Homework #7 (group) – Thursday, April 5 by 4:00 pm

5290 exercises (individual) – Thursday, April 5 by 4:00 pm

extra credit (individual) – Tuesday, April 10 by 4:00 pm

Readings for this homework assignment and upcoming lectures

- Chapter 5. Gas Turbines and Jet Engines (Weston Textbook)
- Chapter 9. Advanced Systems, §9.1 – §9.3
- Review lecture notes:
  - Part 3. Chemical Energy & Fuels
  - Part 7. Rankine Cycle
  - Part 8. Brayton Cycle

Homework Submission

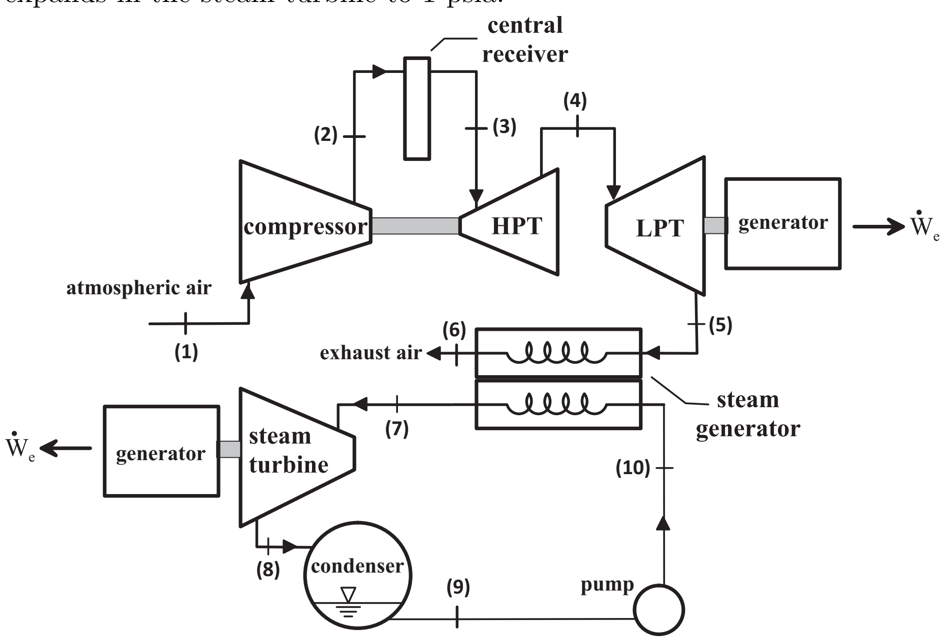
- For this assignment, the 4200-portion of the homework is to be worked as a group assignment and submitted as a group in class or by dropping off at my office (room 905). If you use EES for this assignment, then print a copy of the code and solution and include with the homework.
- MEEM 5290 problems are always to be worked and submitted individually.
- Extra credit exercises 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'.**
- Include the course number (MEEM4200, MEEM5290) in the subject line of any email correspondence.

Homework #7 - due Thursday, April 5 by 4:00 pm

1. A combined-cycle plant uses a gas-turbine with a thermal efficiency of 38% and the turbine exhaust is directed into a heat recovery steam generator (HSRG) to generate steam for a Rankine cycle. No supplemental heat is added to the exhaust gas flow. The Rankine cycle has a thermal efficiency of 24%. Determine the overall thermal efficiency of the combined cycle.

2. Weston 9.1

3. A combined thermal solar power plant operates as shown. Heliostats track the sun and focus the solar energy on a central tower (receiver), which heats compressed air for expansion in a gas turbine. At peak solar insolation, 10^7 lbm/hr of atmospheric air at 520 °R is compressed to 9.76 atm, after which it is heated in the central receiver, entering the high pressure gas turbine at 9.6 atm and 1960 °R. The air leaves the low pressure turbine at 20 psia to the steam generator, then exiting at 600 °R. Superheated steam is generated at 1000 psia and 780 °F and expands in the steam turbine to 1 psia.



The compressor and both gas turbines have isentropic efficiencies of 0.82 and 0.88, respectively. The steam turbine has an isentropic efficiency of 0.90. The mechanical efficiencies of the compressors and turbines are all 0.95. The electrical generators have a combined mechanical-electrical efficiency of 0.96.

(a) Calculate the steam flow rate in lbm/hr.
(b) Calculate the net power output of the plant, in MW_e, if 20% of the gross power is used internally.
(c) Calculate the combined plant net efficiency.
(d) Estimate the number of heliostats required if the reflective area of each is 100 m^2 and the radiation transmission losses to the air in the tower are 40% of the solar insolation. The solar insolation is 1000 W/m^2.

Cite your source(s) of information and data.

Homework #7 – 5290 only

4. A combined Brayton-Rankine power plant uses four 50-MW gas turbines and one 120-MW steam turbine. Each Brayton cycle operates with a compressor inlet temperature of 505 °R, turbine inlet temperature of 2450 °R, pressure ratio of 5.0 for both compressor and turbine with isentropic and mechanical efficiencies of 0.87 and 0.96, respectively. The exhaust gases exiting the turbines pass through a heat-recovery steam generator (HRSG) and then to a regenerator with an effectiveness of 0.87. The fuel for the gas turbine is Ohio Natural Gas burned in 200% theoretical air.

   The Rankine cycle has steam turbine throttle conditions at 1200 psia and 1460 °R, one open-feedwater heater (not optimally placed) with feedwater exit temperature of 920 °R, condenser pressure of 1 psia, and isentropic and mechanical efficiencies of 0.87 and 0.96, respectively. All electric generators have an efficiency of 0.96. Supplemental firing at rated power is used to increase the gas turbine exhaust temperature to 2000 °R before entering the HRSG.

   (a) Draw the cycle and T-s diagrams for this combined cycle.
   (b) Calculate the required mass flow rate of steam in lbm/hr.
   (c) Calculate the required mass flow of air for each gas turbine in lbm/hr.
   (d) Calculate the heat added in the Brayton cycle and in supplementary firing at full load in Btu/hr.
   (e) Calculate the stack gas temperature in °F.
   (f) Calculate the combined cycle efficiency at full load.
   (g) Calculate the combined cycle efficiency at startup when only one gas turbine is used at its full load with no supplemental firing or regeneration.

   Ignore the pump work in the Rankine cycle.

extra credit (individual) – Tuesday, April 10 by 4:00 pm

5. A combined Brayton-Rankine cycle, with both cycles ideal, has air entering the compressor of the Brayton cycle at 1 atm and 500 °R. The air, treated as an ideal gas, enters the gas turbine at 2400 °R. The pressure ratio for both the compressor and turbine is 6.624. No intercooling, reheat, or regeneration is used with the Brayton cycle. The exhaust of the gas turbine is used directly in a heat recovery steam generator (HSRG) without any supplemental firing and leaves the stack at 1000 °R. Steam is produced at 1000 psia and 1000 °F. The condenser pressure is 1 psia. No feedwater heating is used and the pump work may be ignored.

   (a) Draw the cycle and T-s diagrams.
   (b) Calculate the heat added, per lbm of air.
   (c) Calculate the steam flow rate, per lbm of air.
   (d) Calculate the combined work in Btu/lbm air.
   (e) Calculate the combined cycle thermal efficiency.
   (f) Calculate the thermal efficiency if the Rankine cycle is not operating.