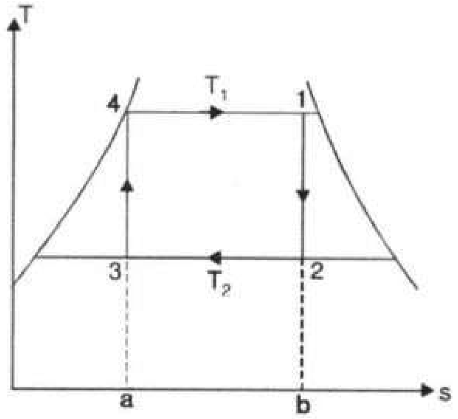
6.8 Solved Numerical

Ex 6.1. ***[GTU; Jun-2010; 7 Marks]***

A Carnot cycle works on steam between the pressures limits of 7 MPa and 7KPa. Determine (a) The thermal efficiency, (b) Turbine work and (c) Compression work per kg of steam.

Solution:



Given Data:

$p_1 = 7MPa = 70bar$

$p_2 = 7kPa = 0.07bar$

To be Calculated:

a) $\eta_{th} = ?$

b) $w_t = ?$

c) $w_c = ?$

⇨ From Steam Table:

$@\,\boldsymbol{p_1 = 70bar}$

$$h_g = 2773.5\frac{kJ}{kg}, s_g = 5.8162\frac{kJ}{kg-K}, h_f = 1267.42\frac{kJ}{kg}, s_f = 3.1219\frac{kJ}{kg-K}$$

$@\,\boldsymbol{p_2 = 0.07bar}$

$$h_f = 163.38\frac{kJ}{kg}, s_f = 0.5591\frac{kJ}{kg-K}, h_{fg} = 2409.2\frac{kJ}{kg}, s_{fg} = 7.7176\frac{kJ}{kg-K}$$

⇨ Enthalpy at point 1,

$$h_1 = (h_{g1})_{@70\,bar}$$

$$\therefore \boldsymbol{h_1 = 2773.5\ kJ/kg}$$

⇨ Enthalpy at point 2,

$$h_2 = (h_{f2} + x_2 h_{fg2})_{@0.07\,bar}$$

But,

$$s_1 = s_2$$

$$(s_{g1})_{@70\,bar} = (s_{f2} + x_2 s_{fg2})_{@0.07\,bar}$$

$$5.8162 = 0.5591 + x_2 7.7176$$

$$\therefore x_2 = 0.6811$$

$$\therefore h_2 = 163.38 + 0.6811 \times 2409.2$$

$$\therefore \boldsymbol{h_2 = 1804.286\ kJ/kg}$$

⇨ Enthalpy at point 3,

$$h_3 = (h_{f3} + x_3 h_{fg3})_{@0.07\,bar}$$

But,

$$s_3 = s_4$$

$$(s_{f3} + x_3 s_{fg3})_{@0.07\,bar} = (s_{f4})_{@70\,bar}$$

$$0.5591 + x_3 7.7176 = 3.1219$$
$$\therefore x_3 = 0.3320$$
$$\therefore h_3 = h_{f3} + x_3 h_{fg3}$$
$$\therefore h_3 = 163.38 + 0.3320 \times 2409.2$$
$$\therefore \boldsymbol{h_3 = 963.408\ kJ/kg}$$

⇨ Enthalpy at point 4,

$$h_4 = (h_{f4})_{@70\ bar}$$
$$\therefore \boldsymbol{h_4 = 1267.42\ kJ/kg}$$

⇨ Heat Supplied,

$$q_s = h_1 - h_4$$
$$\therefore q_s = 2773.5 - 1267.42$$
$$\therefore q_s = 1506.08\ kJ/kg$$

⇨ **The Turbine Work:**

$$w_t = h_1 - h_2$$
$$\therefore w_t = 2773.5 - 1804.286$$
$$\therefore \boldsymbol{w_t = 969.214\ kJ/kg}$$

⇨ **The Compression Work:**

$$w_c = h_4 - h_3$$
$$\therefore w_c = 1267.42 - 963.408$$
$$\therefore \boldsymbol{w_c = 304.012\ kJ/kg}$$

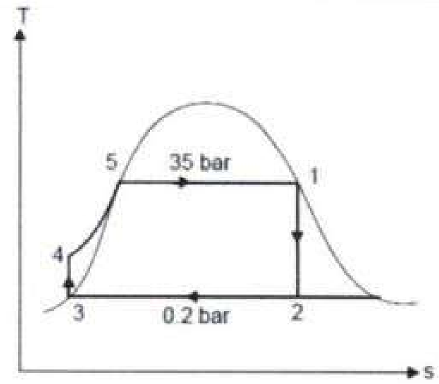
⇨ **The Thermal Efficiency:**

$$\eta = \frac{w_{net}}{q_s} = \frac{w_t - w_c}{q_s}$$
$$\therefore \eta = \frac{969.214 - 304.012}{1506.08}$$
$$\therefore \boldsymbol{\eta = 0.4416 = 44.16\%}$$

Ex 6.2. ***[GTU; Jan 2015; 7 Marks]***

In a Rankine cycle, the steam at inlet to the turbine is saturated at pressure of 35bar and exhaust pressure is 0.2bar. Determine: (a) The pump work, (b) The turbine work, (c) The Rankine efficiency, (d) The quality of steam at the end of expansion. Assume flow rate of 9.5kg/sec. **Use of steam table is permitted.**

Solution:



Given Data:

$p_1 = 35\ bar$

$p_2 = 0.2\ bar$

$\dot{m} = 9.5\ kg/sec$

To be Calculated:

a) $w_p = ?$

b) $w_t = ?$

c) $\eta_{th} = ?$

d) $x_2 = ?$

⇨ From Steam Table:

$@\,\boldsymbol{p_1 = 35\ bar}$

$h_g = 2802\frac{kJ}{kg}, s_g = 6.1228\frac{kJ}{kg-K}$

$@\,\boldsymbol{p_2 = 0.2\ bar}$

$h_f = 251.45\frac{kJ}{kg}, h_{fg} = 2358.4\frac{kJ}{kg}, s_f = 0.8321\frac{kJ}{kg-K}, s_{fg} = 7.0773\frac{kJ}{kg-K}$

$v_f = 0.0010172\ m^3/kg$

⇨ Enthalpy at point 1,

$$h_1 = (h_{g1})_{@35\ bar}$$
$$\therefore \boldsymbol{h_1 = 2802\ kJ/kg}$$

⇨ Enthalpy at point 2,

$$h_2 = (h_{f2} + x_2 h_{fg2})_{@0.2\ bar}$$

But,

$$s_1 = s_2$$
$$(s_{g1})_{@35\ bar} = (s_{f2} + x_2 s_{fg2})_{@0.2\ bar}$$
$$6.1228 = 0.8321 + x_2 \times 7.0773$$
$$\therefore x_2 = 0.7475$$
$$\therefore h_2 = h_{f2} + x_2 h_{fg2}$$
$$\therefore h_2 = 251.45 + 0.7475 \times 2358.4$$
$$\therefore \boldsymbol{h_2 = 2014.49\ kJ/kg}$$

⇨ Enthalpy at point 3,

$$h_3 = (h_{f3})_{@0.2\ bar}$$
$$\therefore \boldsymbol{h_3 = 251.45\ kJ/kg}$$

⇨ Pump Work,

$$w_p = \int_{P_2}^{P_1} vdP = (v_{f3})_{@0.2\ bar}(P_1 - P_2)$$
$$\therefore w_p = 0.0010172 \times (35 \times 10^2 - 0.2 \times 10^2)$$
$$\therefore w_p = 3.5398\ kJ/kg$$

⇨ **Pump Power:**

$$W_p = \dot{m} \times w_p$$
$$W_p = 9.5 \times 3.5398$$
$$\boldsymbol{W_p = 33.6281\ kW}$$

⇨ Enthalpy at point 4,

$$w_p = h_4 - h_3$$
$$\therefore h_4 = 3.5398 + 251.45$$
$$\therefore \boldsymbol{h_4 = 254.9898\ kJ/kg}$$

⇨ Heat Supplied,

$$q_s = h_1 - h_4$$
$$\therefore q_s = 2802 - 254.9898$$
$$\therefore q_s = 2547.01\ kJ/kg$$

⇨ **The Turbine Power:**

$$W_t = \dot{m}(h_1 - h_2)$$
$$\therefore W_t = 9.5 \times (2802 - 2014.49\ )$$

$$\therefore \boldsymbol{W_t = 7481.345\ kW}$$

⇨ **The Thermal Efficiency:**

$$\eta = \frac{W_{net}}{Q_s} = \frac{W_t - W_p}{\dot{m}(h_1 - h_4)}$$

$$\therefore \eta = \frac{7481.345 - 33.6281}{9.5(2802 - 3.5398)}$$

$$\therefore \boldsymbol{\eta = 0.2801 = 28.01\%}$$

⇨ **The Dryness Fraction:**

$$\boldsymbol{x_2 = 0.7475}$$

6.9 References

[1] Engineering Thermodynamics by P.K. Nag, McGraw-Hill Publication.

[2] Thermal Engineering by Mahesh M Rathore, McGraw-Hill Publication.

[3] Thermodynamics – An Engineering Approach by Yunus Cengel & Boles, McGraw-Hill Publication.

[4] Fundamentals of Engineering Thermodynamics by Moran & Shapiro, 6th Edition, Wiley India (P) Ltd.

[5] Thermal Science and Engineering by D. S. Kumar, S K Kataria and Sons Publications.

[6] Engineering Thermodynamics by R. K. Rajput, Laxmi Publications.

[7] National Programme on Technology Enhanced Learning (NPTEL), A Joint Initiate by IIT's and IISc. (Web: http://nptel.ac.in/)