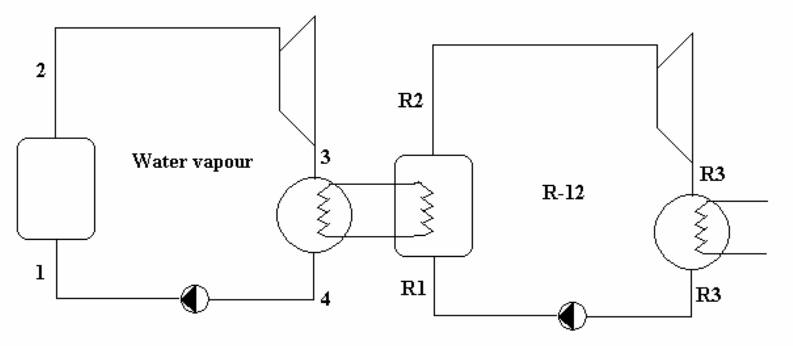
THERMODYNAMICS 201 2004

Q1 A steam power plant operates on the Rankine cycle. The high pressure steam is at 60 bar and 500°C at entry to the turbine. The turbine produces 20 MW of power. The condenser pressure is 2 bar.

During day time operation the waste heat from the condenser is used for process heating. During night time operation the waste heat is used in a R-12 power plant that also operates on the Rankine cycle. The refrigerant cycle uses vapour with no superheat at 80°C at entry to the turbine and condenses at 10°C.

Assuming no heat losses and negligible power usage at the pumps, calculate the power output from the R-12 cycle and the thermal efficiency of the plant. The isentropic efficiency of both turbines is 85%. (This question very similar to Q1 1997)

SOLUTION



WATER/VAPOUR CYCLE.

$h_4 = h_f$ @ 2 bar= 505 kJ/kg $\quad h_1 = h_4 = 505$ kJ/kg

$h_2 = h$ @ 60 bar and 500°C = 3421 kJ/kg

$s_2 = s$ @ 60 bar and 500°C = 6.879 kJ/kg K

$s_{3'} = s_2 = 6.879$ kJ/kg K = $s_f + x\ s_{fg}$ @ 2bar

$6.879 = 1.530 + 5.597x \quad x = 0.9557$

$h_{3'} = h_f + x\ h_{fg}$ @ 2bar = 505 + 0.9557 x 2202 = 2609.4 kJ/kg

Power out = 20 000 kW = m_s x η_I (3421 - 2609.4)

20 000 = m_s x 0.85 (3421 - 2609.4)

m_s = 20 000/689.8 = 29 kg/s

We need to find h_3. $\dfrac{3421 - h_3}{3421 - 2609.4} = 0.85 \quad h_3 = 2731$ kJ/kg

Check Power out = 29(3421 - 2731) = 20 000 kW

Heat lost from the condenser = $29(h_3 - h_4)$ = 29(2731 – 505) = 64554 kW

This becomes the heat input to the evaporator in the R-12 cycle.

R-12 CYCLE

$h_{R2} = h_g$ at 80°C = 212.83 kJ/kg

$h_{R1} = h_{R4} = h_f$ @ 10°C = 45.37 kJ/kg

Φ(in) = 64554 = m_R(212.83 - 45.37) $\quad m_R = 385.48$ kg/s

$s_{R2} = s_g$ at 80°C = 0.6673 kJ/kg K = $s_{R3} = s_f + x\ s_{fg}$ @ 10°C = 0.1752 +x(0.6921 - 0.1752)

x = (0.6673 - 0.1752)/0.5169 = 0.952

$h_{R3} = h_f + x\ h_{fg}$ @ 10°C = 45.37 + 0.952(191.74 - 45.37) = 184.72 kJ/kg

Power output = m_R (h_{R2} - h_{R3}) = 385.48 (212.83 - 184.72) = 10 837 kW

Thermal efficiency P(out)/ Φ(in) = 10 837/ 64554 = 0.168 or 16.8%