**NORTHEASTERN UNIVERSITY**
Department of Mechanical, Industrial and Manufacturing Engineering
THERMODYNAMICS
EXPERIMENT 1 - " STEAM BOARD"

**LOCATION**: Basement of Richards Hall.

## OBJECTIVE

The overall objective of this experiment is to obtain familiarity with the properties of steam, especially the quality of steam, x. The electrical power consumption of the steam boiler is to be determined for various steam mass flow rates. This lab will also.

- Review steam data and energy balance analysis.
- Illustrate techniques for measuring steam quality, x , using a throttling calorimeter. Please review the subject of throttling calorimetry in your thermodynamics book.

## EXPERIMENTAL PROCEDURE

It is suggested that the student become familiar with the equipment in this experiment before the laboratory period. Refer to the schematic attached to the equipment for description of all valves, pressure and temperature measurement points. It is suggested that the student prepare a data collection sheet and review all the necessary calculations prior to performing the laboratory. Bring a copy of your steam tables to the lab.
The following steps should be followed in order to measure the parameters needed to calculate the power consumption of the electric boilers.

1. Startup of the Steam Boilers

- On boiler: Turn the thermostat to OFF position. Open valves V2, V3, V4, and V10. Close valves V5, V6, V8, V13 and V14.

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[1] Care should be exercised when performing this experiment since all surfaces of the piping system will be hot and any steam discharges will be at a high temperature. It is strongly advised that one should wear safety glasses, use gloves when making any adjustments to the system and in general stay at a safe distance from the equipment when the experiment is being conducted.

- Fill the feedwater tank until the 15 inch mark on the height indicator on the exterior of the tank. Place the steam discharge hose in a bucket of water.
- Turn main power switch to ON position (this will start pump & the cooling system).
- Check and record ambient temperatures and pressures in the system. Bring any errant readings to the attention of the TA. Record the barometric pressure. Check the boiler water level. The water level should be midway on the sight glass on the side of the boiler.
- Set the pressure $p_{pump}$ to approximately 100 psi.
- Set thermostat of the boiler to 300 F.
- Now the system is in operation and will take several minutes to reach equilibrium.

While the system is warming up, watch the pressure and temperature at the boiler exit (P1 and T1) and at the orifice inlet (P3, T3). When these measurements do not change over a five minute interval, the boiler is in equilibrium. When equilibrium is reached, record the following parameters: temperatures T1, T2, T8, and $T_{water}$, pressure P1 (from the bourdon gauge) as well as P7 - P8 from the Pressure Transducer. So approximately one minute before taking the readings, open valves V13 and V14 briefly to drain the water from the lines.

Slowly close valve V10 to increase the boiler pressure (P1) to approximately 430 kPa (as measured by the bourdon gage at location one). You will notice a change in the noise of the steam discharge into the bucket when the valve starts to throttle the flow. Several turns of the valve are required before it starts to throttle the steam flow rate. After reaching this point the steam flow is very sensitive to the valve position. Use the orifice inlet manometer to help you adjust the valve V10. Upon reaching equilibrium record your measurement and check the conditions at the boiler exit. Is the steam superheated or saturated? Repeat these tests at 100 kPa intervals, starting at 400 kPa until the boiler cutoff switch turns the boiler off (approximately 430, 400, 300, 200 and 100 kPa). Always remember to wait for equilibrium and to bleed the water from the pressure lines to the manometers.

At each pressure setting, after completing your data taking for the flow through the orifice, open valve V6 and close valves V8 and V10 to direct the flow of steam to the **Throttling Calorimeter**. Carefully open the upper valve of calorimeter (turn handle counterclockwise approximately by a quarter turn) while maintaining the pressure P1 at the same valve as in the previous set of data (approximately 100, 200, 300, 400 and 500 kPa). Take readings of P1, T1 and of the Throttling

Calorimeters Temperature. Take the temperature T9 and assume normal atmospheric pressure at the exit of the throttling calorimeter. The steam quality from the boiler is determined from the above measurements by analyzing the throttling calorimeter as a constant enthalpy process with a negligible kinetic energy change. Compare these calculations on the quality of steam with those using the orifice under similar conditions.

Periodically, the water in the bucket will become hot and start to steam. At this point you need to change the water in the bucket (about every half hour). Carefully move the discharge hose into a separate container while you change the water in the bucket. Be sure to wear gloves when you move the hose. When moving the hose examine the steam leaving the hose carefully. What do you see? Since steam is invisible, how do you account for what you see?

2. Shutting off The System

The following steps will be performed by the staff present.

- Let the throttling calorimeter valve be open to vent of steam.
- Turn the main power switch to OFF.
- Turn thermostat of the boiler to OFF.
- Close valve V10 and remove the hose from the feedwater tank. This will prevent siphoning of the feedwater from the tank. Move the bucket over to the boiler drain and insert the boiler drain hose in the bucket.
- When the boiler pressure is reduced to about 200 kPa, turn the main power switch off and unplug the unit from the wall outlet.
- Slowly open the boiler drain valve (V5) to drain the boiler and blow off the excess steam. Be careful that the steam does not burn you or the hot water splash on you.
- After the boiler is drained, close the boiler drain valve (V5) and the trottling calorimeter valve (V6).

**ANALYSIS**

1. Dose the quality measured with the throttling calorimeter depend on the adjustment of the inlet valve to this device (i.e. what happens if we open the valve more?)? Explain your answer with proper reasoning.

2. The mass flow rate through the orifice can be described by the equation:

$m_f = K A [2\rho_3 \Delta P]^{1/2}$

where

$m_f$ = Mass Flow Rate

K = Calibration Constant =0.6 (unitless)

A = Throat area of the orifice, given that throat diameter is 0.25 inch.

$\rho_3$ = steam density upstream of the orifice.

$\Delta P$ = Pressure loss across the orifice

In these calculations use a consistent set of units.

Using the measured pressures upstream and downstream of the orifice calculate the mass flow rate of steam for the different settings used in the experiment. Calculate the enthalpy of steam at location one for each of your data points. Compare with the valves obtained by using the commercial steam calorimeter. Is the steam saturated or superheated? How do you know? Plot the pressure and temperature of the steam at location one in a P-T as well as in a P-v diagram.

3. Using an overall energy balance on the boiler and the measurements taken in this experiment estimate the amount of electrical power consumption to operate the boiler. Include in your calculation the estimated uncertainty of the power consumption. It is known that the boiler is heavily insulated and can be treated as adiabatic.