ESO 201A: Thermodynamics

2016-2017-I semester

Vapor Power Cycle: part 1

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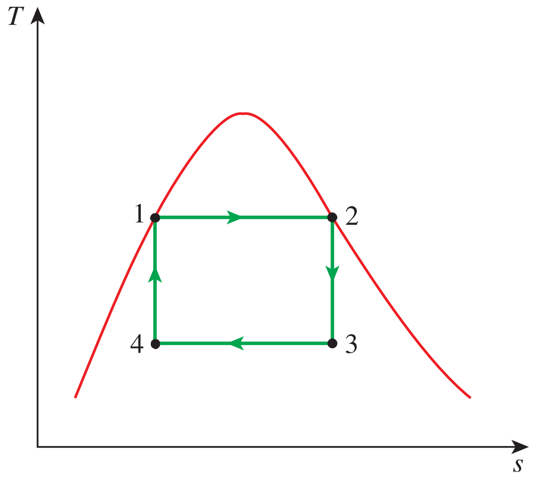
Learning Objectives

- Analyze *vapor power cycles* in which the working fluid is alternately vaporized and condensed.
- Investigate ways to modify the *basic Rankine vapor power cycle* to increase the cycle thermal efficiency.
- Analyze the *reheat and regenerative* vapor power cycles.
- Perform second-law analysis of vapor power cycles
- Analyze power generation coupled with process heating called *cogeneration*.
- Analyze power cycles that consist of two separate cycles known as combined cycles

The Carnot Vapor Cycle

Steady-flow Carnot cycle within the saturation dome

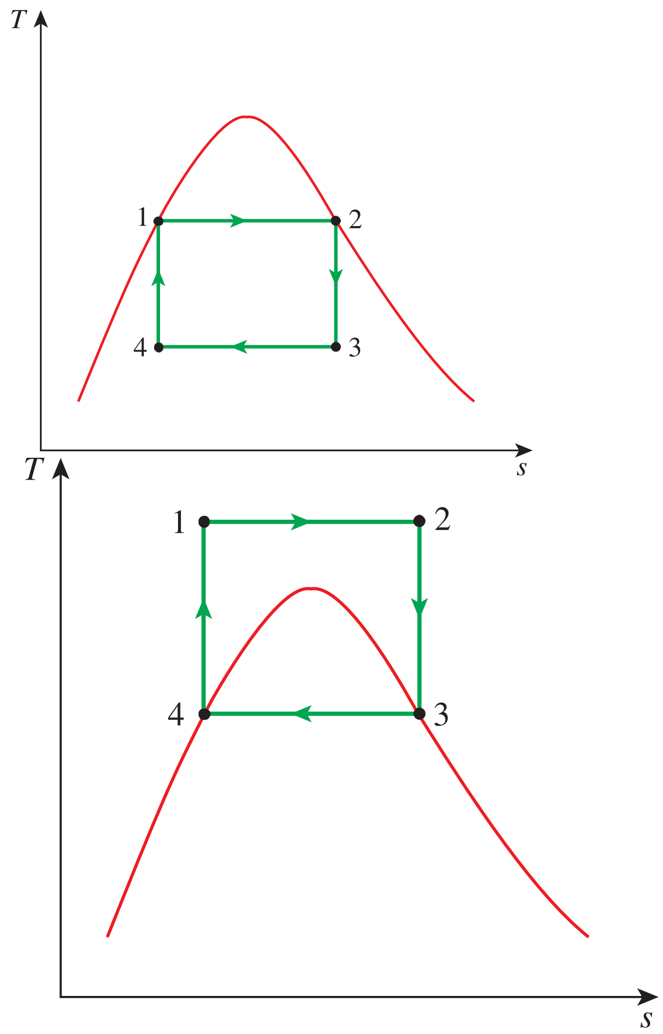
Steam as a working fluid



- Fluid is heated reversibly heated isothermally in boiler (1-2)
- Expanded isentropically in a turbine(2-3)
- Condensed isothermally, reversibly in a condenser (3-4)
- Compressed isentropically by a compressor

Is Carnot cycle a suitable model for power cycle ?

The Carnot Vapor Cycle



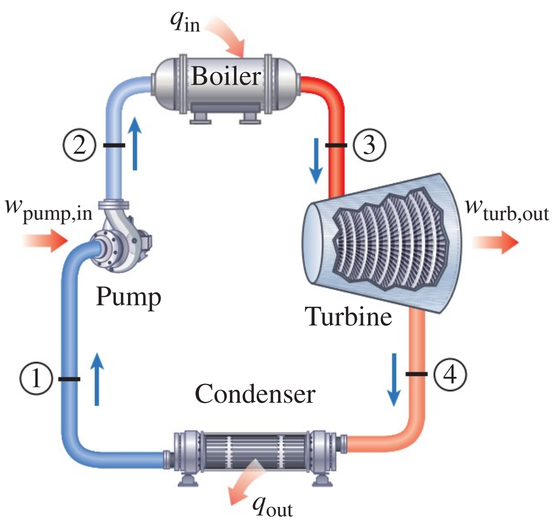
Impracticality

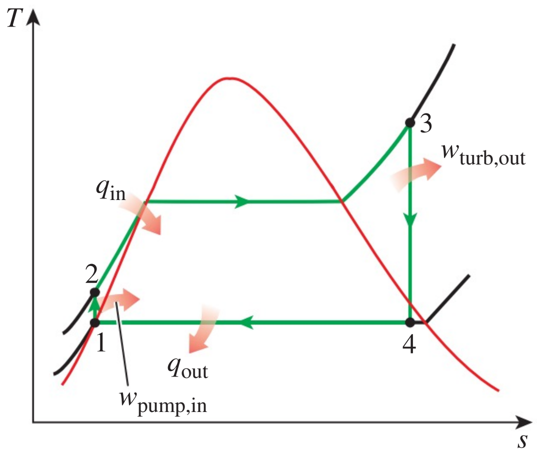
- Limiting the heat transfer to 2-phase system limits the maximum temperature that can be used – *limited thermal efficiency*
- Isentropic expansion decreases the quality and turbine cannot handle low quality steam (less than 90%)
- Compressor cannot easily handle two phase compression.

Hence, the Carnot cycle cannot be approximated in actual devices and is not a realistic model for vapor power cycles.

Rankine cycle: The ideal cycle for vapor power cycles

Avoid impracticalities by superheating the steam in boiler and condensing it completely in condenser: **Rankine Cycle**





The simple ideal Rankine cycle.

1-2 Isentropic compression in a pump

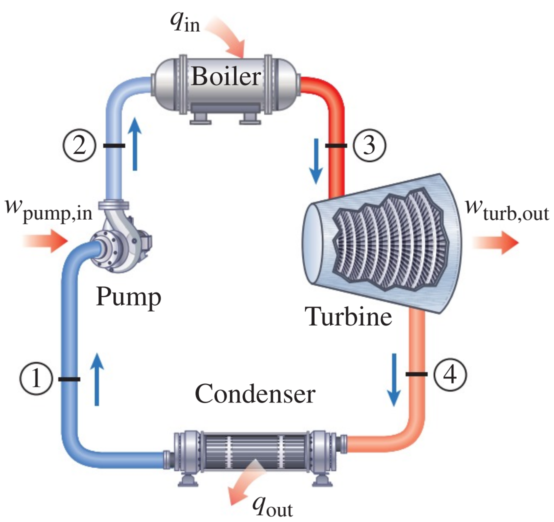
2-3 Constant pressure heat addition in a boiler

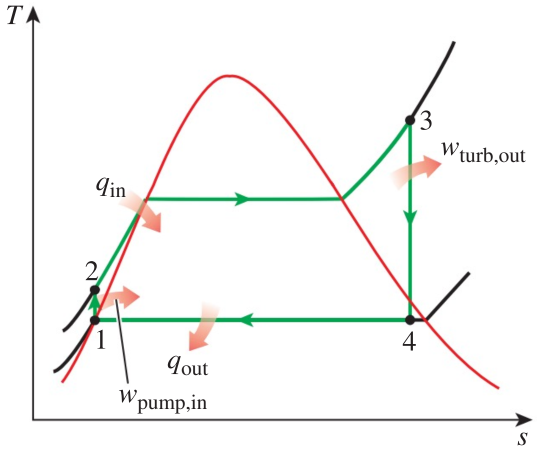
3-4 Isentropic expansion in a turbine

4-1 Constant pressure heat rejection in a condenser

- Sat liquid enters pump, which isentropically compressed to the operating P of the boiler.
- Water enters the boiler as compressed liquid at 2 and leaves as superheated vapor at 3
- Turbine expands isentropically, P & T of the steam drop such that it reaches a two phase state
- Steam is condensed at constant pressure. It leaves as sat liquid to the pump at 1

Rankine cycle





Since all the four devices are steady-flow devices:

$$(q_{in} - q_{out}) + (w_{in} - w_{out}) = h_e - h_i$$

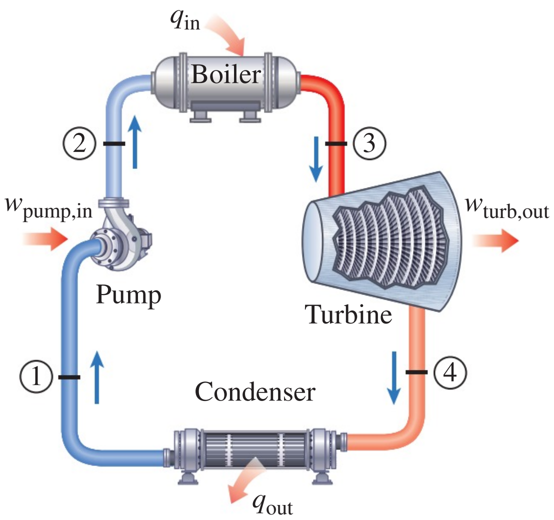
Pump ($q = 0$): $\quad w_{pump,in} = h_2 - h_1$

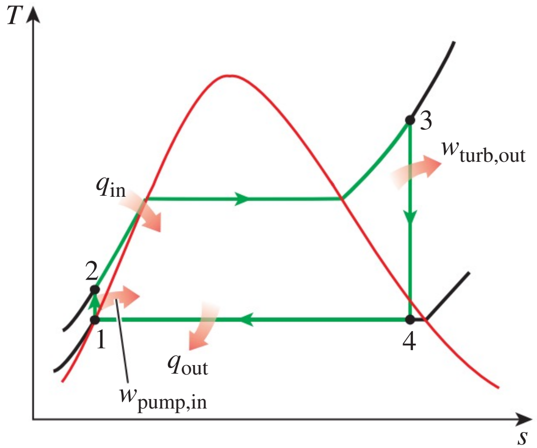
Boiler ($w = 0$): $\quad q_{in} = h_3 - h_2$

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

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

Rankine cycle





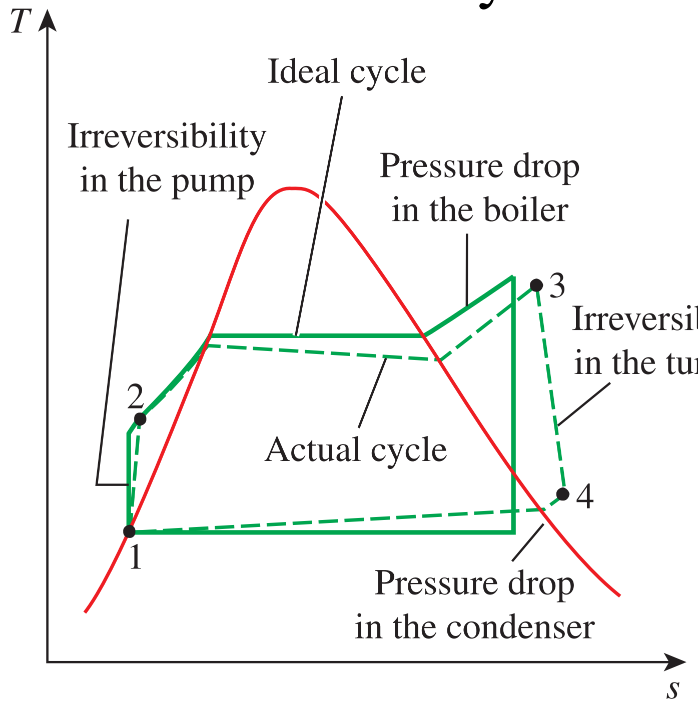
thermal efficiency

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

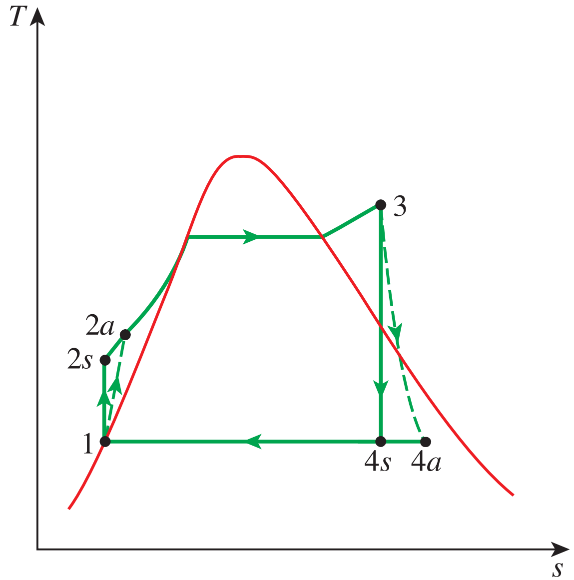
$$w_{net} = q_{in} - q_{out} = w_{turb,out} - w_{pump,in}$$

Deviation from idealized Rankine cycle

Deviation of actual vapor cycle from the ideal Rankine cycle



The effect of pump and turbine irreversibility on the ideal Rankine Cycle



Deviation quantified using isentropic efficiencies:

Pump:

$$\eta_P = \frac{w_s}{w_a} = \frac{h_{2s} - h_1}{h_{2a} - h_1}$$

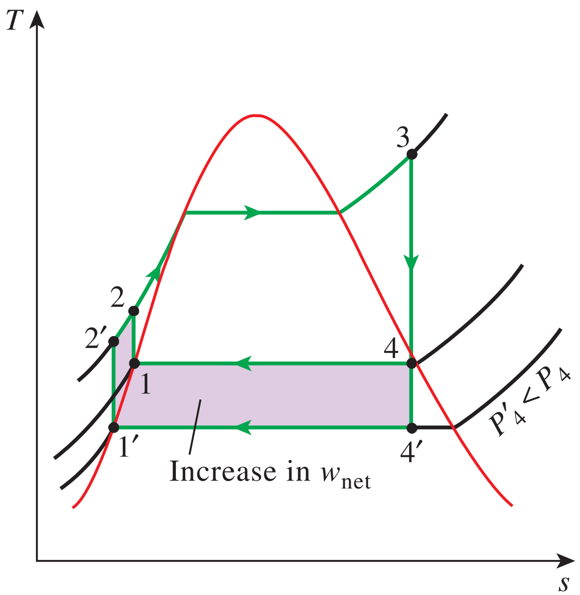
Turbine

$$\eta_T = \frac{w_a}{w_s} = \frac{h_3 - h_{4a}}{h_3 - h_{4s}}$$

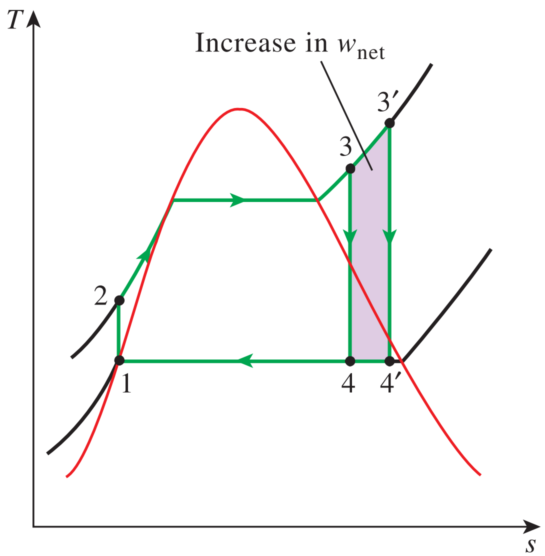
Increasing the efficiency of Rankine cycle

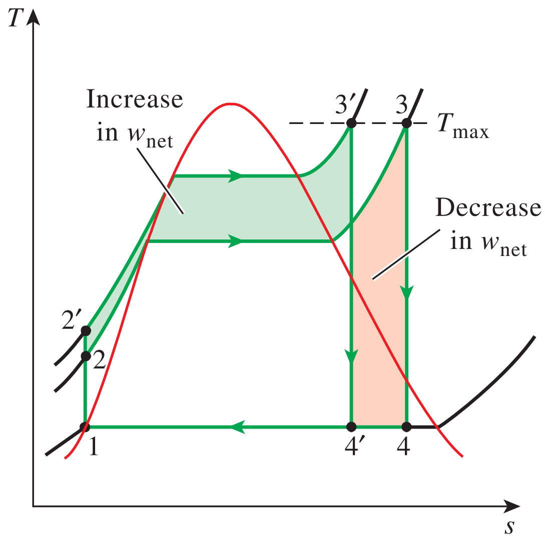
- Average fluid temperature should be as high as possible during heat addition and as low as possible during heat rejection

Lowering condenser pressure



Superheating the steam to higher temperature





Increasing the boiler pressure (increases T_{avg})

- Moisture content increase at 4’, can be corrected by reheating

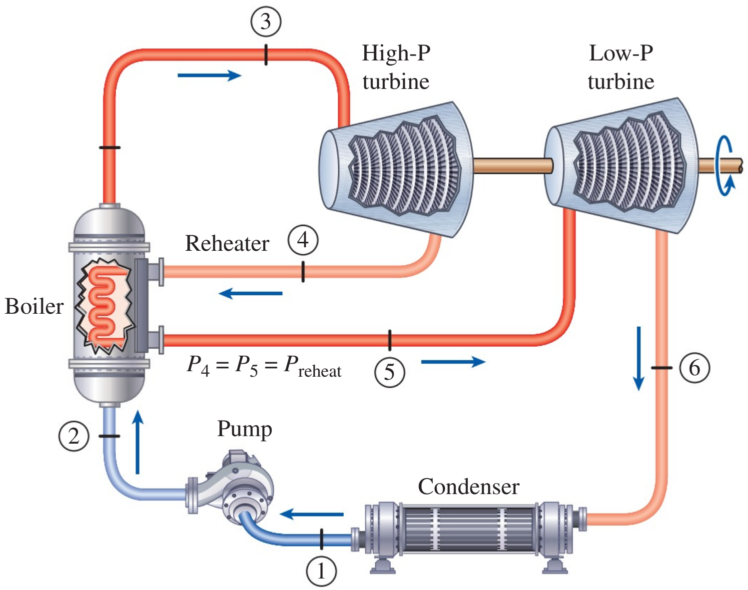
The ideal reheat Rankine cycle

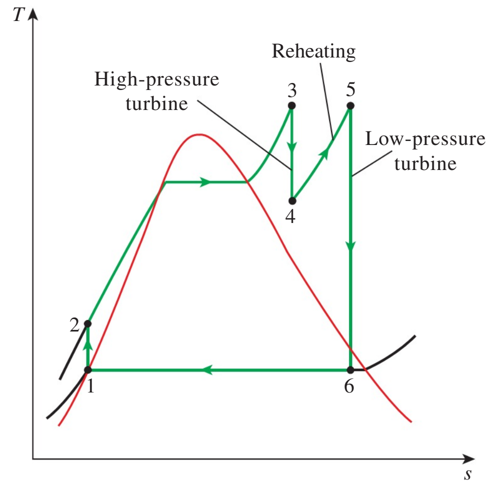
How can we take advantage of the increased efficiencies at higher boiler pressures without facing the problem of excessive moisture at the final stages of the turbine?

- Superheating to very high temperature not viable-metallurgical unsafe level
- Expand the steam in two stages, with a reheat process-practical solution

$$q_{in} = q_{primary} + q_{reheat} = (h_3 - h_2) + (h_5 - h_4)$$

$$w_{turb,out} = w_{turb,I} + w_{turb,II} = (h_3 - h_4) + (h_5 - h_6)$$

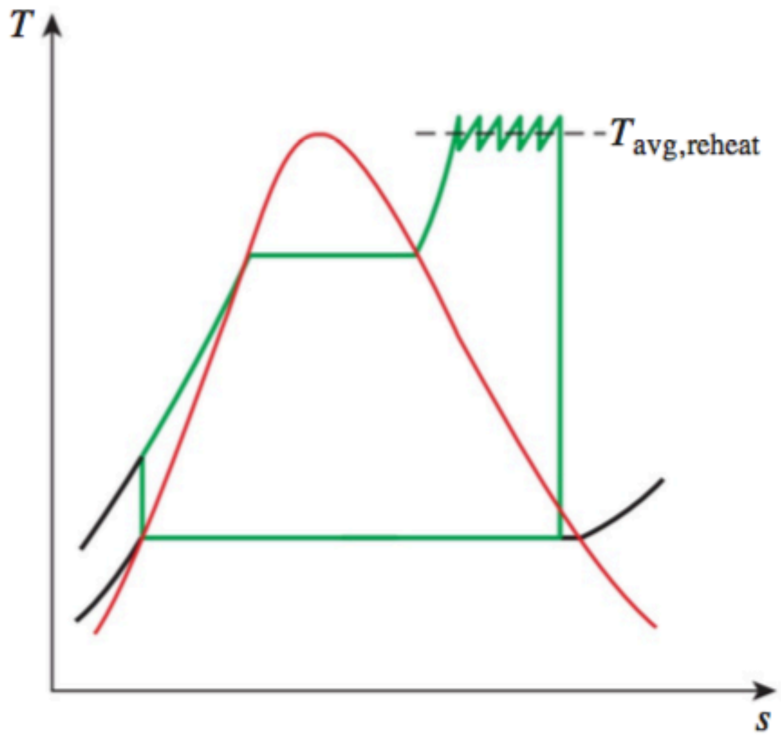




$$\eta_{th} = \frac{w_{net}}{q_{in}}$$

The ideal reheat Rankine cycle

The average temperature during reheat can be increased by increasing the number of expansion and reheat stages



Next lecture

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