Chapter 9 - Power and Refrigeration Systems - With Phase Change

Lecture 30
Section 9.5

MEMS 0051 Introduction to Thermodynamics

Mechanical Engineering and Materials Science Department
University of Pittsburgh

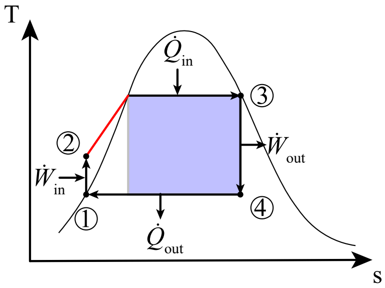
Student Learning Objectives

At the end of the lecture, students should be able to:

- Apply the Conservation of Energy and Conservation of Mass to basic power cycles, i.e. the Rankine cycle, with open and closed feedwater heaters

Regeneration

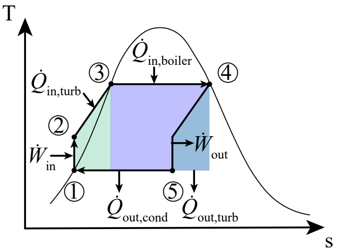
- Looking at the standard Rankine cycle, we see the heat addition process from the exit of the pump to the saturated liquid curve (red line) occurs at a lesser temperature than the constant-pressure heat addition process that causes phase change
- This low-temp heat addition process make the Ranking cycle less efficient than the Carnot cycle (blue box)

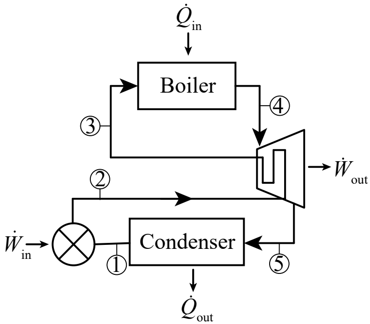


- We can't mimic the Carnot cycle - pumps require $x = 0$

Regeneration

- How do we remove the area on the $T-s$ diagram that is not reflective of the Carnot cycle (green)?

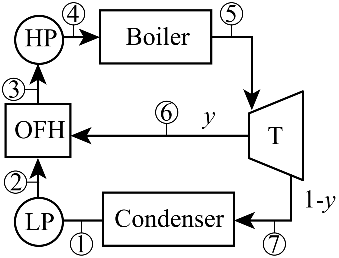


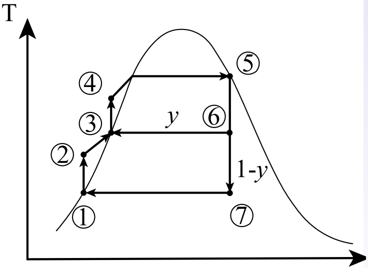


- We circulate the fluid that exits the pump around the hot-turbine in a reversible process, preheating it before it enters the boiler - a completely idealized scenario that is not physically obtainable

Open Feedwater Heater

- An OFH extracts a portion of steam from the turbine, y, and preheats the output of a low-pressure (LP) pump. The mixture of fluid for the LP pump and turbine is then fed into a high-pressure (HP) pump.





Example #1

- Consider a regenerative Rankine cycle with one open feedwater heater (OFH). Steam enters the turbine at 8.0 [MPa], 480 °C and expands to 0.7 [MPa], where some of the steam, denoted as y, is extracted and diverted to the OFH, which is operating at 0.7 [MPa]. The remaining steam, denoted as $1 - y$, expands through the second-stage turbine to the condenser pressure of 8.0 [kPa]. This quantity of working fluid, $1 - y$, runs through a low-pressure pump, where upon exit, it is mixed with the diverted steam (quantity y) in the OFH. Saturated liquid exits the OFH at 0.7 [MPa] before entering the high-pressure pump, which supplies water to the boiler. The net power output it is 1,000 [MW].

Example #1

- Determine:
  a) The thermal efficiency η_{th};
  b) The mass low rate of the steam $\dot{m}_{steam}$ in [kg/hr];
  c) The rate of heat transfer into the boiler $\dot{Q}in$ in [MW];
  d) The rate of heat transfer out of the condenser $\dot{Q}_{out}$ in [MW];
  e) The mass flow rate of cooling water supplied to the condenser $\dot{m}_{CW}$, in [kg/hr], assuming saturated liquid water enters at 15°C and saturated liquid water exits at 35°.

Example #1

Example #1

Example #1

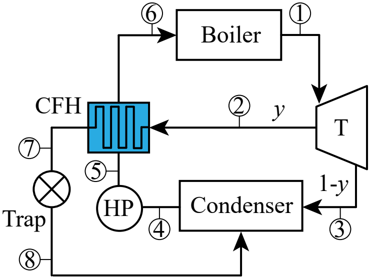
Example #1

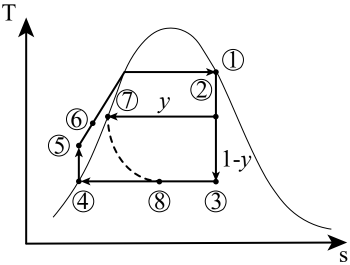
Example #1

Example #1

Closed Feedwater Heater

- A CFH also extracts a portion of steam from the turbine, y, however, this fluid does not





Example #2

- Consider a regenerative Rankine cyle with a CFH. Steam enters the turbine at 8.0 [MPa], 480 °C and expands to 0.7 [MPa], where some of the steam, denoted as y, is extracted and diverted to the CFH. Heat is extracted from this fluid to the point it reaches zero quality. It this expands through a trap and mixes with the fluid in the condenser. The remaining steam, denoted as $1 - y$, expands through the second-stage turbine to the condenser pressure of 8.0 [kPa]. The net power output it is 1,000 [MW].

Example #2

- Determine:
  a) The thermal efficiency η_{th};
  b) The mass low rate of the steam $\dot{m}_{steam}$ in [kg/hr];
  c) The rate of heat transfer into the boiler $\dot{Q}in$ in [MW];
  d) The rate of heat transfer out of the condenser $\dot{Q}_{out}$ in [MW];

Example #2

Example #2

Example #2

Example #2

Example #2

Example #2

Example #2

Example #2

Student Learning Objectives

At the end of the lecture, students should be able to:

- Apply the Conservation of Energy and Conservation of Mass to basic power cycles, i.e. the Rankine cycle, with open and closed feedwater heaters
  - An OFW preheats the working fluid before entering the HP pump.
  - A CFW preheats the fluid after it exits the pump and before it enters the boiler. A CFW requires a trap - a constant-enthalpy device.

Suggested Problems

- 9.40-9.60 - all are excellent practice!