Homework #4 - due Thursday, October 15 by 4:00 pm
bonus problems - due Tuesday, October 21 by 6:00 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 6. & 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 (room 831). If you use EES for this assignment, then print a copy of the code and include with your solution.

- MEEM 5290 problems are always to be worked and submitted individually.

- Bonus problems are always to be worked and submitted individually.

- At the end of each problem, 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 Thursday, October 15 by 4:00 pm

1. What are the four processes that are used to model an ideal, simple Rankine cycle? Draw these processes on $T$-$s$ and $P$-$v$ diagrams.

2. A coal-fired steam plant is rated at 450 MW$_e$ and operates on an ideal, simple Rankine cycle. The turbine inlet conditions are 6 MPa and 500°C and the condenser pressure is 25 kPa. The coal used has a heating value of 23 200 kJ/kg. The combustor-steam generator is 75% efficient; that is, 75 percent of the energy available in the coal is transferred to the steam. The electrical generator is 96% efficient.
   1. What is the overall plant efficiency?
   2. What is the rate of coal consumption? [tons/hr]

3. Weston 2.36

4. To reduce the volume flow rate and hence the physical size of the turbine, powerplants that operate with low initial temperature water as a heat source, such as some types of geothermal and ocean temperature energy conversion (OTEC), use working fluids other than steam. Examples include Freon-12, ammonia, and propane. Compare the mass flow rates [lbm/hr], volume flow rates [$ft^3$/s], and boiler and condenser pressures of (a) Freon-12, (b) propane, and (c) steam, if all cycles operate with ideal turbines that receive saturated vapor at 200°F and condense at 70°F, each producing 100 kW$_m$.

5. Weston 2.44 (don’t forget part (f)).

6. An ideal Rankine cycle operates with turbine throttle at 90 bar and 500°C, and condenser temperature of 40°C. Calculate the efficiency and work ratio for the following cases:
   - no feedwater heating,
   - one open feedwater heater,
   - one closed feedwater heater throttled back to the condenser, and
   - one closed feedwater heater with drain pumped forward.

In each case, the feedwater heater is optimally placed. Use TTD = 2.5°C.
7. A 3800-MW<sub>th</sub> 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<sub>e</sub>, if the turbine drives a generator with an efficiency of 94%.
5. What is the thermal efficiency of the cycle?
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8. Compare the net work \([\text{Btu/lbm}]\) and efficiency of two ideal, saturated Rankine cycles using Freon-12 (R12) as a working fluid operating between 200 \(^\circ\)F and 72 \(^\circ\)F. One cycle has no feedwater heaters and the other has one open feedwater heater optimally placed. Explain why feedwater heating is not usually used in such cycles.

9. Weston 2.55

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 \(^\circ\)F. The low-pressure heater has a TTD = +5 \(^\circ\)F.

(a) Sketch the cycle and T-s diagrams.

(b) Calculate the mass flow rate at the turbine inlet in pounds mass per hour.

(c) Calculate the mass flow rate to the condenser.

(d) Calculate the mass flow rate of the condenser cooling water, in pounds mass per hour, if it undergoes a 25 degree F temperature rise.

(e) Calculate the cycle efficiency.

(f) Calculate the cycle heat rate, in Btus per kilowatt hour.
11. Compare the inlet steam mass and volume flow rates in lbm/s and ft$^3$/s of
   (a) a fossil-fuel powerplant turbine with an isentropic efficiency of 0.9 receiving steam at 2400 psia and 1000°F, and
   (b) a nuclear powerplant turbine with an isentropic efficiency of 0.88 and receiving saturated steam at 1000°F.

   Each turbine produces 1000 MW, and exhausts to 1 psia.

12. Rework problem 6 with isentropic pump and turbine efficiencies of 0.70 and 0.89, respectively.

13. 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.

14. 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.