Homework #4 (group) – Tuesday, 27 by 4:00 pm

5290 exercises (individual) – Tuesday, 27 by 4:00 pm

extra credit (individual) – Tuesday, 27 by 4:00 pm

Readings for this homework assignment and upcoming lectures

- Read Chapter 2. Rankine Cycle (Weston Textbook)
- Read Chapter 2. Rankine Cycle (El-Wakil, posted on Canvas)
- Review lecture notes:
  - Part 5. The Rise of Heat Engines
  - Part 6a. & 6b. Review of Engineering Thermodynamics
  - Part 7. Rankine Cycle
- Review Chapter 1 of Weston Textbook
- Review Thermodynamics textbook
- Review Chapter 1. Power Plant Technology, El-Wakil

Homework Submission

- For this assignment, the 4200-portion of the homework is to be worked as a group assignment and submitted as a group in class or by dropping off at my office. If you use EES or Matlab for this assignment, print a copy of the code and include with your solution.
- MEEM 5290 exercise are always to be worked and submitted individually.
- Extra Credit exercises are always to be worked and submitted individually.
- **At the end of each exercise, rank your confidence in the answer from 1 to 5; 5 being very confident and 1 being 'a guess'.**
- PLEASE include the course number (MEEM4200, MEEM5290) in the subject line of any email correspondence.

Homework #4 - due Tuesday, 27 by 4:00 pm

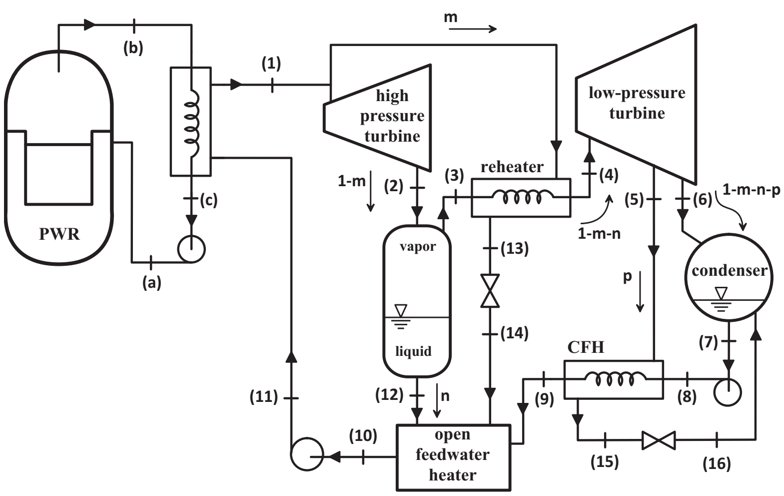
1. A solar-pond power plant operates on an ideal, simple Rankine cycle with R-134a as the working fluid. The refrigerant enters the turbine as saturated vapor at 1.3 MPa and exits at 0.6 MPa. The mass flow rate is 5 kg/s. Draw the cycle on a T-s diagram with the saturation line and determine:
   (a) the thermal efficiency of the cycle, and
   (b) the power output of the plant.
2. Weston 2.7
3. Weston 2.35
4. Weston 2.36
5. An ideal Rankine cycle operates with turbine throttle at 90 bar and 500 °C, and condenser temperature of 40 °C. Complete the following for each cycle configuration.
   (a) Tabulate temperature, pressure, enthalpy, and entropy of all states. Determine the quality and moisture fraction for all mixed states.
   (b) Calculate the heat transferred in the condenser and steam generator and the turbine work, all per unit mass. Calculate the thermal efficiency.
   (c) Calculate the pump work and the ratio of turbine to pump work.

   Cycle configurations:

   A. no feedwater heating,
   B. one open feedwater heater,
   C. one closed feedwater heater throttled back to the condenser, and
   D. one closed feedwater heater with drain pumped forward.

   In each configuration, the feedwater heater is optimally placed. Use TTD = 2.5 °C.

6. A 3800-MW$_{th}$ PWR is cooled with 15.3-MPa water that enters the core at 300 °C and leaves at 332 °C. In the once-through steam generator, high pressure water is used to produce steam at 8.0 MPa and 315 °C. The steam expands to 0.68 MPa in the high-pressure turbine. Moisture is separated and the saturated steam is reheated with live steam to 288 °C before it enters the low-pressure turbine. The steam expands to 110 kPa, where a fraction is bled to a closed feedwater heater. Expansion continues to the condenser pressure of 10 kPa. The separated moisture is drained to an open feedwater heater and the reheater condensate is 'trapped' to the same heater. The closed feedwater heater has a terminal temperature difference of 3 °C. Each segment of the turbine expansion is 85% efficient and the pumps are 65% efficient.
   1. Sketch the cycle on a T-s diagram.
   2. Find the cooling water flow rate in the core, in L/min.
   3. Find the steam generation rate, in kg/hr.
   4. Determine the power output of the system, MW$_e$, if the turbine drives a generator with an efficiency of 94%.
   5. What is the thermal efficiency of the cycle?



Homework #4 – 5290 only

7. Weston 2.55

8. An superheated nonideal steam cycle operates with inlet steam at 2400 psia and 1000 °F and condenses at 1 psia. It has five feedwater heaters, all optimally placed. Assume the isentropic efficiencies of the turbine sections before, between, and after the bleed points to be all the same and equal to 0.90.
   (a) Calculate the specific enthalpies of the extracted steam to each feedwater heater, in Btu/lbm.
   (b) Calculate the overall isentropic efficiency of the turbine.
   (c) Estimate the terminal temperature difference for each feed water heater.

9. If a Rankine cycle is to be used in a space craft, heat rejection at the condenser can only be done through thermal radiation to deep space, which has an effective temperature of absolute zero. To reduce the size and mass, and hence the energy required to leave Earth's gravitational field, the condenser would have to operate at temperatures much higher than that used in terrestrial Rankine cycles. Condensing temperatures of 1000 to 1500 ^{c}ircF are required, which are higher than the critical point of water. Therefore, a liquid metal such as sodium must be used as the working fluid.

   Consider a 100 kW_{th} Rankine cycle using sodium, operating with a turbine inlet of 24.692 psia and 2400 °R and condensing at 1500 °R. The turbine and pump isentropic efficiencies are 0.85 and 0.65, respectively. There are no feedwater heaters and pressure drops are negligible.

   (a) Calculate the cycle efficiency.
   (b) Calculate the heat transfer area of the condenser-radiator if it has an overall heat transfer coefficient of 5 Btu/ft^2,hr °F.

10. An 850-MW Rankine cycle operates with turbine inlet steam at 1200 psia and 1000 degrees F and condenses at 1 psia. There are three feedwater heaters place optimally as follows: (a) the high-pressure heater is of the closed type with drains cascaded backward; (b) the intermediate-pressure heater is of the open type; (c) the low-pressure heater is of the closed type with drains pumped forward. Each of the turbine sections have the same isentropic efficiency of 90 percent. The pumps have isentropic efficiencies of 80 percent. The high-pressure heater has a TTD = -3 °F. The low-pressure heater has a TTD = +5 °F.
    (a) Tabulate temperature, pressure, enthalpy, and entropy at all states. Determine the quality for all mixed states.
    (b) Sketch the cycle and T-s diagrams.
    (c) Calculate the mass flow rate at the turbine inlet in pounds mass per hour.
    (d) Calculate the mass flow rate to the condenser.
    (e) Calculate the mass flow rate of the condenser cooling water, in pounds mass per hour, if it undergoes a 25 degree F temperature rise.
    (f) Calculate the cycle efficiency.
    (g) Calculate the cycle heat rate, in Btus per kilowatt hour.

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11. Rework problem 5 with isentropic pump and turbine efficiencies of 0.70 and 0.89, respectively.

12. Determine the thermal efficiency, the required steam flow rate, and the moisture at the turbine exhaust for a reheat, regenerative cycle which is to produce 200 MW at the turbine coupling if the throttle conditions are 15.5 MPa and 540 °C; reheat is at 8.0 MPa and 590 °C; one closed feedwater heater is at 3.4 MPa; an open feedwater heater is at 170 kPa; and the condenser pressure is 13 kPa. The turbine and pump efficiencies are 84%. The terminal temperature difference for both feedwater heaters is 3 °C and the drain from the closed feedwater heater is pumped into the steam generator. Also sketch the T-s diagram of the cycle.

13. An advanced supercritical power plant has a turbine inlet stream at 7000 psia and 1400 °F, double reheat at 1600 psia and 400 psia, both to 1200 °F, and condenser at 1 psia. The three turbine sections have isentropic efficiencies of 0.93, 0.91, and 0.89 in order of descending pressures. The pump has an isentropic efficiency of 0.75. The plant receives one unit train of coal daily, which is composed of 100 cars carrying 110 short tons each. The coal has a heating value of 11 000 Btu/lbm. The turbine-generator combined mechanical and electrical efficiency is 0.90. The steam generator efficiency is 0.87. Eight percent of the gross output is used to run plant auxiliaries. Ignoring, for simplicity, all steam line pressure drops and all feedwater heaters, calculate
    (a) the plant gross and net outputs, in MW_e,
    (b) the plant cycle gross and net efficiencies, and
    (c) the cycle and station gross and net heat rates, in Btu/kWh.