

$$Q_{slab} = \quad '' \quad 0.5 \quad '' \quad = 2475\,W$$

wall	362 W
slab	2475 W
roof	990 W
window	2178 W

* for convection and radiation losses the area is assumed to be the entire surface area of the house.

5.3 Grab all hours that are below 15°C. Say there are n (out of 8000). For each temperature T, we know how much heat will be lost (from all the $\dot{Q}$ calculations), ~~and~~ but we can't calculate how much heat E is needed to raise the temperature to 15°C since

$$\dot{Q} = AU\Delta T$$

Note $\dot{Q}$ is our output and ΔT will be determined by each input, and so we have to find the ~~constant~~ total energy dissipated each second AU,

$$AU = (AU)_{total} = (AU)_{wall} + (AU)_{window} + (AU)_{roof} + (AU)_{slab}$$

And since besides conduction the U-values for convection and radiation are also given (labelled 'misc')

$$(AU)_{total} = (AU)_{wall} + (AU)_{window} + (AU)_{roof} + (AU)_{slab}$$

for code

$\uparrow$

AU

$$+ (AU)_{misc,\ inside} + (AU)_{misc,\ out}$$

$$= 11{,}119.4725 \sim 1.11 \times 10^4 \ (W/K) =: \ \cancel{AU}$$

$$[\dot{Q}] = \frac{W}{K} K = W$$

Then hourly E dissipated is $3600\ AU =: E_h$, $[E_h] = Wh$

* E_h is represented as variable 'E' in code.

So now all I have to do is write a program that

1. Searches the csv and checks if the temperature is under 15°C
2. If it is (for each iteration), then define
   $\Delta T = 15 - T$, where T is that temperature
3. If ΔT is defined, use
   $Q = C \Delta T$ to define
   $Q := C \Delta T$
4. If Q is defined, print the Q value

5+4

as to show how much the heating demand was for that hour.

8.3 Done in code

8.4 COP of 3 means for each fixed amount of heat E provision we have triple the amount produced per each investment (e.g. to produce 100 kWh only 33 kWh is used — and hence you are only billed for 33 kWh, i.e., only a third of what you actually produce).

~~TODO: use this property to compute the \$~~

$\$0.15 / kWh = \$150 / MWh$

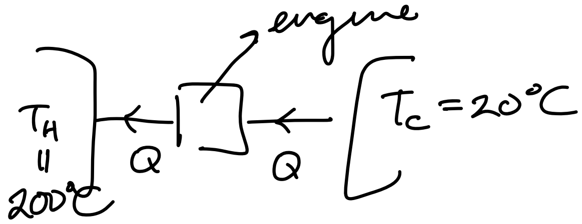
REST DONE IN CODE

6. In a patent application for a new type of heat engine, the inventor states that the engine's thermal efficiency amounts to 40%. The application further states that heat is supplied to the process at a maximum temperature of 200 °C and removed at 20 °C. If you were to review this patent application, how would you react to this information? Motivate the answer!

$\eta \to 0.40$

$T_H = 200°C$

$T_c = 20°C$



dumping heat from T_c to T_H.

Theoretical Maximum of a heat engine is $\eta = 1 - \frac{T_c}{T_H}$ (or $\frac{T_H - T_c}{T_H}$)

~~So $\eta = 1 - \frac{20°C}{200°C} = \frac{9}{10} = 90\%$~~

~~40% efficiency is way below the theoretical maximum efficiency of 90%.~~

Use Kelvin

$$\eta = 1 - \frac{20 + 273.15}{200 + 273.15} = 0.38 < 0.40$$

~~I call BS?~~

Since 0.38 is the theoretical maximum and 0.40 is higher than that I'd be suspicious of possible mendacity of the inventor, who seems to have faults/errors in his calculations.

7. An investor is to install a total of 40 identical wind turbines in a location with an average wind speed of 7.2 m/s. The blade diameter of each turbine is 18 m and the average overall wind turbine efficiency is 33%. The turbines are expected to operate under these average conditions 6000 hrs/year and the electricity produced is to be sold to a local utility at a price of 0.075 \$/kWh. If the total investment cost of this installation is 1,2 M\$, determine how long it will take for these turbines to pay for themselves. Take the density of air to be 1.18 kg/m^3.

Givens

✓ 40 turbines

✓ $d = 18$ m

✓ $\eta = \cancel{33\%}$ 0.33

✓ $v_{wind_{avg}} = 7.2$ m/s

✓ 6000 hrs / yr

✓ sold at \$ 0.075 per KWh

✓ Startup-cost \$ 1.2×10^6

✓ $\rho_{air} = 1.18$ kg / m^3

How much money does this turbine save?

$$\dot{W}_{available} = \frac{1}{2}\rho A v^3 , \quad \rho = 1.18 \, kg/m^3 , \quad A = \pi\left(\frac{d}{2}\right)^2 = 254 \, m^2$$

[W]

$$v = 7.2 \, m/s$$

$$\frac{J}{s} = \frac{Nm}{s} = N\frac{m}{s} = \left(\frac{kg\,m}{s^2}\right)\frac{m}{s} = \frac{kg\,m^2}{s^3}$$

$$= \frac{1}{2}\left(1.18 \frac{kg}{m^3}\right)\left(254\, m^2\right)\left(7.2 \frac{m}{s}\right)^3$$

$$\left(\frac{kg}{\cancel{m^3}}\, m^2\, \frac{\cancel{m^3}}{s^3} = W\right)$$

$$= 56038 \, W = 56 \, kW$$

$$\dot{W}_{electric} = \eta_{wt,overall}\,\dot{W}_{available} = (0.33)(56\,kW) = 18.5\,kW$$

$$W_{elec}\Big|_{\text{annual, one turbine}} = (\text{oper. hrs})\,\dot{W}_{elec} = (6000\text{ hr})(18.5\text{ kW}) = 111\text{ MWh}$$

$$W_{electric}\Big|_{\text{annual, 40 turbines}} = 111 \times 40\text{ MWh} = 4440\text{ MWh}$$

So these turbines make 4440 MWh every year, and we're selling this made energy at \$ 0.075 per kWh to a local utility

= \$75 per MWh

Question: how many years will it take for the ~~sold~~ revenue to be equal to the startup cost of 1.2 million dollars?

$$(\text{yearly revenue}) = \left(\frac{4440\text{ MWh}}{\cancel{\text{yr}}}\right)\left(\frac{\$75}{\text{MWh}}\right) = 333{,}000 \text{ dollars} \cancel{\text{/ year}}$$

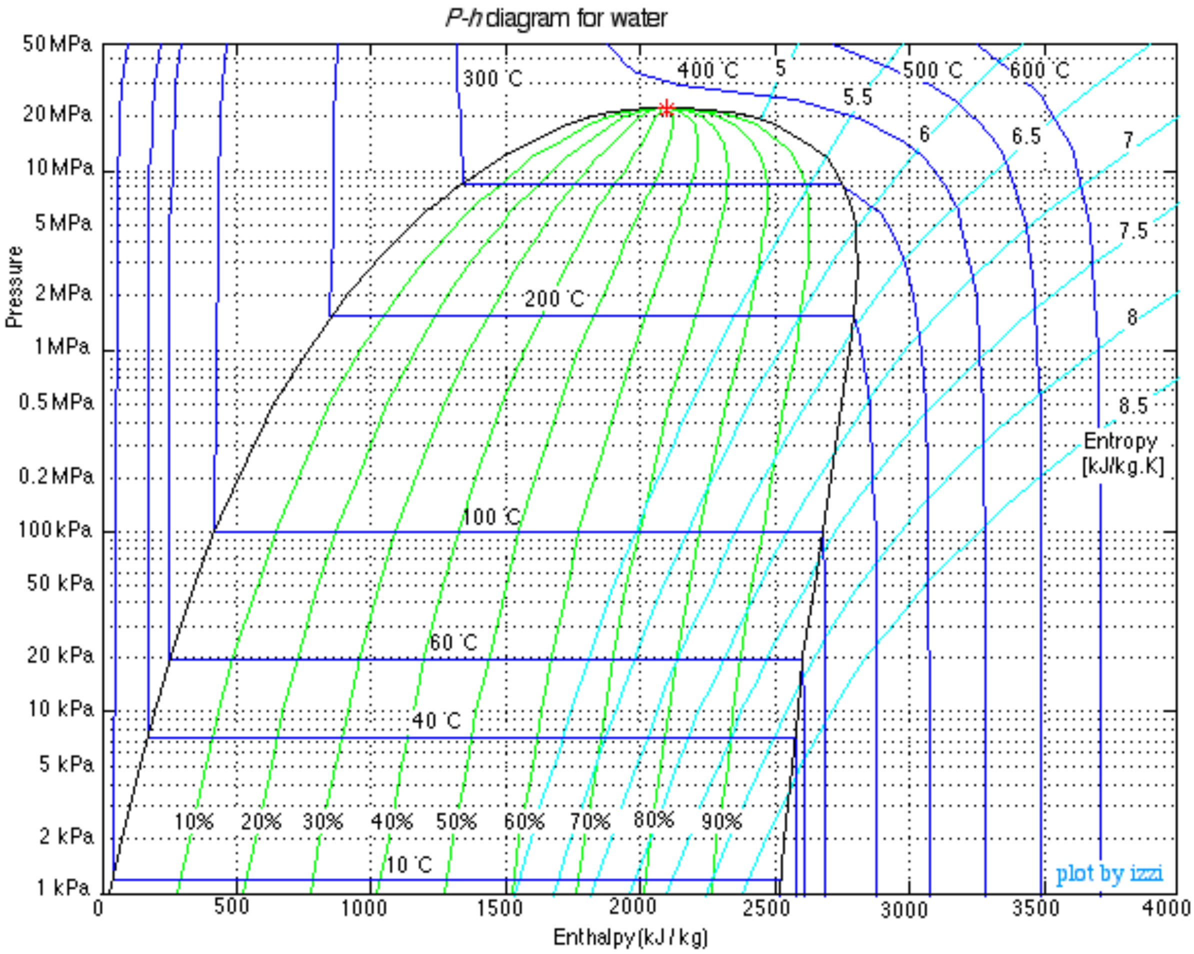
$$\frac{\$\,1{,}200{,}000}{\$\,333{,}000} = 3.6$$

$$\boxed{\text{So it takes about 3.6 yrs to reach break-even}}$$

(flash chamber) ≡ (compressor)

8. The schematic of a single-flash geothermal power plant with state numbers (=state points) is given in Fig.P7-73 (see p237 of the textbook). The geothermal resource exists as saturated liquid at 230°C. The geothermal liquid (water) is withdrawn from the production well at a rate of 230 kg/s, and is flashed to a pressure of 500 kPa by an essentially isenthalpic flashing process where the resulting vapor is separated from the liquid in a separator and directed to the turbine. The steam leaves the turbine at 10 kPa with a moisture content of 10 percent and enters the condenser, where it is condensed and routed to a reinjection well along with the liquid coming off the separator.
   Determine:
   8.1. The mass flow rate of steam through the turbine (use the concept of vapor quality or mass fraction of vapor)
   8.2. The isentropic efficiency of the turbine
   8.3. The mechanical power output from the turbine (pre-generator)
   8.4. The thermal efficiency of the plant

You may use the P-h diagram below as an aid.

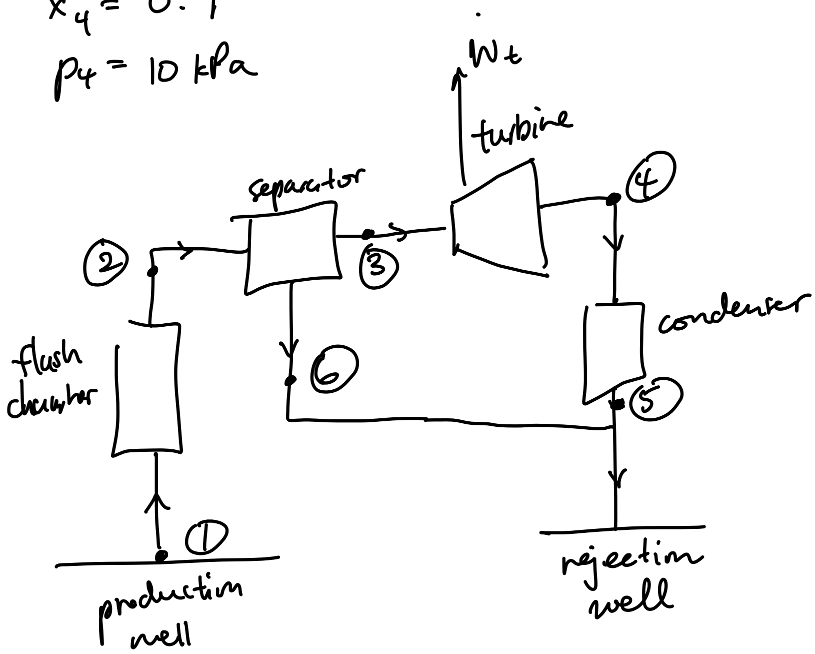


$x_1 = 0$
$T_1 = 230°C$
$p_2 = 500$ kPa
$s_1 = s_2$

$x_3 = 1$
$p_3 = p_2 = 500$ kPa

$\dot{m}_1 = 230$ kg/s
water is the working fluid

$x_4 = 0.9$
$p_4 = 10$ kPa



* Assume referencing textbook thermodynamic tables
* no stray heat
* internally reversible
* $\Delta K \sim \Delta P \sim 0$

$$s_1(x_1 = 0,\ T_1 = 230°C) = s_f(T_1 = 230°C) = 2.6100\ \frac{kJ}{kg\,K}$$

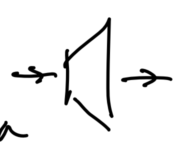
$$s_2 = s_1 = 2.6100\ \frac{kJ}{kgK}$$

$$x_2\left(p_2 = 500\text{ kPa},\ s_2 = 2.6100\ \frac{kJ}{kgK}\right) \Rightarrow \begin{pmatrix} s_f = 1.8604 \\ s_g = 6.8207 \end{pmatrix}$$

$$x_2 = \frac{s_2 - s_f}{s_g - s_f} = \frac{2.6100 - 1.8604}{6.8207 - 1.8604} = 0.15$$

$$\dot{m}_3 = x_2 \dot{m}_1 = 35\ kg/s$$

$x_3 = 1$
$p_3 = 500$ kPa



$x_4 = 0.9$
$p_4 = 10$ kPa

Use the definition of isentropic efficiency of turbine, $\eta_t = \dfrac{h_3 - h_4}{h_3 - h_{4s}}$

$$h_3 (x_3 = 1, p_3 = 500\,kPa) = 2748.1\ \frac{kJ}{kg}$$

$$h_4 (x_4 = 0.9, p_4 = 10\,kPa) = h_{f4} + x_4 (h_{g4} - h_{f4})$$

$$= 191.81 + 0.9 (2583.9 - 191.81) = 2344\ kJ/kg$$

$$s_3 (x_3 = 1, p_3 = 500\,kPa) = 6.8207\ \frac{kJ}{kg\,K}$$

$s_{4s} = s_3 = 6.8207\ \frac{kJ}{kg\,K}$ (by def'n of isentropic efficiency)

$p_{4s} = p_4 = 10\,kPa$ (by def'n of isentropic efficiency)

$$\Rightarrow \quad x_{4s} = \frac{s_{4s} - s_{f4s}}{s_{g4s} - s_{f4s}} = \frac{6.8207 - 0.6492}{8.1488 - 0.6492} = 0.82$$

$$h_{4s} (s_{4s} = 6.8207\ \frac{kJ}{kg\,K}, p_{4s} = 10\,kPa)$$

$$= h_{f4s} + x_{4s} (h_{g4s} - h_{f4s}), \quad \left\{ \begin{array}{l} h_{f4s} = 191.81 \\ h_{g4s} = 2583.9 \end{array} \right\}$$

$$= 2160\ kJ/kg$$

$$\Rightarrow \quad \eta = \frac{h_3 - h_4}{h_3 - h_{4s}} = 0.69$$

$$\frac{\dot{W}_t}{\dot{m}_3} = h_3 - h_4 = 403\ kJ/kg$$

$$\dot{W}_t = \dot{m}_3 (h_3 - h_4) = 14021\ kJ \sim 14000\ kJ \sim 14\ MJ$$

Use definition $\eta_{th} = \frac{\dot{W}_{out}}{\dot{E}_{in}} = \frac{\dot{m}_3 (h_3 - h_4)}{\dot{m}_1 (h_1 - h_0)}$ Eq 7-18

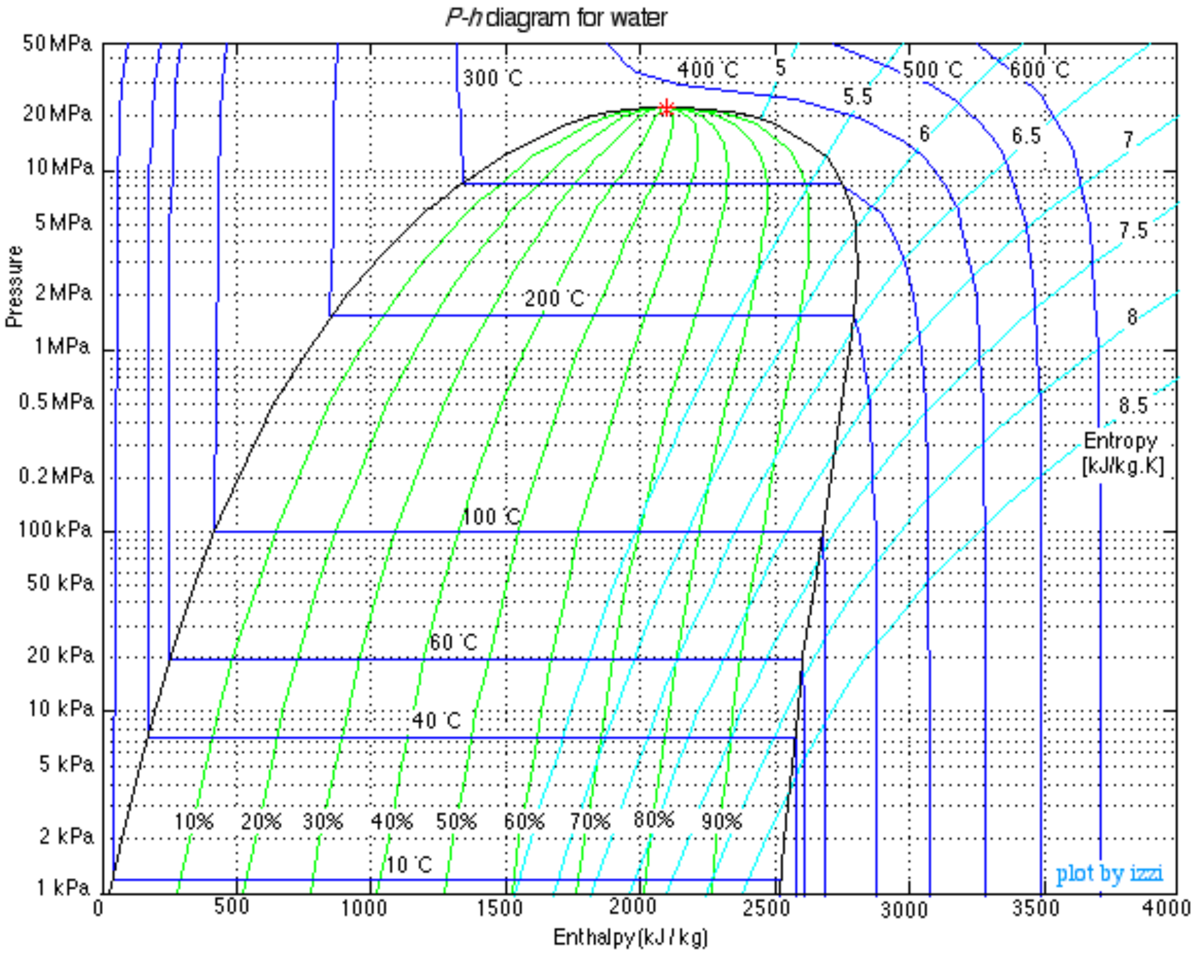
Def'n of h_0

$$h_0 (25°C, 1\,atm, x=0) = 104.83 \frac{kJ}{kg}$$

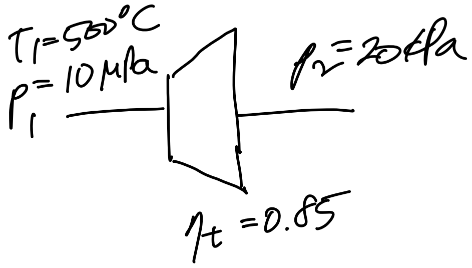
$$h_1 \left(\begin{matrix} x_1 = 0 \\ T_1 = 230°C \end{matrix} \right) = 990.14\ kJ/kg$$

$$\eta = \frac{\dot{m}_3 (h_3 - h_4)}{\dot{m}_1 (h_1 - h_0)} = 0.069$$

9. Solve Example 4-5 using steam temperature and pressure of 500°C and 10 MPa, respectively (at turbine inlet). You may solve using the tables in the appendix of the book or using the P-h diagram below (or both to check your results!).



$\dot{m} = 20\ kg/s$ $\qquad A = 8 \times 10^4\ m^2 \qquad G = 950\ W/m^2$



$$\frac{\dot{W}_t}{\dot{m}} = h_1 - h_2 = ?$$

$$\eta_t = \frac{h_1 - h_2}{h_1 - h_{2s}} \Rightarrow h_1 - h_2 = \eta_t (h_1 - h_{2s})$$

$h_1(T_1 = 500°C, p_1 = 10 MPa) = 3375.1\ kJ/kg$ (superheated).

$s_1(T_1 = 500°C, p_1 = 10 MPa) = 6.5995\ kJ/kgK$

$h_{2s}(p_{2s} = p_2 = 20\ kPa, s_{2s} = s_1 = 6.5995\ kJ/kgK)$

$$= 251.42 + \left(\frac{6.5995 - 0.8320}{7.9073 - 0.8320}\right)(2608.9 - 251.42) = 2173\ \frac{kJ}{kg}$$

$\Rightarrow \dot{W}_t/\dot{m} = 1021\ kJ/kg \rightarrow \dot{W}_t = 20433\ kJ/s$

$$\eta_{th} = \frac{\dot{W}_{out}}{AG} = \frac{\dot{W}_t}{AG} = \frac{20433 \text{ kJ/s}}{(8 \cdot 10^4 \text{ m}^2)(0.950 \frac{\text{kW}}{\text{m}^2})} = 0.27$$

Since part (b) in Example 4-5 is unaltered with the particular changes for this problem, it'll be skipped.

10. Discuss advantages and disadvantages of the different types of renewable energy sources

See typed_submission.pdf