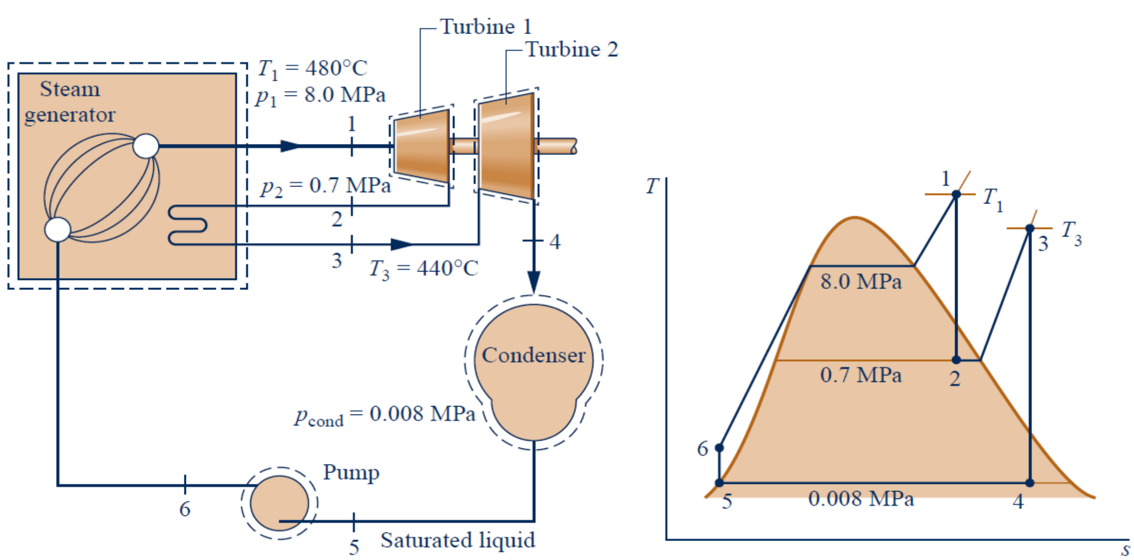
Exam / 11/9/2019

Q.1. Steam is the working fluid in an ideal Rankine cycle with superheat and reheat. Steam enters the first-stage turbine at 8.0 MPa, 480°C, and expands to 0.7 MPa. It is then reheated to 440°C before entering the second-stage turbine, where it expands to the condenser pressure of 0.008 MPa. The net power output is 100 MW. Determine
(a) the thermal efficiency of the cycle, (b) the mass flow rate of steam, in kg/h, (c) the rate of heat transfer from the condensing steam as it passes through the condenser, in MW. (20Marks)



To begin, we fix each of the principal states. Starting at the inlet to the first turbine stage, the pressure is 8.0 MPa and the temperature is 480oC, so the steam is a superheated vapor. $h1$= 3348.4 kJ/kg and $s1$= 6.6586 kJ/kg .K.

State 2 is fixed by $p2$ = 0.7 MPa and $s2$ = $s1$ for the isentropic expansion through the first-stage turbine. Using saturated liquid and saturated vapor data from table, the quality at state 2 is

$$x_2 = \frac{s_2 - s_f}{s_g - s_f} = \frac{6.6586 - 1.9922}{6.708 - 1.9922} = 0.9895$$

The specific enthalpy is then

$$h_2 = h_f + x_2 h_{fg}$$
$$= 697.22 + (0.9895)2066.3 = 2741.8 \text{ kJ/kg}$$

State 3 is superheated vapor with p_3 = 0.7 MPa and T_3 = 440$_o$C, so from table, h_3 =3353.3 kJ/kg and s_3 = 7.7571 kJ/kg .K

To fix state 4, use p_4 = 0.008 MPa and s_4 = s_3 for the isentropic expansion through the second-stage turbine.

With data from table, the quality at state 4 is

$$x_4 = \frac{s_4 - s_f}{s_g - s_f} = \frac{7.7571 - 0.5926}{8.2287 - 0.5926} = 0.9382$$

The specific enthalpy is

$h4$ = 173.88 + (0.9382)2403.1 = 2428.5 kJ/kg

State 5 is saturated liquid at 0.008 MPa, so $h5$ 5 173.88 kJ/kg. Finally, the state at the pump exit $h6$ = 181.94 kJ/kg.

(a) The *net* power developed by the cycle is

$$\dot{W}_{cycle} = \dot{W}_{t1} + \dot{W}_{t2} - \dot{W}_p$$

Mass and energy rate balances for the two turbine stages and the pump reduce to give, respectively

Turbine 1:	$\dot{W}_{t1}/\dot{m} = h_1 - h_2$
Turbine 2:	$\dot{W}_{t2}/\dot{m} = h_3 - h_4$
Pump:	$\dot{W}_p/\dot{m} = h_6 - h_5$

where $\dot{m}$ is the mass flow rate of the steam.

The total rate of heat transfer to the working fluid as it passes through the boiler–superheater and reheater is

$$\frac{\dot{Q}_{in}}{\dot{m}} = (h_1 - h_6) + (h_3 - h_2)$$

Using these expressions, the thermal efficiency is

$$\eta = \frac{(h_1 - h_2) + (h_3 - h_4) - (h_6 - h_5)}{(h_1 - h_6) + (h_3 - h_2)}$$
$$= \frac{(3348.4 - 2741.8) + (3353.3 - 2428.5) - (181.94 - 173.88)}{(3348.4 - 181.94) + (3353.3 - 2741.8)}$$
$$= \frac{606.6 + 924.8 - 8.06}{3166.5 + 611.5} = \frac{1523.3 \text{ kJ/kg}}{3778 \text{ kJ/kg}} = 0.403(40.3\%)$$

(b) The mass flow rate of the steam can be obtained with the expression for net power given in part (a).

$$\dot{m} = \frac{\dot{W}_{cycle}}{(h_1 - h_2) + (h_3 - h_4) - (h_6 - h_5)}$$
$$= \frac{(100 \text{ MW})|3600 \text{ s/h}||10^3 \text{ kW/MW}|}{(606.6 + 924.8 - 8.06) \text{ kJ/kg}} = 2.363 \times 10^5 \text{ kg/h}$$

(c)The rate of heat transfer from the condensing steam to the cooling water is

$$\dot{Q}_{out} = \dot{m}(h_4 - h_5)$$

$$= \frac{2.363 \times 10^5 \text{ kg/h } (2428.5 - 173.88) \text{ kJ/kg}}{|3600 \text{ s/h}||10^3 \text{ kW/MW}|} = 148 \text{ MW}$$