Sustainable Energy Homework 1 Solutions

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1 Question 1

Solution: Since we do not consider any heat transfer and neglect kinetic energy except out of nozzle, we have the following:

- Compressor: $Q = \Delta h + W_t = 0$, therefore we have $W_t = -\Delta h$. Evaluate the equation above we have $W_t = -539.96\ (KJ \cdot Kg^{-1})$
- Turbine: For the same reason, we have $Q = \Delta h + W_t = 0$. Therefore $W_t = -(933.15 - 1635.8) = 702.65\ (KJ \cdot Kg^{-1})$
- Nozzle: As analyzed above, we can reach this equation $Q = \Delta h + E_k = 0$ where E_k stands for the kinetic energy of gases. Thus, $\frac{1}{2}v^2 = -\Delta h$, evaluate this equation we have exit velocity $v = \sqrt{2 * 283.62 * 10^3} = 753.2\ m/s$
- Compressor: If the turbine specific work is completely used to drive the compressor, we have $Q = \Delta h + W_t$ where $W_t = 0$. Thus, $Q = \Delta h = 1635.8 - 800.28 = 835.52\ (KJ/Kg)$.
  So the jet efficiency is $\eta = \frac{0.5 * v^2}{q}$, evaluate this equation we have $\eta = 33.9\%$.
- Enthalpy: When $W_{turbine} = W_{compressor}$, we have $1635.8 - W_{tout} = 539.96$, so the turbine outlet enthalpy is $1095.84\ (KJ/Kg)$

2 Question 2

From this page `https://en.wikipedia.org/wiki/R-410A` we know the physical properties of R-410A. Since the boiling point for R-410A is −48.5°C, so it will stay in gas form all the circulation.

For easy calculation we assume the volume of R-410A is constant. Since the flow rate is 0.05 Kg/s, we use flow time $t = 1s$.

- Thus $m = 0.05 * 1 = 0.05\ Kg$

  $$W_{comp} - Q_{comp} = m * (h_{state6} - h_{state1}) \tag{1}$$

  This is inferred from 1st law of thermaldynamics. Evaluate (1) we have heat transfer from the compressor is $(377 - 384) * 0.05 = 4.65\ KJ$.

- Following a similar scheme, we have the heat transfer in the condenser is $(134 - 367) * 0.05 = 11.65\ KJ$

- As above, the expansion valve does not change the enthalpy during a throttling process, so we have

  $$Q_{evap} = m * (h_{state5} - h_{state4}) \tag{2}$$

  Evaluate (2) we have $Q_{evap} = 7.3\ KJ$

- From the question we have $W_{in} = P_{comp} * t = 5\ KJ$, and $Q_{cond} = 11.65\ KJ$. Thus we have,

  $$COP_{HP} = \frac{Q_{cond}}{W_{in} = W_{comp}} \tag{3}$$

  Evaluate the above equation we have $COP = 2.33$

3 Question 3

From general physics background we have:

- $m_{water} = 100 * 10^{-3} * 0.001043^{-1} = 95.87\ Kg$

- For the turbine we can infer $Q = \Delta h + W_t$, then

  $$W_t = -\Delta h = -(2675.5 - 2763.5) = 88 KJ/Kg \tag{4}$$

  Therefore the total turbine work is $88 * 95.87 = 9436.56\ KJ$

- For burner we have $Q = \Delta h$. Evaluate (4) we have total heat equals $(2763.5 - 417.36) * 95.87 = 224924.4\ KJ$

4 Question 4

Law 1 *It is impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from a lower-temperature body to a higher-temperature body.*

From this expression of 2^{nd} law of thermaldynamics we can easily reach the conclusion that this machine is **possible but irreversible**.

5 Question 5

For the three solids mentioned in the question, we have:

- Silicon: $Q = C * m * \Delta T$, where C is the heat capacity (the rest of this question use same notation), m is the mass of solid, and ΔT stands for the temperature change.
  Evaluate this equation we have $Q_{silicon} = 50 * 10^{-3} * 55 * 0.712 * 10^3 = 1958\ J$

- Copper: Following the same algorithm, we have $Q_{copper} = 20 * 0.385 * 55 = 423.5\ J$

- Polyvinyl chloride: $Q_{poly} = 1.0049 * 50 * 55 = 2763.475\ J$