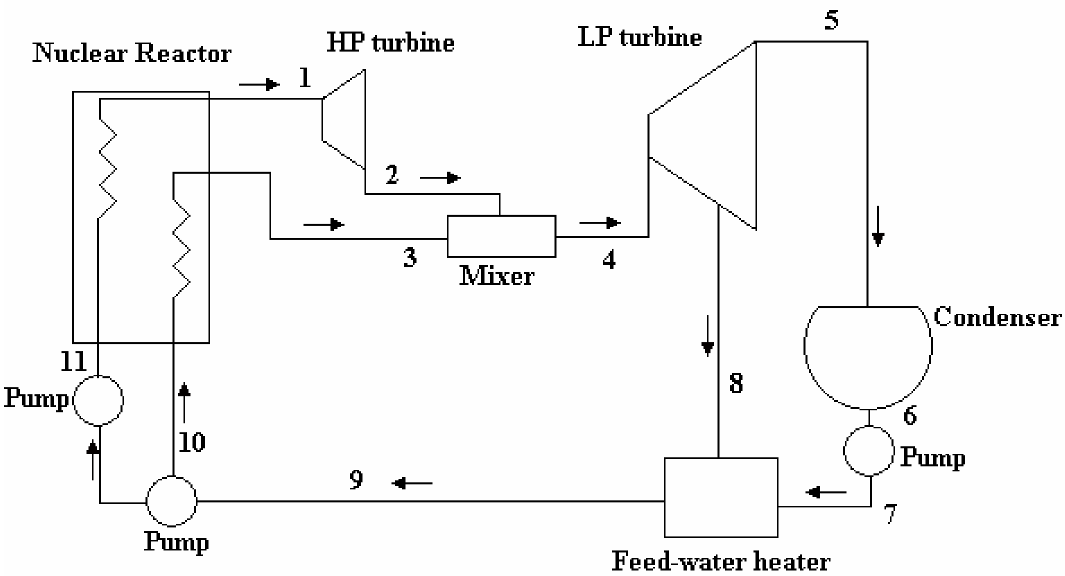
Q3 In a water-cooled nuclear reactor the coolant water to the reactor is divided into high-pressure and low-pressure circuits. The high-pressure circuit generates 200 kg/s of steam at 100 bar and 500 °C. The low-pressure circuit generates 100 kg/s of dry saturated steam at 30 bar. A line diagram of the plant is shown.

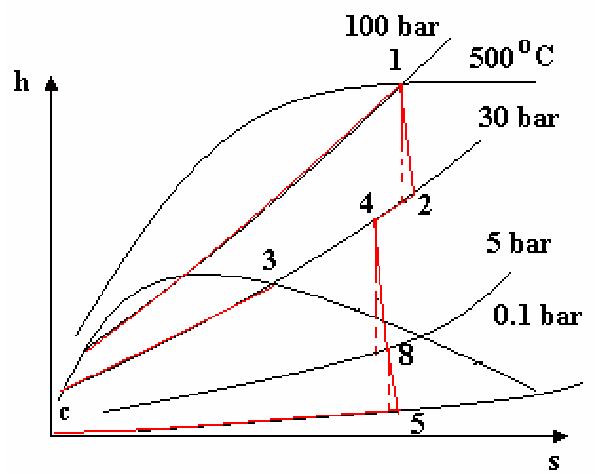
The high-pressure steam expands in a high-pressure turbine to 30 bar with an isentropic efficiency of 90%, and the exhaust is mixed adiabatically with the low-pressure steam all of which is then expanded in a low-pressure turbine to 0.10 bar with an isentropic efficiency of 92%. The optimum quantity of dry saturated steam is bled at 5 bar from the low-pressure turbine into an open-type feed-water heater positioned prior to the separation into the two coolant-water circuits.

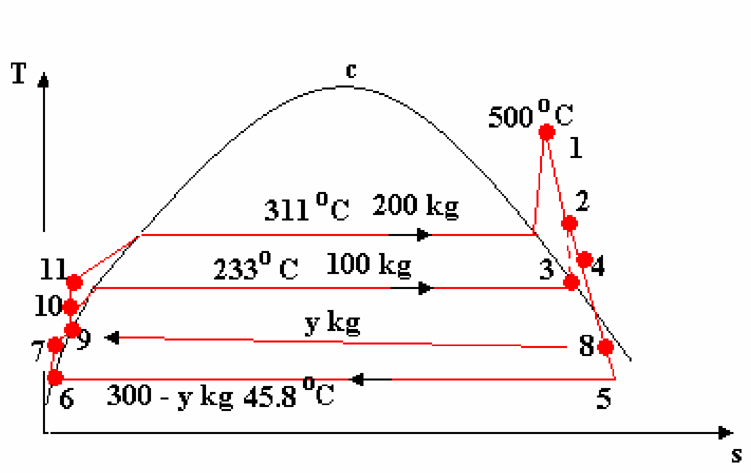
(a) Sketch the T-s and h-s diagrams for the cycle.

(b) Calculate the power developed and the cycle efficiency.

Neglect the feed-pumps work, and assume a straight line of condition for the low-pressure turbine.







Start with known points.

Point 1	100 bar	500°C	h = 3373 kJ/kg	s = 6.596 kJ/kg K
Point 2	30 bar			
Point 3	30 bar	dss	h = 2803 kJ/kg	s = 6.186 kJ/kg K
Point 4	30 bar			
Point 5	0.1 bar			
Point 6	0.1 bar	sw	h = 192 kJ/kg (assumed to be saturated water in absence of information)	
Point 8	5 bar			
Point 9	5 bar	sw	h = 640 kJ/kg (assumed to be saturated water in absence of information)	

HP Turbine m = 200 kg/s

Ideal expansion $s_2 = s_1 = 6.596$ From h – s chart the steam is superheated at 30 bar and 310°C

$h_{2'} = 3020$ kJ/kg

$\eta = 0.9 = \frac{3373 - h_2}{3373 - 3020}$ $h_2 = 3055.3$ kJ/kg – the actual enthalpy

Power output = $200(h_1 - h_2) = 63\,540$ kW

MIXING $200\,h_2 + 100\,h_3 = 300\,h_4$ 200(3055.3) + 100(2803) = 891360 = 300 h_4

$h_4 = 2971.2$ kJ/kg

LP TURBINE

First expansion to 5 bar

Point 4 30 bar $h_4 = 2971.2$ kJ/kg Locate on h – s chart and find h_8'=2620 kJ/kg

$\eta = 0.92 = \frac{2971.2 - h_8}{2971.2 - 2620}$ $h_8 = 2648.1$ kJ/kg

Power out = 300 (2971.2 - 2648.1) = 96931.2 kW

Expansion to 0.1 bar

Locate point 8 and then point '5 h_5' = 2090 kJ/kg

$\eta = 0.92 = \frac{2648.1 - h_5}{2648.1 - 2090}$ $h_5 = 2134.6$ kJ/kg

Power out = m(2648.1 - 2134.6) = 513.45 m kW m = mass flowing to condenser.

FEED HEATER

$y\,h_8 + (300 - y)\,h_7 = 300\,h_9$ y = mass bled at 5 bar

$h_6 = h_7 = 192$ kJ/kg

y 2648.1 + (300 –y) 192 = 300 x 640

2648.1y + 57600 – 192 y = 192000

2456.1 y = 134400 y = 54.72 kg/s

m = 300 – 54.72 = 245.28 Power out of second part of expansion 513.45 m = 125938.6 kW

Total power from LP turbine = 96931.2 + 125938.6 = 222869.7 kW

Total power out from both turbines = 222869.7 + 63 540 = 286409.7 kW say 286.41 MW

BOILER

$\Phi(in) = 200(h_1 - h_{11}) + 100(h_3 - h_{10})$ $h_{11} = h_{10} = h_9 = 640$ kJ/kg

Φ(in)= 200(3373 - 640) + 100 (2803 – 640) = 762900 kW say 762.9 MW

CONDENSER

$\Phi(out) = (300 - 54.72)(h_5 - h_6)$ = (300 - 54.72)(2134.6 – 192) = 476481 kW

Check P = Φ(in)- Φ(out) = 762.9 – 476.48 = 286.4 MW

$\eta = P/\Phi$ = 286.41/1036.2 = 27.6%