University of Victoria
Department of Mechanical Engineering

MECH 390 Laboratory 2

Steam Engine

1. Objective

Since the middle of the 18th century steam engines became the standard device to produce large amounts of power. The invention of reliable steam engines with reasonable efficiencies, most notably through the contributions of J. Watt, triggered the industrial revolution which shaped the world we live in.

The quest for improving the efficiency of steam engines triggered the development of thermodynamics, see the works of Carnot, Clausius and others.

The first steam engines were piston engines, but since the early 20th century the expansion takes place in steam turbines. About 75% of the electricity produced world-wide relies on steam cycles (this includes nuclear power plants, and geothermal energy conversion), and this will not change in the foreseeable future. The average thermal efficiency of the worlds steam power plants is 33% (36% in North America), while efficiencies of 45% are possible with advanced cycles. Combined cycles which consist of gas turbine cycles on top of steam engines – the gas turbine exhaust provides the heat for the steam generator – can reach close to 60%. Details on the operation of steam cycles can be found in your thermodynamics textbook, and will not be repeated here.

The goal of this laboratory is to observe an actual (model) steam power plant in operation, and evaluate measured data on the performance, to compute work, mass flows, isentropic turbine efficiency etc.

www-links on the history of steam engines:
http://inventors.about.com/library/inventors/blsteamengine.htm
http://en.wikipedia.org/wiki/Steam_engine
BBC steam engine animations:
http://www.bbc.co.uk/history/games/beam/game_window.html
http://www.bbc.co.uk/history/games/rocket/game_window.html

2. The *Rankine Cycler*

Figures 1 shows the steam engine set-up used, the *Rankine Cycler* from *Turbine Technologies* (Chetek, WI). Figs. 2 and 3 show details and Fig. 4 gives a schematic of the set-up.

Basically, the Rankine cycler is an open cycle, were the steam is generated in the boiler by evaporating, and superheating, of water. The steam passes through a valve where it is throttled to lower pressure and then enters the turbine where it is expanded. The turbine drives the generator; the generator load can be controlled. After expansion in the turbine, the steam is exhausted into the “cooling tower”, where part of the steam condenses. Note that a condenser is not employed, and that fresh water must be filled into the boiler after a while (no continuous operation).

Pressure and temperature measurements are taken at the boiler outlet, before the turbine, and after the turbine. This allows to find important thermodynamic quantities, in particular enthalpies and entropies, which are important for the evaluation of the turbine performance.

Fig. 1: Photograph of Turbine Technologies' *Rankine Cycler*.

Fig. 2: Close up of steam valve (the red wheel), turbine (in steel casing), and generator (black). In the background the boiler with its blower (right), and the condensation "tower" (left).

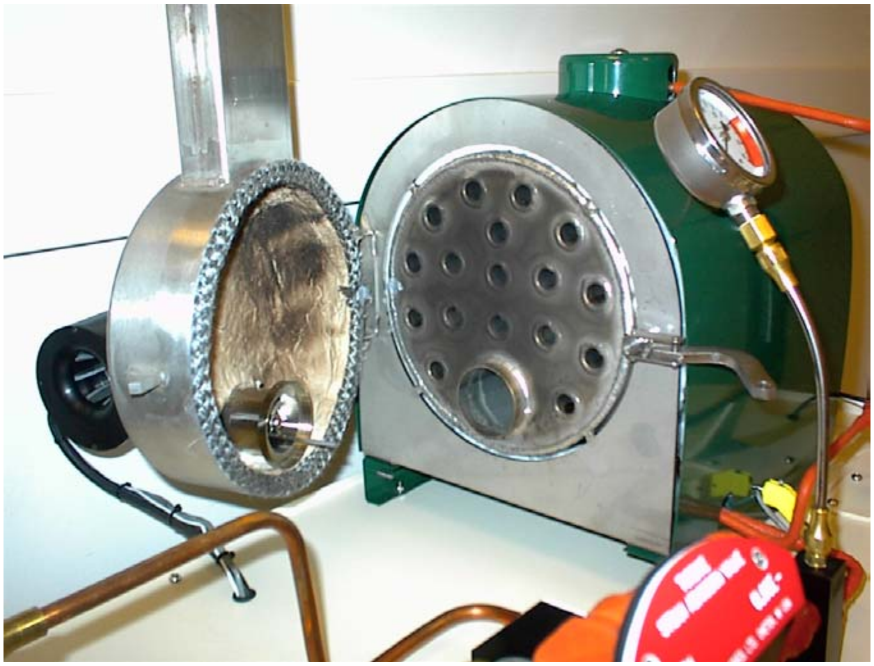

Fig. 3: The boiler (open). The flame burns in the large pipe, and the hot combustion gas returns through the smaller pipes to the exhaust chimney. The burner is mounted in the door. The lower part of the boiler contains liquid, the upper part contains steam. At least the upper five pipes are surrounded by steam, which can be superheated.

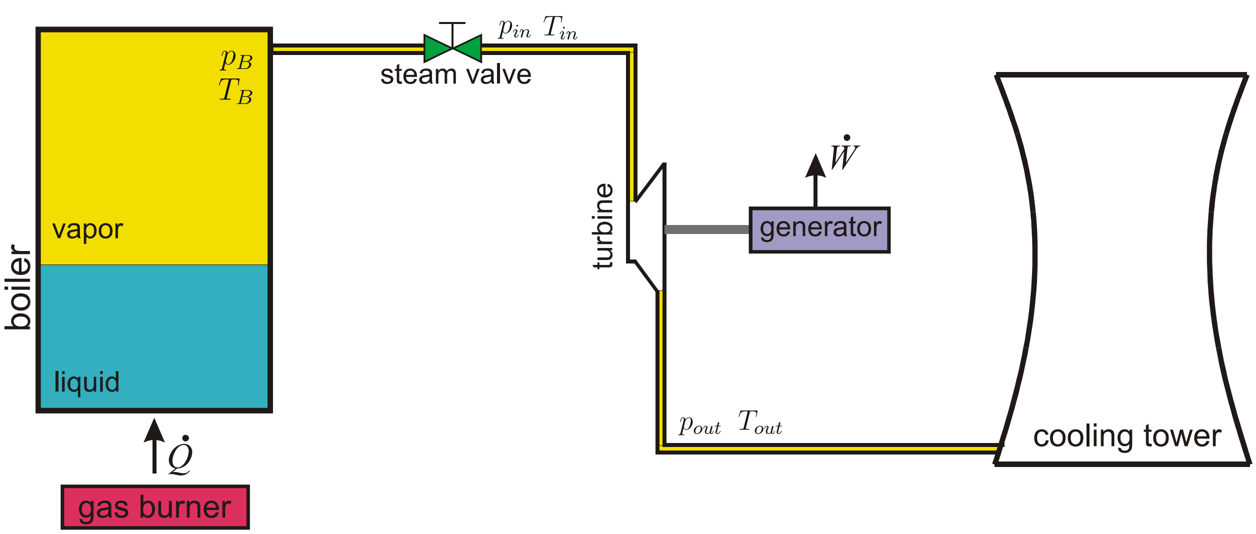

Fig. 4: **S**imple schematic for the *Rankine Cycler*. The indicated pressures and temperatures are recorded during the experiment; the generator power can be computed from the measured current I and voltage V as $\dot{W} = VI$. Additionally, the volume flow of the propane gas is measured.

3. Using the *Rankine Cycler*

Operator 1: Turn on the computer and open the DigiDAQ software. Collect Data.

Operator 2: With stopwatch in hand, note down the events and time

Operator 3: Prepare the *Cycler*:

Preparation of the *Cycler*:

1. Make sure the Fire Extinguisher, key to *Rankine Cycler* are near-by, and 6 liters of distilled water is available (source: Biology Building).
2. Steam Admission Valve turned to OPEN.
3. Drain boiler by inserting the metal ended hose at the back of the boiler.
4. Fill boiler with water (6 liters). Water visible in the sight glass.
5. Disconnect fill tube from the back of the boiler.
6. Clean excess oil around the turbine. Unscrew oiler caps and add oil to front and rear turbine bearings to within 3mm of the top of the oiler.
7. Steam Admission Valve turned to CLOSED.
8. Goggles ON.
9. Turn Gas valve to ON, on the propane gas canister.
10. Turn Gas valve to ON, on the Rankine Cycler.
11. Listen for suspicious hissing noise and smell for propane gas. If none then next step.
12. Keyed Master Switch to ON
13. Burner switch to ON
14. LOAD rheostat fully counterclockwise, LOAD is OFF
15. Wait 45 seconds till you hear the flames
16. Watch the Pressure dial – it will reach 120 psig after about 7 minutes.
17. Turn Steam Admission Valve to OPEN slowly till pressure = 40 psig.
18. Turn Steam Admission Valve to CLOSE and wait for pressure to reach 120 psig.
19. Turn Steam Admission Valve to OPEN slowly till pressure = 40 psig.
20. Turn Steam Admission Valve to CLOSE and wait for pressure to reach 120 psig.
21. Very slowly open the Steam Admission Valve to about 118 psig – the generator should be spinning and voltage out should be 15 volts or more.
22. Turn on LOAD switch and set load to about 300mA at 6 volts while maintaining a steam pressure of about 118 psig with by manipulating the Steam Admission Valve.
23. Do not use the Cycler past the half way water level in the sight glass.
24. When finished, turn BURNER to OFF, let it cool off for three minutes, then gently open the Steam Admission Valve.

If you smell propane gas, turn of burner and the two gas valves immediately.
Do not touch the boiler or the turbine while its running – it is very hot.

4. Experiment and Evaluation

Vary generator load, and steam flow, while keeping boiler pressure high enough (p_B = 95psig or higher, but not more than 130psig; follow the TA's advice). After changing conditions, you should wait a bit, so that a steady state can evolve. For the evaluation, chose states that refer to steady state, chose at least 4 different states, and evaluate the measurements as follows:

- Determine enthalpy and entropy at all points where measurements are taken.
- Draw a qualitative *T-s-diagram* and indicate the principal points with respect to saturation lines and critical point.[1]
- Compute the specific work and the isentropic efficiency of the turbine.
- Determine the mass flow of steam.
- Determine the mass flow of propane (C_3H_8) under the assumption that gaseous propane obeys the ideal gas law, and compute the heat added to the system (heating value LHV_{C3H8} = 46332 kJ/kgK, molecular mass: M_{C3H8} = 44 kg/kmol).
- Discuss the steam valve, by means of the first and second law. Is it adiabatic?
- Consider an isentropic turbine expanding the fresh boiler steam (at p_B, T_B) to atmospheric pressure. Compare to the actual turbine and discuss.
- Discuss the performance of the system altogether.
- How does performance of turbine and system change with load, boiler pressure?
- What could be done to improve performance.

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[1] Unless the conditions changed drastically, one diagram is enough.