Gmail
Thermodynamics
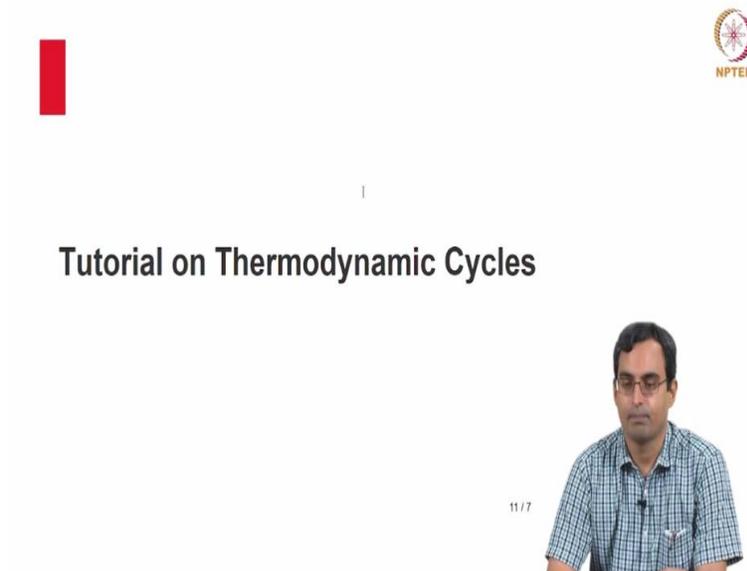**Professor Anand T N C**
Department of Mechanical Engineering
Indian Institute of Technology, Madras
Lecture – 85
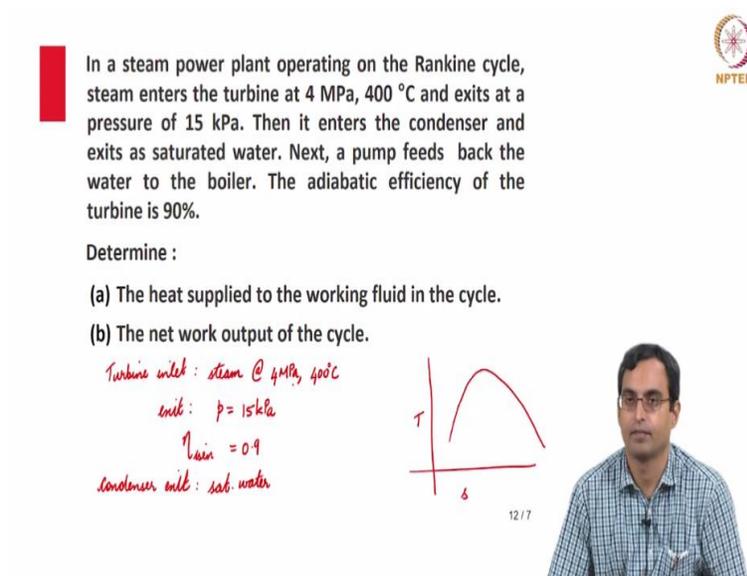**Tutorial Problem (1 number)**

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Figure 1.

Solution of the problem in Fig. 1:

Turbine inlet: $p = 4\ MPa, T = 400\ ℃$

Turbine exit: $p = 15\ kPa$

$\eta_{isen,turbine} = 0.9$

We have saturated water at the condenser exit. It would help in solving the problem if we draw this cycle on a T-S diagram. Hence, we need to know the states.

At 4 MPa, T_{sat} = 250 ℃. Since 400 ℃ > T_{sat}, the steam is in superheated zone at the inlet of the turbine. At the turbine inlet, h = 3214.5 kJ/kg and s = 6.771 kJ/kg·K

The condensation process happens at 15 kPa. If the expansion process in the turbine is isentropic (from 4 MPa to 15 kPa), the entropy at the inlet of the condenser is s = 6.771 kJ/kg·K.

At 15 kPa, s_g = 8.007 kJ/kg·K. As 6.771 < 8.007, the inlet to the condenser lies inside the liquid-vapor dome. Now, we can qualitatively draw the Rankine cycle on a T-S diagram as shown in Fig. 2.

The processes are:

Process 1-2: isentropic compression in a pump

Process 2-3-4-5: constant pressure heat addition in a boiler

Process 5-6: isentropic expansion in a turbine

Process 6-1: constant pressure heat rejection in a condenser

Heat supplied to the working fluid in a boiler, $q = h_5 - h_2$ (enthalpy at the inlet of the turbine − enthalpy at the exit of the pump)

The state 2 has the same entropy as state 1. We also know the pressure at state 2. Knowing pressure and entropy values at state 2, we can get h_2 from the tables for subcooled liquids. However, we don't have those tables here.

We can also get h_2 through the expression $w_p = h_1 - h_2$, where w_p is the work input to the pump. If we consider the isentropic compression, $w_p = h_1 - h_2 = -v_1(p_2 - p_1) = -0.001014(4 \times 10^6 - 15 \times 10^3) = -4.04 \frac{kJ}{kg}$

Hence, $h_2 = h_1 - w_p = 225.8 - (-4.04) = 229.84 \frac{kJ}{kg}$

Hence, heat supplied to the working fluid in a boiler, $q = h_5 - h_2 = 3214.5 - 229.84 = 2984.66 \frac{kJ}{kg}$

Net work output on a unit mass basis $= w_{net} = w_t + w_p = |w_t| - |w_p|$ (w_t is the turbine work output)

$w_t = h_5 - h_6$

For calculating h_6, we need the quality x_6. We know that $s_5 = s_6 = 6.771 = \left[s_f + x_6 s_{fg}\right]_{15\ kPa} \rightarrow x_6 = 0.829 \rightarrow h_6 = \left[h_f + x_6 h_{fg}\right]_{15\ kPa} = 2192.5 \frac{kJ}{kg}$

Hence, $w_t = h_5 - h_6 = 1022 \frac{kJ}{kg}$.

Hence, net work output on a unit mass basis $= w_{net} = w_t + w_p = |w_t| - |w_p| = 1022 - 4.04 = 1017.96 \frac{kJ}{kg}$ (considering isentropic processes)

$\eta_{isen,turbine} = 0.9 = \frac{w_{t,act}}{w_{t,ideal}} = \frac{w_{t,act}}{1022} \rightarrow w_{t,act} = 919.8 \frac{kJ}{kg}$

Hence, $w_{net} = w_{t,act} + w_p = 915.76 \frac{kJ}{kg}$

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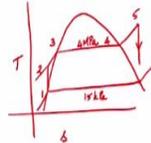

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Figure 2.

In a steam power plant operating on the Rankine cycle, steam enters the turbine at 4 MPa, 400 °C and exits at a pressure of 15 kPa. Then it enters the condenser and exits as saturated water. Next, a pump feeds back the water to the boiler. The adiabatic efficiency of the turbine is 90%.

Determine :

(a) The heat supplied to the working fluid in the cycle.

(b) The net work output of the cycle.

Turbine inlet : steam @ 4 MPa, 400°C

exit : $p = 15 kPa$

$\eta_{isen} = 0.9$

condenser exit : sat. water

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4 MPa 400°C
$h_5 = 3214.5$ kJ/kg
$s_5 = 6.771$ kJ/kgk

s_g @ 15kPa = 8.007 kJ/kgk

$Q_{added} = ?$ $\dfrac{dE}{dt} = \dot{Q} - \dot{W} + \dot{m}[h_i + ke + pe]_i - \dot{m}[h_e + ke + pe]_e$

$q = h_e - h_i$

$\dfrac{dm}{dt} = m_i - m_e = 0$

$h_2 = ?$
$s_1 = s_f$ @ 15kPa = 0.7543 $\dfrac{kJ}{kg\,k}$ $h_1 = 225.8$ kJ/kg
$s_2 = s_1 = 0.7543$ kJ/kgk

2 = point on the 4 MPa line

$W_p = ?$ $\dfrac{dE}{dt} = \dot{Q} - \dot{W} + \dot{m}[h_i + ke_i + pe_i] - \dot{m}[h_e + ke_e + pe_e]$

$\dot{W} = \dot{m}[h_i - h_e]$ or $w = h_i - h_e$

$h_2 = h_1 + |w|$

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$Tds = dh - vdp$, = 0

$\Delta h = \int dh = \int v\,dp$ v = sp. vol of liq @ 15kPa

$\Delta h = 0.001014 \times [4\times10^6 - 15\times10^3] \times 10^{-3}$

$|w_p| = \Delta h = 4.04$ kJ/kg

$h_2 = h_1 + \Delta h$
$= 225.8 + 4.04$
$h_2 = 229.84$ kJ/kg

$q = h_5 - h_2 = 3214.5 - 229.84$
$q = 2984.66$ kJ/kg

Net work = ?
For ideal process 5-6, $s_5 = s_6 = 6.771 = s_f + x\,s_{fg}$ @ 15kPa

$0.7543 + x \times 7.2535$

$\Rightarrow x = 0.829$

$h_6 = h_f + x\,h_{fg}$ @ 15kPa $= 225.8 + 0.829 \times 2372.4$
$h_6 = 2192.5$

$$W_T = h_5 - h_6$$
$$= 3214.5 - 2192.5$$
$$W_{T, ideal} = W_T = 1022 \ kJ/kg$$

$$\eta = 90\% = \frac{[h_5 - h_6']}{h_5 - h_6} = \frac{W_{act}}{W_{T, ideal}}$$

$$\Rightarrow W_{act} = 919.8 \ kJ/kg.$$

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4 MPa   400° C
$h_5 = 3214.5 \ kJ/kg$
$s_5 = 6.771 \ kJ/kg k$

$s_g @ 15 kPa = 8.007 \ kJ/kg k$

$Q_{added} = ?$

$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \dot{m}[h_i + ke + pe]_i - \dot{m}[h_e + ke + pe]_e$$

$$q = h_e - h_i = h_5 - h_2$$

$$\frac{dm}{dt} = \dot{m}_i - \dot{m}_e$$

$h_2 = ?$
$s_1 = s_f @ 15 kPa = 0.7543 \ \frac{kJ}{kg k}$ $h_1 = 225.8 \ kJ/kg$
$s_2 = s_1 = 0.7543 \ kJ/kg k$

2 = point on the 4 MPa line

$W_p = ?$

$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \dot{m}[h_i + ke + pe_i] - \dot{m}[h_e + ke_e + pe_e]$$
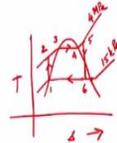
$$\dot{W} = \dot{m}[h_i - h_e] \ or \ w = h_i - h_e$$

$$h_2 = h_1 + |W|$$

In a steam power plant operating on the Rankine cycle, steam enters the turbine at 4 MPa, 400 °C and exits at a pressure of 15 kPa. Then it enters the condenser and exits as saturated water. Next, a pump feeds back the water to the boiler. The adiabatic efficiency of the turbine is 90%.

Determine :

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Turbine inlet : steam @ 4MPa, 400°C

exit : $p = 15 kPa$

$\eta_{turbin} = 0.9$

condenser exit : sat. water

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