Thermodynamics: An Engineering Approach
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CHAPTER 10

VAPOR AND COMBINED POWER CYCLES

Lecture slides by

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THE CARNOT VAPOR CYCLE

The Carnot cycle is the most efficient cycle operating between two specified temperature limits but it is not a suitable model for power cycles. Because:

Process 1-2 Limiting the heat transfer processes to two-phase systems severely limits the maximum temperature that can be used in the cycle (374°C for water)

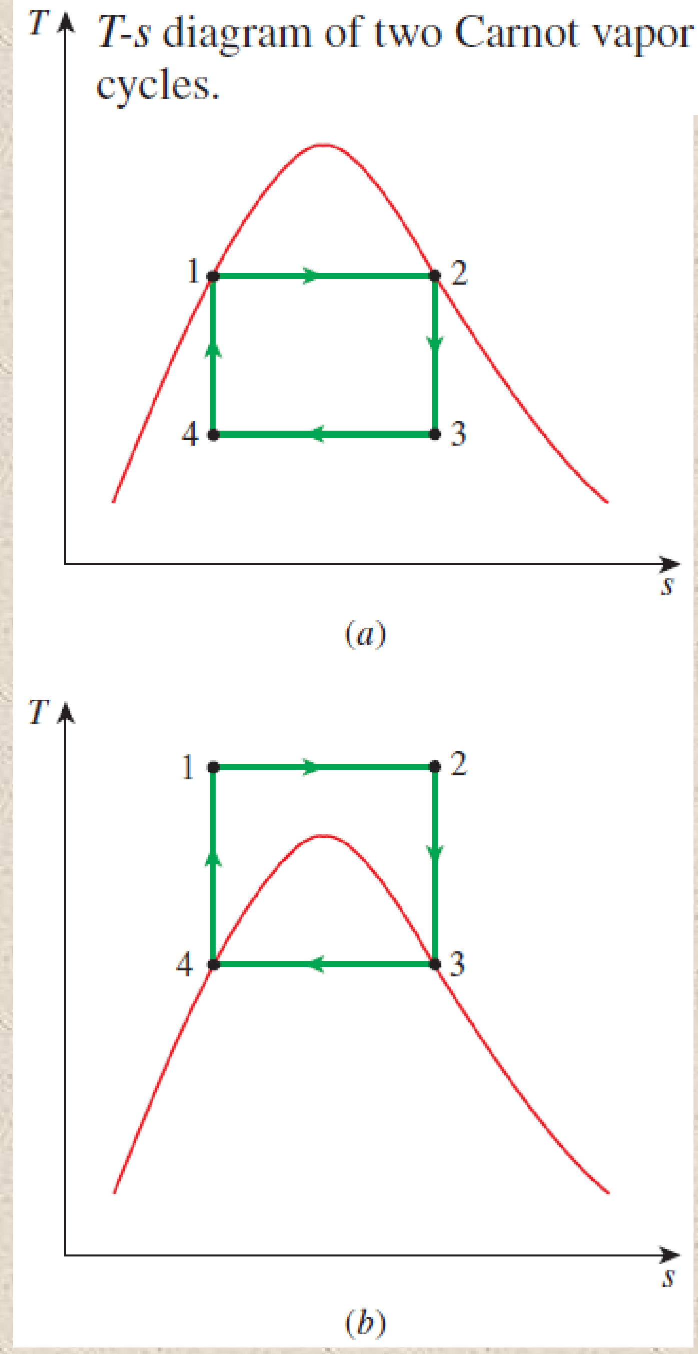
Process 2-3 The turbine cannot handle steam with a high moisture content because of the impingement of liquid droplets on the turbine blades causing erosion and wear.

Process 4-1 It is not practical to design a compressor that handles two phases.

The cycle in (b) is not suitable since it requires isentropic compression to extremely high pressures and isothermal heat transfer at variable pressures.

1-2 isothermal heat addition in a boiler
2-3 isentropic expansion in a turbine
3-4 isothermal heat rejection in a condenser
4-1 isentropic compression in a compressor

FIGURE 10–1
T-s diagram of two Carnot vapor cycles.



RANKINE CYCLE: THE IDEAL CYCLE FOR VAPOR POWER CYCLES

Many of the impracticalities associated with the Carnot cycle can be eliminated by superheating the steam in the boiler and condensing it completely in the condenser.

The cycle that results is the **Rankine cycle**, which is the ideal cycle for vapor power plants. The ideal Rankine cycle does not involve any internal irreversibilities.

1-2	Isentropic compression in a pump
2-3	Constant pressure heat addition in a boiler
3-4	Isentropic expansion in a turbine
4-1	Constant pressure heat rejection in a condenser

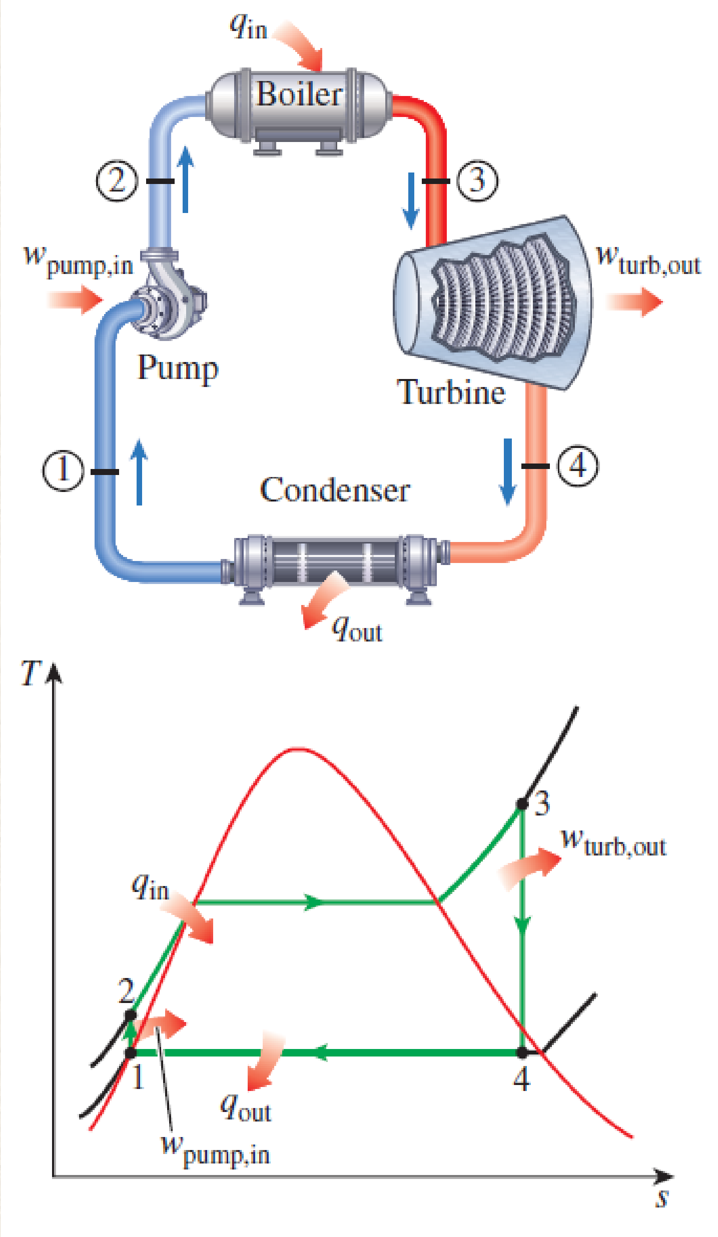
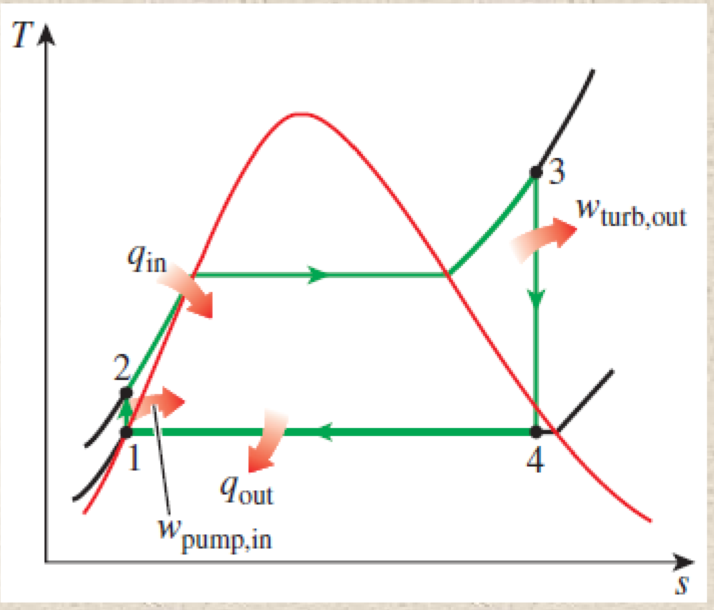


FIGURE 10–2
The simple ideal Rankine cycle.

Energy Analysis of the Ideal Rankine Cycle



Steady-flow energy equation

$$(q_{in} - q_{out}) + (w_{in} - w_{out}) = h_e - h_i \qquad \text{(kJ/kg)}$$

Pump ($q = 0$): $$w_{pump,in} = h_2 - h_1$$

$$w_{pump,in} = v(P_2 - P_1)$$

$$h_1 = h_{f\,@\,P_1} \quad \text{and} \quad v \cong v_1 = v_{f\,@\,P_1}$$

Boiler ($w = 0$): $$q_{in} = h_3 - h_2$$

Turbine ($q = 0$): $$w_{turb,out} = h_3 - h_4$$

Condenser ($w = 0$): $$q_{out} = h_4 - h_1$$

$$w_{net} = q_{in} - q_{out} = w_{turb,out} - w_{pump,in}$$

$$\eta_{th} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}}$$

The efficiency of power plants in the U.S. is often expressed in terms of **heat rate**, which is the amount of heat supplied, in Btu's, to generate 1 kWh of electricity.

$$\eta_{th} = \frac{3412\ \text{(Btu/kWh)}}{\text{Heat rate (Btu/kWh)}}$$

The thermal efficiency can be interpreted as the ratio of the area enclosed by the cycle on a *T-s* diagram to the area under the heat-addition process.