Lecture Two

Actual Rankine Cycle

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The actual cycle differs from the ideal Rankine cycle as a result of irreversibilities in various components. Fluid friction and heat loss to the surroundings are the main sources of irreversibilities.

Fluid friction causes pressure drops in the boiler, condenser and the piping between various components. As a result, steam leaves the boiler at a somewhat lower pressure. Also, the pressure at the turbine inlet is somewhat lower than that at the boiler exit due to the pressure drop in the connecting pipes. The pressure drop in the condenser is usually very small. To compensate for these pressure drops, the water must be pumped to a higher pressure than the ideal cycle calls for. This requires a larger pump and larger work input to the pump.

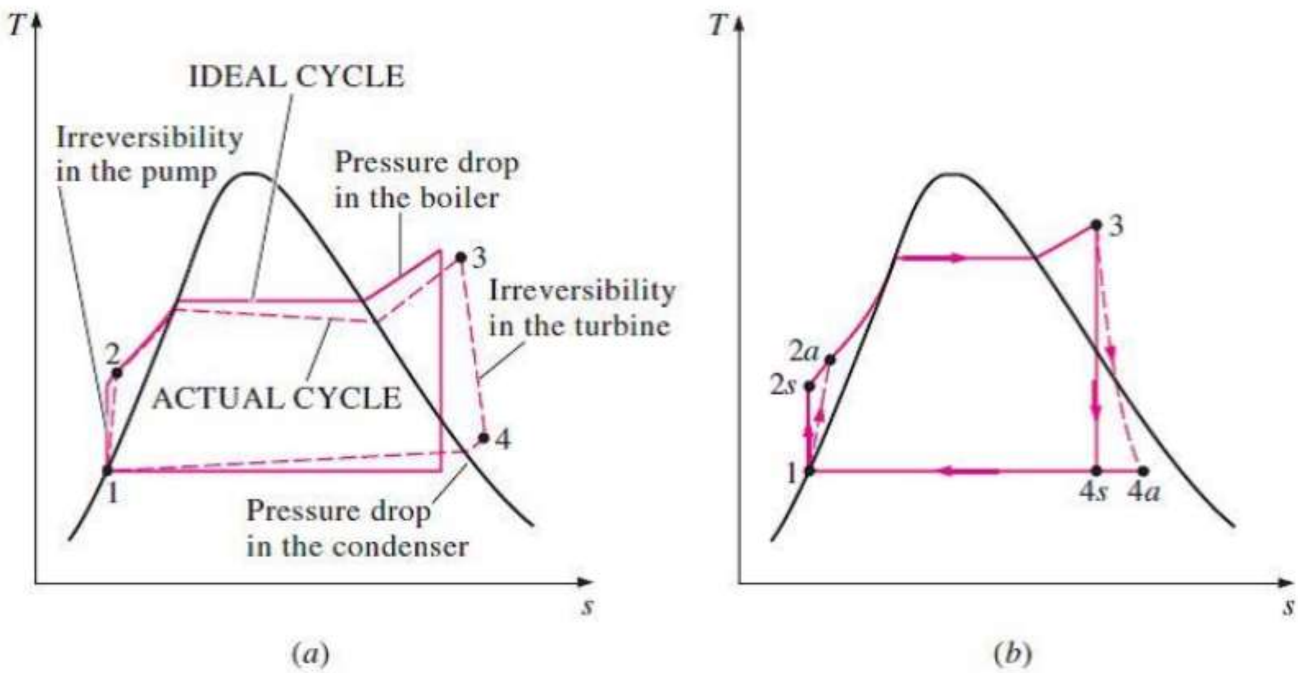
The other major source of irreversibility is the heat loss from the steam to the surroundings as the steam flows through various components. To maintain the same level of net work output, more heat needs to be transferred to the steam in the boiler to compensate for these undesired heat losses. As a result, cycle efficiency decreases.

Of particular importance are the irreversibilities occurring within the **pump** and the **turbine**. A pump requires a greater work input, and a turbine produces a smaller work output as a result of irreversibilities. Under ideal conditions, the flow through these devices is isentropic. The deviation of actual pumps and turbines from the isentropic ones can be accounted for by utilizing isentropic efficiencies, defined as:

$$\eta_P = \frac{w_{Ps}}{w_{Pa}} = \frac{h_{2s} - h_1}{h_{2a} - h_1} \qquad \text{For pump}$$

$$\eta_T = \frac{w_{Ta}}{w_{Ts}} = \frac{h_3 - h_{4a}}{h_3 - h_{4s}} \qquad \text{For turbine}$$

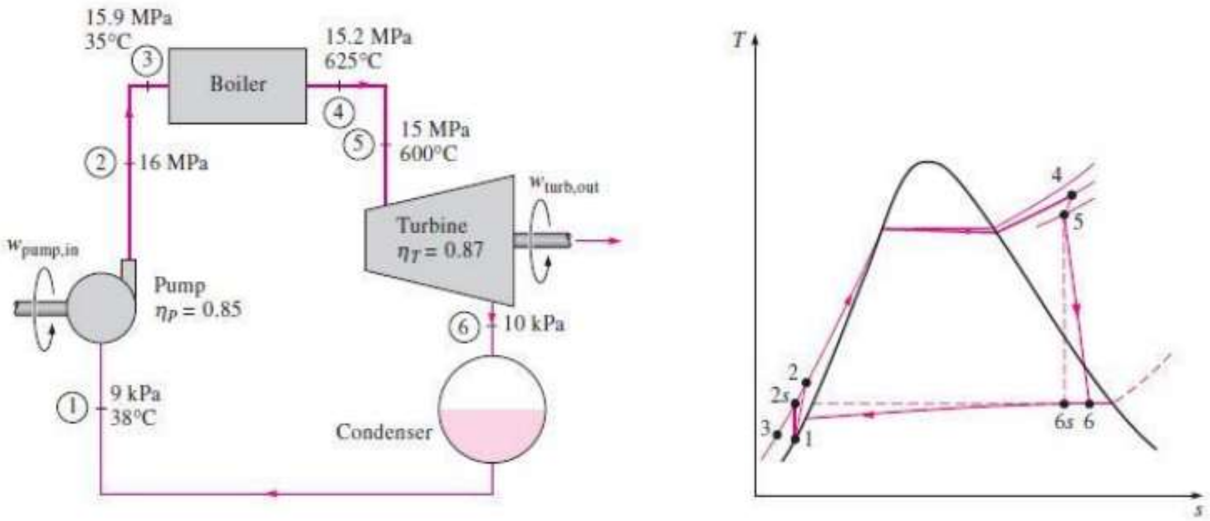
Where states **2a** and **4a** are the actual exit states of the pump and the turbine respectively, and **2s** and **4s** are the corresponding states for the isentropic case.



(*a*) Deviation of actual vapor power cycle from the ideal Rankine cycle. (*b*) The effect of pump and turbine irreversibilities on the ideal Rankine cycle.

Example (5.2): A steam power plant operates on the cycle shown in the figure below. If the isentropic efficiency of the turbine is 87% and the isentropic efficiency of the pump is 85%, determine: (a) the thermal efficiency of the cycle (b) the net power output of the plant for a mass flow rate of 15 kg/s.

Solution:



a. The thermal efficiency of the cycle is the ratio of the net work output to the heat input.

$$\eta_P = \frac{w_{Ps}}{w_{Pa}} = \frac{v_1(P_2 - P_1)}{w_{Pa}} \rightarrow w_{Pa} = \frac{v_1(P_2 - P_1)}{\eta_P}$$

$$w_{Pa} = \frac{0.001009 \times (16 \times 10^3 - 9)}{0.85} = 18.98 \text{ kJ/kg}$$

$$\eta_T = \frac{w_{Ta}}{w_{Ts}} \rightarrow w_{Ta} = \eta_T \times w_{Ts} = \eta_T \times (h_5 - h_{6s})$$

$$w_{Ta} = 0.87 \times (3583.1 - 2115.3) = 1277 \text{ kJ/kg}$$

$$w_{net} = w_{Ta} - w_{pa} = 1277 - 18.98 = 1258.02 \text{ kJ/kg}$$

$$q_{add} = h_4 - h_3 = 3647.6 - 160.1 = 3487.5 \text{ kJ/kg}$$

$$\eta_{th} = \frac{w_{net}}{q_{add}} = \frac{1258.02}{3487.5}$$

$\boldsymbol{\eta_{th} = 36.1\%}$ **Ans.**

b. The net power output of the plant is:

$$Power = m^{\circ} \times w_{net} = 15 \times 1258.02$$

$\boldsymbol{Power = 18.9 \text{ kW}}$ **Ans.**