Yash Gokhale

Andrew ID: ysg

Homework 3: Energy Conversion and Supply

Q1]

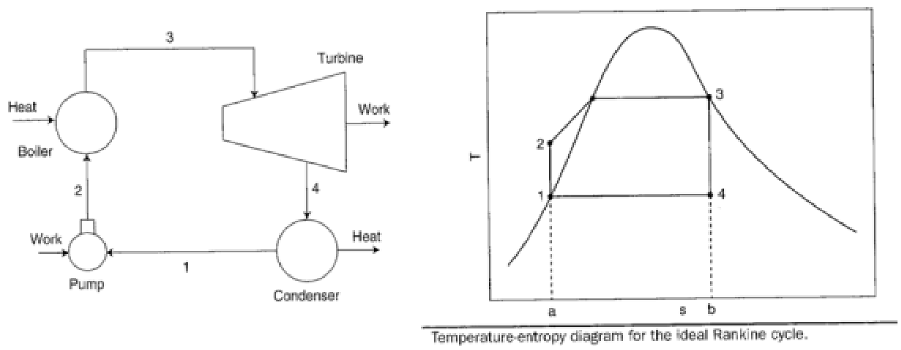


*Figure 1: Ideal Rankine cycle given*

In this problem, the vapor enters the turbine at a pressure of 12MPa and leaves the condenser at 45 kPa. The thermal efficiency is given as 0.3.

First step in the problem is to calculate the enthalpies at all the four points:

Based on steam table:

$$h_3 = 2684.9\frac{kJ}{kg}, s_3 = 5.4924\left(\frac{\frac{kJ}{kg}}{K}\right)$$

As 3-4 is isentropic: $s_4 = 5.4924\left(\frac{\frac{kJ}{kg}}{K}\right)$

As the condenser output pressure is given as 0.045 MPa, the values for 0.4 and 0.5 bar in the steam table are averaged to get the value.

Thus, At 4: $s_f = \frac{1.0259+1.0910}{2} = 1.05845\left(\frac{\frac{kJ}{kg}}{K}\right)$; $s_g = \frac{7.67+7.5939}{2} = 7.63195\left(\frac{\frac{kJ}{kg}}{K}\right)$

Assuming ideal conditions to calculate

$$x_4 = \frac{s_2-s_f}{s_g-s_f} = 0.6745$$

Based on this: $h_f = \frac{317.58+340.49}{2} = 329.035\frac{kJ}{kg}$; $h_{fg} = \frac{2319.2+2305.4}{2} = 2312.3\frac{kJ}{kg}$

$$h_4 = h_f + x_4 * h_{fg} = 329.035 + 0.6745 * 2312.2 = 1888.68\frac{kJ}{kg}$$

From steam table: $h_1 = 329.035\ kJ/kg$

To calculate $h_2$:

$$v_1 = \frac{1.0265+1.03}{2} = 1.02825$$

Using this, $h_2$ is calculated as follows:

$$h_2 = h_1 + v_1 * (\Delta P) * \frac{10^6}{10^3}\frac{kJ}{kg}$$

Substituting: $h_2 = 329.035 + (1.02825 * 10^{-3}) * (12 - 0.045) * 10^3 = 341.3277\ kJ/kg$

Thus, the enthalpies obtained are:

| Enthalpies | Value (kJ/kg) |
|---|---|
| $h_1$ | 329.035 |
| $h_2$ | 341.327 |
| $h_3$ | 2684.9 |
| $h_4$ ( Ideal) | 1888.68 |

Calculating the required quantities:

(a) Work output:

$$W_{output} = \eta Q + W_{input}$$

$$Q = h_3 - h_2; W_{input} = h_2 - h_1$$

$$W_{output} = (2684.9 - 341.327) * 0.3 + (341.327 - 329.035) = \mathbf{715.364}\frac{\mathbf{kJ}}{\mathbf{kg}}$$

(b)

Heat is supplied to the boiler at the rate of (2.5*10^6) kJ/s

Thus, mass flow rate, $\dot{m} = \frac{\dot{Q}}{h_3 - h_2}$

$$\dot{m} = \frac{2.5*10^6}{2684.9-341.328}$$

$$\boldsymbol{\dot{m} = 1066.75\frac{kg}{s}}$$

And:

$$Net\ Power\ output\ of\ the\ system = W_{turbine} * \dot{m}$$

$$P_{output} = 715.364 * 1066.75 * 1000\frac{J}{s} = \mathbf{763.11\ MW}$$

Q2]

Given:

$T_1 = 295K, C = 9:1, T_3 = 1280\ K$

Based on this, from the thermodynamic tables:

$h_1 = 295.17 \frac{kJ}{kg}, \mathrm{Pr}_1 = 1.3068, \mathrm{h}_3 = 1372.24, \mathrm{Pr}_3 = 310.4$

Consider $h_2$:

$\mathrm{Pr}_2 = 9 * \mathrm{Pr}_1 = 11.7612$

This is close to the value of 11.86 from the thermodynamic table at 550K.

Thus, taking the value from $h_2 = 554.74 \frac{kJ}{kg}$

Also, for $h_4$: $\mathrm{Pr}_4 = \frac{\mathrm{Pr}_3}{9} = 34.49$

In order to find the fraction of interpolation:

At 430K, Pr=33.72 and h=745.62

Whereas 440K, Pr=35.50 and h=756.44

$f = \frac{34.49-33.72}{35.50-33.72} = 0.43$

$h_4 = 745.62 + 0.43 * (756.44 - 745.62) = 750.300$

Based on these calculations:

$q_{in} = h_3 - h_2 = 817.5$

$w_{turbine} = h_3 - h_4 = 621.94$

$w_{compressor} = h_2 - h_1 = 259.57$

$\eta_{th} = \frac{w_{turbine} - w_{compressor}}{q_{in}} = \frac{621.94-259.57}{817.5}$

$\boldsymbol{\eta_{th} = 0.443 \sim 44.3\%}$

Q3]

Data:

| | |
|---|---|
| CapEx | 275 million $ |
| Capacity | 500 MW |
| Capacity factor | 0.75 |
| Efficiency | 0.58 |
| Lifetime | 20 years |
| Operating Cost per kWh electricity | $0.005/kWh |
| Fuels Cost per kWh gas | $0.012/kWh |

(A)

Electricity generated in a year=$0.75 * 500 * 24 * 365 = \mathbf{3.285 * 10^6}\ \boldsymbol{MWh}$

(B)

Energy consumption of gas=Electricity generated/Efficiency

Energy consumption of gas in a year=$\frac{3.285*10^6}{0.58} = \mathbf{5.66 * 10^6}\ \boldsymbol{MWh}$

(C-E)

Fixed costs=Operating cost*Cost of electricity+ Raw Material cost*Cost of gas

Fixed costs=$(0.005 * 3.285 * 10^6 + 0.012 * 5.66 * 10^6) * 10^3 = 84.3\ million\ \$/year$

To calculate the annualized cost:

$P = A * \frac{(i+1)^N - 1}{i(i+1)^N}$

If $i = 0,\ \ taking\ \lim_{i \to 0} A * \frac{(i+1)^N - 1}{i(i+1)^N} = A * N$

Tabulating the following cases:

| Case | Discount rate | A/P | ACC | Total cost |
|---|---|---|---|---|
| (C) | 0 | 0.05 | 13.75 million | 98.05 |
| (D) | 6 | 0.087 | 23.97 million | 108.27 |
| (E) | 6 | 0.087 | 23.97 million | 108.27 |

Based on the total cost calculation, the profit component is incorporated into the total annual cost as follows:

$Profit = \%Profit * Total\ annualized\ cost$

| Case | Total cost (million) | Profit Percentage | Profit cost (million) | Total annual cost (million) |
|---|---|---|---|---|
| (C) | 98.05 | 0 | 0 | 98.05 |

| | | | | |
|---|---|---|---|---|
| (D) | 108.27 | 0 | 0 | 108.27 |
| (E) | 108.27 | 10 | 10.83 | 119.1 |

Based on the total annual cost computed, LCOE can be computed as follows:

$$LCOE = \frac{Total\ annual\ cost}{Total\ annual\ output}$$

$$LCOE = \frac{Total\ annual\ cost}{3.285*10^9 kWh}$$

Substituting the same to get the LCOE for parts (C)-(E)

| **Case** | **LCOE ($/kwh)** |
|---|---|
| **(C)** | **0.298** |
| **(D)** | **0.3296** |
| **(E)** | **0.363** |