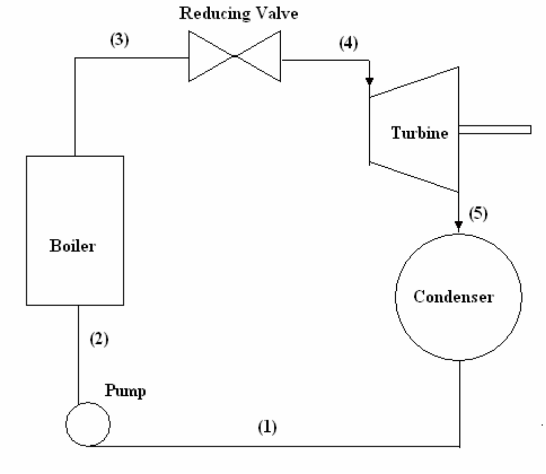
THERMODYNAMICS 201 2003

Q1 A schematic of a Rankine-cycle steam power plant is shown. This plant uses a boiling-water nuclear reactor as the heat source and a pressure reducing valve is located between the reactor and the turbine.



The water in the reactor is at a pressure of 7 MPa and leaves the reactor as superheated vapour at a temperature of 400°C. The pressure reducing valve lowers the steam pressure adiabatically by 2 MPa before it enters the steam turbine which has an isentropic efficiency of 80%. The steam expands through the turbine exiting at a pressure of 0.005 MPa and then is condensed at constant pressure before entering the feed-water pump. The condensate enters the feed-water pump at a pressure of 0.005 MPa and a temperature of 25°C. The pump has an isentropic efficiency of 90%. The water conditions at entry to the reactor are exactly the same as at exit from the pump and there are no pressure losses in the reactor. The net power output from the plant is 500 MW.
It may be assumed that there is no change in enthalpy across the pressure reducing valve, that is, $h_4 = h_3$.
(a) Sketch the temperature-entropy (T-s) diagram for the cycle.
(b) Determine the cycle efficiency, the mass flow rate of steam and the heat input to the boiling-water reactor.
Note. 1 bar = 10^5 N/m^2 = 10^5 Pa, and the specific heat capacity of water is 4.187 kJ/kgK.

SOLUTION

$h_3 = 3158$ kJ/kg (70 bar and 400°C)
$h_4 = 3158$ kJ/kg (50 bar)

Either by interpolation or by use of the h –s chart the temperature at point (4) is 387°C and the specific entropy is 6.592 kJ/kg K

Ideal conditions at point (5) $s_4 = s_5 = s_f + x\, s_{fg}$ at 0.05 bar
$6.592 = 0.476 + 7.918x$ hence $x = 0.772$

$h_{5'} = h_f + x\, h_{fg}$ at 0.05 bar = 138 + 2423 x 0.772 = 2010 kJ/kg

Isentropic Efficiency $0.8 = \dfrac{3158 - h_5}{3158 - 2010}$ hence $h_5 = 2239.6$ kJ/kg

Power = 500 000 kW = m(3158-2239.6) hence m = 544.4 kg/s

Pump Ideal Power = V Δp

The volume of water is approximately 0.001 x 544.4 = 0.544 m^3/s

Pressure rise = 7 – 0.005 = 6.995 MPa Ideal Power = $6.995 \times 10^6 \times 0.544 = 3.8$ MW

Actual Power = 3.8/0.9 = 4.228 MW Net Power = 500 – 4.228 = 495.772 MW

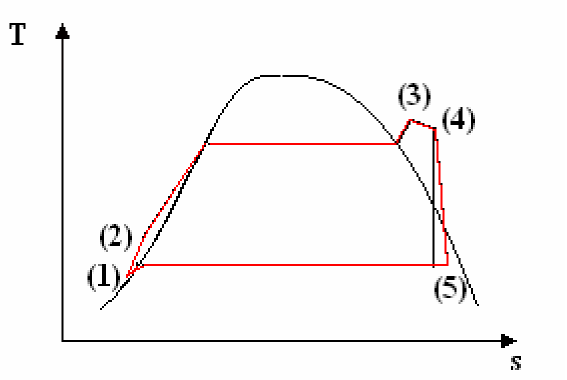
Energy added to water = 4.228/544.4 = 0.00777 MJ/kg or 7.77 kJ/kg

$h_1 = pv + mc\theta = 0.005 \times 10^6 \times 0.001 + 1 \times 4187 \times 25 = 5 + 104675 = 104680$ J/kg

$h_2 = 104.68 + 7.77 = 112.45$ kJ/k

Φ(in) to boiler = $m(h_3\text{-}h_2) = 544.4(3158 - 112.45) = 1658000$ kW or 1658 MW

Cycle Efficiency = 495.772/1658 = 0.299 or 29.9%



On the T –s diagram the water is under-cooled at (1)