UBC MECH327 Assignment 4 Q4

a) Determine the work produced by the turbine in kJ/kg*steam*.

$P_{in} = 3$ MPa, $T_{in} = 673.15$ K, $V_{in} = 160$ m/s.
From the superheated steam table: $h_g = 3231$ kJ/kg, $s_g = 6.921$ kJ/kg K.

$P_{out} = 101.325$ KPa (1 atm), $T_{out} = 373.15$ K, $V_{out} = 100$ m/s.
From the saturated steam table: $h_g = 2675.8$ kJ/kg, $s_g = 7.355$ kJ/kg K.

The turbine lost heat at 30 kJ/kg from its surface at 400 K.

Steady State: $\dot{Q}_{in} - \dot{W}_{out} + \sum_{in} \dot{m}_{in}\left(h_{in} + \frac{V_{in}^2}{2} + gz_{in}\right) - \sum_{out} \dot{m}_{out}\left(h_{out} + \frac{V_{out}^2}{2} + gz_{out}\right) = 0.$

Assuming $\dot{m}_{in} = \dot{m}_{out} = \dot{m}$ and $z_{in} = z_{out} = 0$, $\dot{Q}_{in} - \dot{W}_{out} + \dot{m}\left[\left(h_{in} - h_{out}\right) + \left(\frac{V_{in}^2}{2} - \frac{V_{out}^2}{2}\right)\right] = 0.$

$$\frac{\dot{W}_{out}}{\dot{m}} = \frac{\dot{Q}_{in}}{\dot{m}} + \left[\left(h_{in} - h_{out}\right) + \left(\frac{V_{in}^2}{2} - \frac{V_{out}^2}{2}\right)\right].$$

Given $\frac{\dot{Q}_{in}}{\dot{m}} = \frac{Q_{in}}{m} = -30$ kJ/kg, $\frac{W_{out}}{m} = \frac{\dot{W}_{out}}{\dot{m}} = -30 + \left[\left(3231 - 2675.8\right) + \left(\frac{160^2}{2} - \frac{100^2}{2}\right) \div 1000\right] = 543$ kJ/kg.

Note 1: This is work output per Kg, not per second.

Note 2: From the formula sheet, internal energy change has been accounted for in the enthalpy (h) term.

b) What is the rate of entropy production if the control volume includes only the turbine and its contents?

Formula: $\frac{dS}{dt} = \sum \frac{\dot{Q}_k}{T_k} + \sum_{in} \dot{m}_{in}s_{in} - \sum_{out} \dot{m}_{out}s_{out} + \dot{S}_{gen} = 0$ (Steady State).

Swap time rate with mass rate: $\frac{Q_{in}}{m} \cdot \frac{1}{T} + \sum_{in} s_{in} - \sum_{out} s_{out} + \frac{S_{gen}}{m} = 0.$

$$\frac{S_{gen}}{m} = -\frac{Q_{in}}{m} \cdot \frac{1}{T} - \sum_{in} s_{in} + \sum_{out} s_{out} = -(-30)\frac{1}{400} - 6.291 + 7.355 = 1.139 \text{ kJ/kg K}.$$

c) What is the rate of entropy production if the control volume is expanded to include some of the surroundings, such that the heat transfer is assumed to take place at the temperature of the surroundings (27C)?

Use surrounding temperature T_{sur}=300 K (27°C) instead of the turbine surface temperature 400 K:

$$\frac{S_{gen}}{m} = -\frac{Q_{in}}{m} \cdot \frac{1}{T_{sur}} - \sum_{in} s_{in} + \sum_{out} s_{out} = -(-30)\frac{1}{300} - 6.291 + 7.355 = 1.164 \text{ kJ/kg K}.$$

d) Comment on the difference in entropy production for the two control volumes.

Extra entropy has been produced around the surface of the turbine as the heat transfers through the cooler environment to reach the lower temperature of 27°C.