MEEG346 Thermal Laboratory

Laboratory Problem X3 – Campus Power Plant Operations - Boilers

Objectives

To observe and measure the heat transfer processes in large industrial equipment.

<u>Design Objective</u>: (1) Calculate the over efficiency of the boiler by comparing the energy content of the fuel being supplied to the net change in energy (change in enthalpy) of the water to steam process.

(2) To estimate the effectiveness of the Economizer (a crossflow heat exchanger that preheats boiler feed water with hot combustion exhaust gases).

(3) Observe the steam energy supplied to Spencer Lab

This is not a theoretical exercise. Plant engineering is seriously interested in your calculations and results. Pay attention. Ask questions.

Theoretical Background

The University of Delaware Central Boiler is located a short walk south of Spencer Laboratories. This facility has six steam It supplies steam for heating and hot water to all buildings on the Central Campus.

There is a new Chilled Water Facility behind the ISE. We will visit for X6.

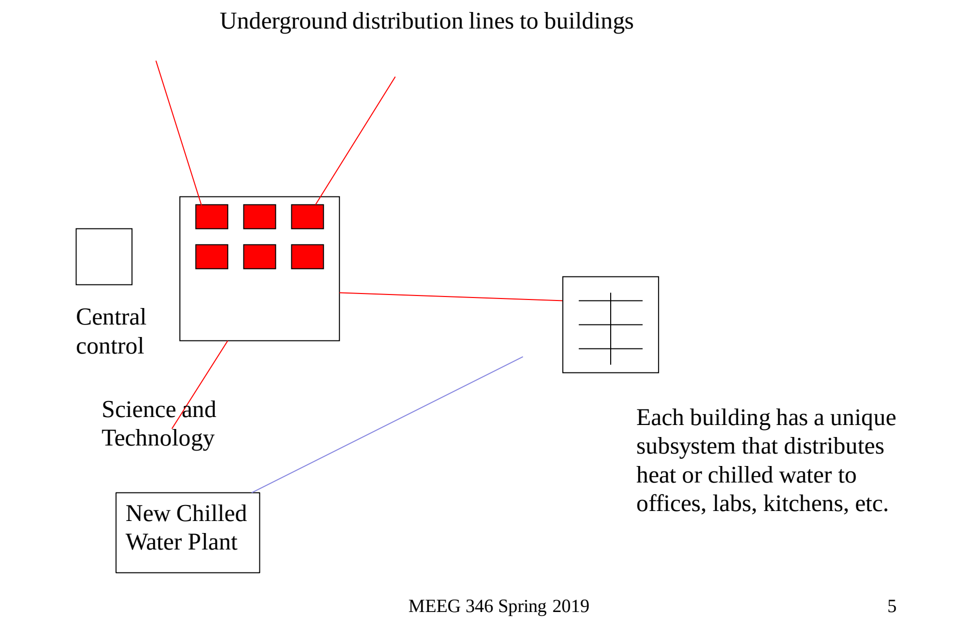

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Figure 1 – Diagram of campus heating and cooling systems

The steam boilers provide steam to the buildings for heating, hot water, and other services. The boilers are fueled by either oil or natural gas, and can be switched to use one or the other depending on supply and pricing. Normally, it is natural gas. There are many types of boilers. Most are basically <u>shell and tube heat exchangers</u>, where on one side are the products of fuel combustion and on the other side water being boiled into steam. Two fundamental designations are fire tube and water tube. This distinction simply specifies whether the combustion products are on the tube side or the shell side. The plant has examples of both types. We will look at whichever one is online at the time, most likely a water tube type.

At each campus building there are equipment rooms where the steam and chill water supplies are distributed. The mechanical systems for doing this are many and varied, but in the end water at a temperature required is delivered to terminal units in rooms and offices, to air handlers supplying warm air to lecture rooms, labs, and halls, to kitchens for cooking and dishwashers, and to showers in the dorms for bathing. We will look at Spencer Lab's system.

These are large systems, but very common. Any large building, from a high school to a New York skyscraper, will have equipment like this somewhere, usually in a basement, but also on rooftops or separate buildings. Mechanical engineering – fluids, heat transfer, control theory, materials, piping, and support structure – is involved throughout the systems!

Procedure

Part 1 – Campus Power House

Each team must assemble in SPL 123 lab at the usual time. You will pick up safety glasses. Ear plugs are not required in the boiler area, but are available if you wish. **Wear shoes with enclosed toes and heels. Flip-flops or equivalent may not be worn.** Complete signup for the lab team tasks. Two people should record data to be sure accuracy. Consider photographing rather sketching the equipment.

The Power Plant is an active operation, responding to weather conditions and other situations. The procedure below may be modified as a result, and you will be briefed on any changes before walking over to the plant.

At one point we will probably ascend a steep steel stair to the top of the boiler for a better view. If you have a condition such that you would rather not go up, simply tell the professor accompanying you. You can be provided the information separately.

The boiler data sheet will help you relate actual parts to the schematic.

1. At the plant we will be given a brief overview and orientation. It is big, and at first glance is a maze of piping. We do not have the time to tour the whole building. We will look more closely at one of the boilers and the control room.

2. The goal is to make calculations related to the amount of energy being supplied to the campus by this boiler on this particular day at this particular time.

    - Record on your data sheet the date, time of day, weather conditions (sun, rain, cloudy, etc.) and ambient temperature.

3. A boiler's parts are typically hard to see because of heavy insulation. I will point out the key parts, such as the economizer, feed water inlet and the steam outlets. Also, locations where instruments (e.g., pressure & temperature) will be pointed out. Note them on your schematic.

4. In the control room, we will see real time operating data on the specific boiler. In addition we may be shown the information that is monitored campus wide on building heating, chillers, and HVAC systems. There are displays of current data, constantly updated, and also pen and analog recorders of various parameters.

    Questions that you might ask the Operator are: How many boilers online today? During winter are there times when all on line, or is there standby capacity? Does this plant supply the new five story building across the street? Is there backup electrical generation for the power house in case of utility power failure? How much does the natural gas fuel cost? How much does oil cost?

Part 2 – Spencer Lab Terminal Heating System.

Returning from the Power House, we will go to the basement of Spencer Lab and in to its mechanical room. It is much smaller, and a maze of pipes- many of them are related to the chill water (air conditioning), or are abandoned. We will focus just on the steam/hot water components that are supplying heat to rooms and offices. Each office has a "terminal unit", which is simply a water to air heat exchanger.

We will take data to calculate the total energy being delivered to offices and rooms, and also the steam consumption at that moment.

1. Relate the schematic provided to the actual piping that you see.
2. We are using existing instrumentation, which is all analog. Note the dial scale: How "readable" is it? To the nearest degree? Half degree? Nearest psi? Half psi?
3. Take the readings required by the data sheet. Note that the system is under a thermostat control, and readings may vary some while you watch. This introduces "uncertainty."

Data Analysis

Part 1 – Power House

1. From your data, calculate the enthalpies of entering water stream (called feed water), and track its change in enthalpy as it goes through the boiler. What is the net change?

2. Calculate the boiler efficiency. For gas the plant currently assumes 1050 Btu/SCF for fuel, but that can vary (=uncertainty). (SCF=standard cubic foot). The fuel flow rate multiplied by this energy content is the energy input. The change in enthalpy from liquid water to saturated steam multiplied by the steam flow rate is the product. A simple measure of efficiency is the ratio of steam production energy to fuel supplied. (We will not calculate combustion efficiency of the fuel).

   A key parameter for thermodynamic analysis of steam cycle systems is the quality, x, of the steam. The Power Plant has no instrument for measuring exit steam quality. Assume values of 95%, and 100% (saturated steam). This will give you two values of efficiency that probably bracket the actual situation.

3. The economizer increases the efficiency by preheating the feed water with hot gas products of combustion. You measured the delta T of both the water side and the gas side, and know the water side flow. From this information we can calculate an effectiveness of the heat exchanger.

Recall this equation from lab X-2, relating energy content of the hot side of a heat exchanger to the cold side.

$$Q = m_h\, c_{ph}\, (T_{h,i} - T_{h,o}) = m_c\, c_{pc}\, (T_{c,o} - T_{c,i}) \qquad (1)$$

The combined term $m*c_p$ is called the Heat Capacity Rate C. Here, the cold side is the feedwater side, and the hot side has the hot products of combustion. We do not know what the hot side mass flow is nor its c_p. However, we know all the temperatures, and can calculate Q from the water side data. From that we can solve for the heat rate capacity of the gas side: $C_h = Q/(T_{h,i} - T_{h,o})$. Compare C_h to C_c. Call the smaller of the two C_{min}. From Second Law considerations, the best heat exchange rate this heat exchanger can ever do is

$$Q_{max} = C_{min} *(T_{h,in} - T_{c,in})$$

The effectiveness is given by $\varepsilon = Q/Q_{max}$. This quantity should be $0< \varepsilon<1$.

Part 2 – Spencer Lab heating

Steam is provided to Spencer Lab via underground insulated piping, as are other buildings. There is limited instrumentation in the SPL Mechanical Room, compared to what we saw in the boiler plant control room. We can make some estimate of the consumption. Record from the digital meter the total steam being delivered at the moment. Some part of the total is condensed in a U-tube heat exchanger, heating water that is circulated around the building for comfort heating and other purposes. Measure this amount based on the circulation pump capacity (180 gpm) and water ΔT's. The balance is used to heat outside intake air for labs and meeting rooms.

Results and Conclusions

This is the best place to exhibit and discuss the calculations that you make using your data. The Power House personnel are seriously interested in your results and conclusions. Be sure to comment on assumptions that you made, or data that you needed but did not have, and make a concluding statement about your faith in the answers provided.

Be sure to comment on the change of state in the steam from power house to Spencer. Where did the energy go? From this discussion, extract very short statements, perhaps even in a table, to place at the beginning of the report as a Summary (always write the Summary last, after know what to summarize).

Uncertainty Analysis

Consider the boiler efficiency calculation, and the factors that went into it. You should have noted fluctuations in the control instrument readings in the short period you were there. These are, in part, your "delta". Also consider your ability to read a steam table or

P-h diagram to get enthalpy values. Put these together into a calculation that gives a band of uncertainty around the Boiler operating point you observed. You choose the statistical analysis method and give a reason for your choice.

On Canvas in Lab X3 Instructions:

Power Plant Data Sheet