

Rankine Cycle (RC) Experiment

Background: A vast majority of the electricity used in this country comes from coal or natural gas power plants. In these facilities, the fuel is burned to generate heat and produce steam, which ultimately drives a turbine to produce electricity. The Rankine cycle is a thermodynamic power cycle in which heat is converted to work, as shown in Figure 1. This power cycle models the performance of most of the world's power plants. In fact, the Rankine cycle is used to model over 80% of the world's electricity generation.

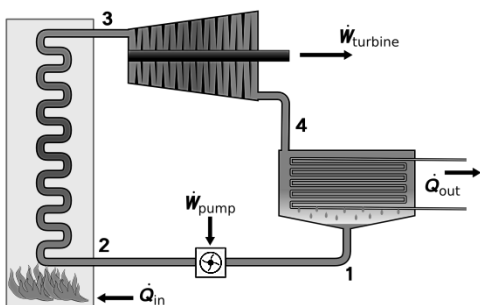


Figure 1. Illustration of the Rankine Cycle

Theory: The practical Rankine cycle closely resembles the theoretical Carnot cycle, except that the heat addition and rejection are isobaric in the Rankine cycle and isothermal in the Carnot cycle. This creates some irreversible losses from pumping the liquid working fluid that can, in reality, be small when compared to the alternative of compressing a gas working fluid. This working fluid is what limits the efficiency of both Rankine and Carnot cycles. While many fluids could be used in theory, water is predominantly the fluid of choice due to its low cost

and lack of toxicity.

The thermodynamic performance of the Rankine cycle is characterized by paths moving from the four major units of the system shown in Figure 1. In path 1→2, the working fluid is pumped from low to high pressure (this is where using liquid is a real advantage). In path 2→3, the liquid is heated at constant pressure to a dry saturated vapor. In path 3→4, the vapor expands through a turbine to generate power (usually along with some condensation of the vapor). Finally, in path 4→1, the wet vapor is condensed back to a saturated liquid and the process begins anew.

A TS diagram can be constructed to analyze the performance of the power cycle, as shown for a real system in Figure 2. In an ideal situation, the pump and turbine would be isentropic and paths 1→2 and 3→4 would be represented by vertical lines.

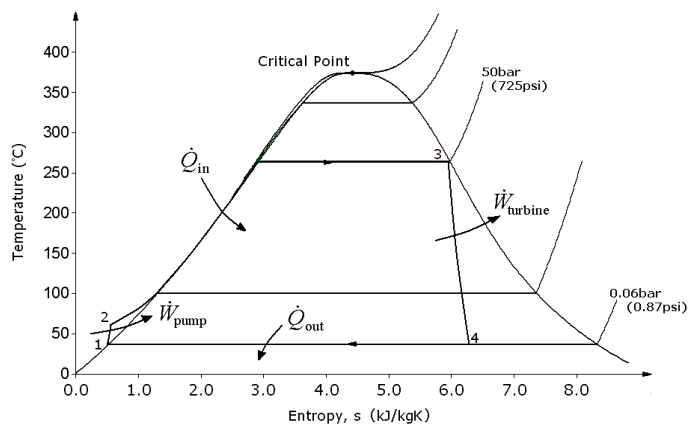


Figure 2. TS Diagram of a Real Steam Rankine Cycle

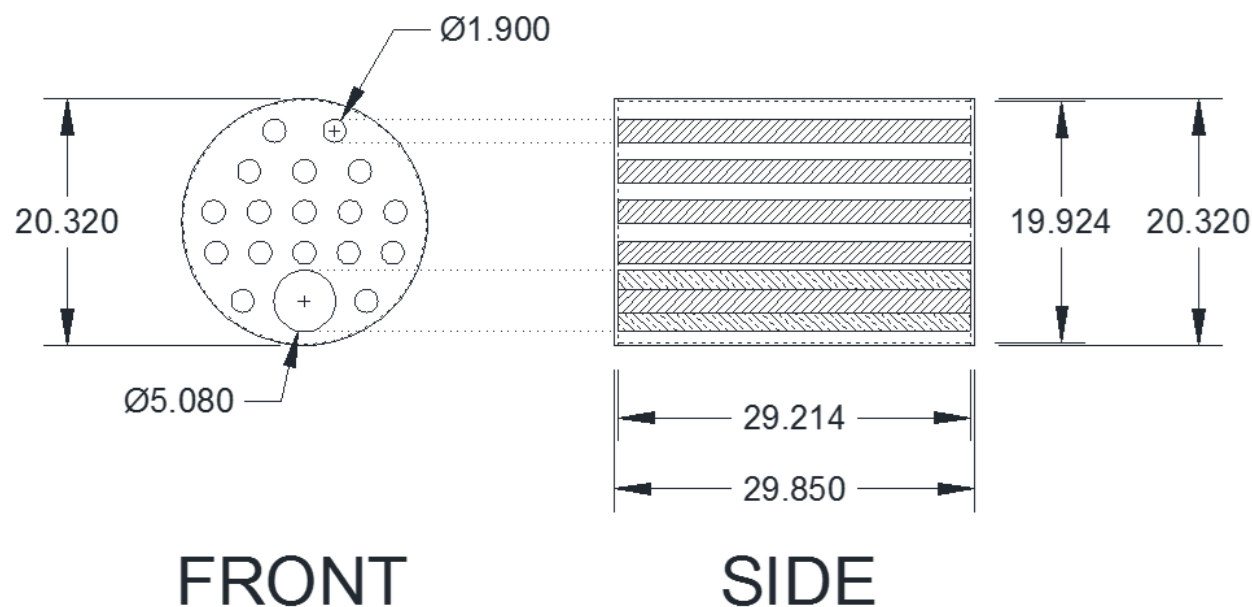
In this experiment, you will evaluate the performance of a steam turbine powered by liquid propane in what is a working miniature version of a power plant. As this experiment is relatively complicated to run, you will need to be very familiar with the operating instructions for the equipment available in the lab. Ultimately, you will need to identify and address inefficiencies in the system and how these would affect full-scale power plants.

Additionally, you will consider the effects of various potential fuel sources for this power cycle.

Pre-Lab Tasks Summary (see [RC Prelab Template FA15.xlsx](#))

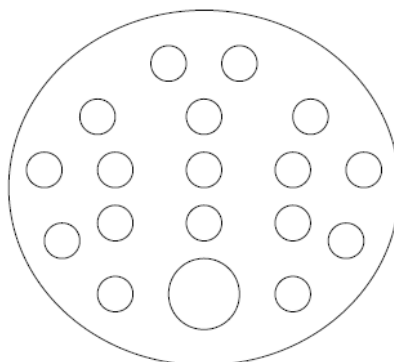
Before performing this experiment, please familiarize yourself with the System Overview as well as the procedures in the operator's manual available in the laboratory.

1. Liquid Propane (LP) is vaporized and used as boiler burner fuel. What is the energy content per unit volume of gaseous LP at STP in MJ/L? Cite source in *Reference* tab where appropriate.
2. If system flow meter measures gaseous LP flow at 6 L/min to boiler burner, what is steady state energy consumption per hour in MJ/hr?
3. The boiler is shell and tube style construction. Calculate the available volume for water in the boiler given the basic construction dimensions.



Main Shell External Length = 29.85 cm
 Main Shell Wall Thickness = 0.198 cm
 End Plate Outside Diameter = 20.32 cm
 End Plate wall thickness = 0.318 cm
 Main Flame Tube Outside Diameter = 5.08 cm
 17 Return Pass Flame Tubes Outside Diameter = 1.90 cm

Locate the water level in the boiler if it is filled with 6000 ml of water. (Sketch location)



Will there be space unoccupied by water? If so, how much volume? Will any of the flame tubes not be covered by water? How many? If so, what is the significance of this?

4. What is the present barometric pressure in your area? Why would barometric pressure be important when planning to operate the Rankine Cycler? What will be your reliable source for accurate barometric pressure readings in the lab?

Post-Lab Tasks Summary (see [RC_Postlab_Template_FA15.xlsx](#))

1. Plot and label the following graphs:
 - Fuel Flow vs. Time
 - Boiler Temperature vs. Time
 - Boiler Pressure vs. Time
 - Turbine Inlet/Outlet Pressure vs. Time
 - Turbine Inlet/Outlet Temperature vs. Time
 - Generator DC Amps Output vs. Time
 - Generator DC Voltage Output vs. Time
 - Turbine RPM vs. Time
2. Mark the steady state start and stop window on each plot.
3. Choose and mark an analysis point at a specific time somewhere within the steady state window. This will be the basis for your steady state, steady flow system performance analysis calculations.
4. From your plots (specific time mark) and data collected from system run, you will need to record the following:

Atmospheric Pressure _____

Initial Boiler Fill Amount _____

Fuel Flow _____

Boiler Pressure _____

Boiler Temperature _____

Turbine Inlet Pressure _____

Turbine Inlet Temperature _____

Turbine Outlet Pressure _____

Turbine Outlet Temperature _____

Steady State Condensate Amount _____

Steady State Boiler Water Use _____

5. Calculate heat flow out of boiler in kJ/s. How does this compare with measured LP gas flow to burner? What assumptions do you need to make to calculate this?
6. Find the Work rate of the Turbine (kJ/s) and Efficiency of Electric Generator
7. What is the total heat flow rate out of the system at the condenser in kJ/s? Again, what assumptions do you have to make?
8. What is the Condenser Efficiency during steady state?
9. What is the electrical power output (kW) versus the fossil-fuel energy input?

NOTE

Procedures for safely operating this equipment can be found below and in section 4 of the Operator's Manual available in the lab. You will be recording most of your data using the data analysis software for later analysis in Excel. **You will additionally need to record the following information during the experiment:**

Steady State Start Time: _____

Steady State Stop Time: _____

Initial Boiler Fill Amount: _____

Amount of Steady State Run Boiler Water Replaced: _____

Amount of Condensate Collected from Condenser: _____

Procedures for Operating the Rankine Cycle Experiment

For the Pre-Lab Report you are required to re-write the procedure by referring to labels on your equipment sketch. For example, 'Turn ON the main power using S1...' where S1 will be the main power switch.

NO EXTERNAL MEMORY DEVICES ARE TO BE USED ON LABORATORY COMPUTERS. ALL DATA FILES MUST BE E-MAILED TO YOUR GROUP.

Safety Considerations

1. Wear safety glasses at all times.
2. No shorts or open-toed shoes.
3. Report any equipment problems or safety issues to the lab supervisor immediately

Additional Equipment Required

1. Two 1000 mL flasks on the bench near the RC experiment
2. Thermal Gloves

Rankine Cycler Operating Steps

1. Inspect your work area. Ensure it is clean and all required ancillary equipment is present.
2. Ensure the switch that activates the snorkel exhaust line is ON
3. Ensure the exhaust line is not covering the entire exhaust chimney on the boiler
4. Ensure that there are two 1000 mL flasks near the condenser outlet tube.
5. Ensure that the pinch-clamp on the condenser outlet tube is OPEN and drains to one of the two flasks provided.
6. Ensure the DAQ software is open on the laptop. If not, inform the TA or the lab supervisor.
7. Turn ON the main power using the master switch
8. Click the play button on each of the three sets of meters—bar graph, analog and digital.
9. Fill the large 6 L graduated cylinder with hot water, place it on the top shelf behind the experiment, and plug the fill line into the back of the boiler
10. Ensure the steam admission valve is OPEN.
11. OPEN the valve on the large graduated cylinder so that the water fills the boiler.
12. After the boiler is filled with water, CLOSE the steam admission valve.
13. Remove fill hose from back of boiler and ensure vent valve is CLOSED.
14. Make sure the propane tank is connected and OPEN the propane tank valve.
15. Turn the gas valve on the control panel counterclockwise to the ON position (3 o'clock position).
16. Turn ON the burner using the burner switch,
17. START the stopwatch
18. Verify the combustion blower is ON and allow operation for 45 seconds.
19. At this point the burner will ignite, but quickly go out.
20. Turn the burner switch OFF then back ON and RESTART the stopwatch.
21. After 45 seconds the burner will ignite.
22. Verify burner is lit. You should hear a popping noise. If it is lit proceed to step 21; if it is not lit return to step 16.
23. Monitor boiler pressure and verify positive pressure within three minutes.

24. Allow the boiler pressure to rise to 110 psig.
25. OPEN and adjust the steam admission valve **SLOWLY** until the boiler pressure lowers to 40 psig then close the valve.
26. Allow boiler pressure to rise to 110 psig.
27. Repeat steps 22 and 23 again until the turbine begins to rotate, allowing the generator to produce electricity and give a reading on the voltmeter. **Monitor the turbine rpm, assuring that it does not exceed 4500. If the rpms approach 4500, CLOSE the steam admission valve quickly. Inform the lab TA or supervisor immediately.**
28. Adjust the steam admission valve and try to maintain 100 ± 1 psig.
29. Turn the load switch ON
30. Adjust the load rheostat to maintain 0.2 amps of current
31. Ensure steady state conditions are established. Use the boiler pressure as the indicator of steady state.
32. When steady state is achieved, swap the 100 mL flask on the condenser outlet line with the second flask. Drain the first flask in the sink.
33. Set the top sight glass bezel to the current liquid level, and simultaneously start recording data by pressing the "Arm Trigger for Disk Recording" button.
34. Start the stopwatch.
35. Monitor the boiler pressure and make **periodic adjustments** to the steam admission valve maintain 100 ± 1 psig.
36. Maintain steady state conditions for 15 minutes or until the water level drops to 1 inch from the bottom of the sight glass.
37. At the end of your steady state period shut off the burner.
NOTE: Steps 36, 37 and 38 should be performed simultaneously
38. Set the lower sight glass bezel to the current liquid level.
39. Stop recording data by clicking the "Arm Trigger for Disk Recording" button.
40. Remove the flask from the condenser outlet line. Measure and record the volume of water. Place an empty flask back under the outlet line.
41. CLOSE the valve on the propane tank.
42. CLOSE the gas valve at the top of the control panel (turn clockwise to the 6 o'clock position).
43. Contact TA or lab supervisor for further shutdown procedures.
44. Allow the system to cool to below 100°C .
45. Fill the large graduated cylinder with hot water to 6 L and plug the fill line into the boiler.
46. OPEN the steam admission valve.
47. OPEN the valve to the 6 L cylinder and fill the boiler. When the liquid level in the boiler comes back to the point where the upper sight glass bezel was set, CLOSE the valve on the 6 L tank.
48. Drain the 6 L cylinder into the sink through the fill line, leaving the water that doesn't drain in the cylinder.
49. Place the 6 L cylinder on the floor, plug the fill line into the back of the boiler, OPEN the valve on the cylinder and drain the boiler to the lower sight glass bezel.
50. Measure and record the volume of water drained from the boiler.
51. Inform the instructor on completion of the experiment for checkout.