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Me304
Lab 1

Objective

There were four goals for this lab: to measure the temperature-pressure saturation curve of water with and without air trapped in the boiler; to determine the amount of heat lost from a boiler to the surroundings when operated as a steady-state closed system; to determine the amount of heat lost from a boiler when operated as a steady-state open system; and to verify the first law of thermodynamics by comparing heat lost from an open versus closed system.

Theory

The first law of thermodynamics, in words, tells us that the change in energy in a system over some time interval is equal to (net amount of energy transferred into the system by heat transfer) – (net amount of energy transferred out of the system as work.)
In symbols,

$$\Delta E = Q - W$$

The implication of this law is that by measuring or calculating two of these quantities – energy, work, or heat transfer – we can calculate the third, and from there we can calculate many other quantities which may be of interest. This energy balance can be applied to an open or closed system.

The properties of a system – pressure, volume, and temperature, as examples – are not all independent of one another. The state principle tells us that by fixing two, or in some cases one, of these properties for a simple compressible system we have automatically fixed the others. The intensive states of systems are of particular importance for engineering applications, especially for commonly encountered substances such as steam. Tabulated data on the state principle behavior of such systems is widely used to predict the behavior of common substances without having to perform additional experiments.

However, before tabulated data or equations can be used in the design or analysis of a real world system it must be verified that the predictions of the table or the equation are supported empirically. To that end, in the present study we compare the predictions of a steam saturation table and of the first law of thermodynamics with the results of actually heating steam in a laboratory setting. Further, to examine the effect of impurities in the system, we also compare the accuracy of the predictions with and without the presence of an incompressible gas (air) inside the boiler.

Methods

A TE5 boiler system was assembled according to manufacturer's directions and was filled with water to the maximum safe level indicated by the manufacturer.

For the closed system tests with air:
The boiler was heated to the desired temperature using both heaters. The boiler was then maintained at the desired temperature (±0.4°C) for five minutes by cycling one heater on and off to establish a steady state. The boiler was then kept at the same temperature in the same manner for a ten-minute measurement period. Heater-on time, voltage, current, and boiler pressure were noted.

For the closed system tests without air, the above procedure was repeated except that air trapped in the boiler was first released by opening the boiler stop valve until steam was observed to exit from the valve, indicating that all of the air had been purged.

For the open system tests, a graduated cylinder was placed at the end of the condensate line such that the condensate line formed a u-trap to prevent steam from escaping as steam. A drip guard was used to prevent loss of sample. Cooling water was used to encourage condensing. With one heater on at a constant level and the throttling calorimeter open, the boiler was kept at the desired temperature for five minutes to establish a steady state by adjusting the boiler stop valve. The boiler was then kept at the same temperature in the same manner for a ten-minute measurement period. The graduated cylinder was emptied immediately prior to the measurement period. Input voltage and current, boiling pressure, and volume of condensate were recorded.

Analysis/Discussion

For the closed system tests with and without air in the boiler, boiler pressure versus temperature are shown in table 1, below.

Table 1: Boiler pressure versus temperature for closed system tests.(Monday data in bold)

	T (°C)	P_{gage} (psi)	P (psi)
Closed, with air			
	110.0	**22.2**	**36.9**
	110.0	24.0	38.7
	110.0	13.5	28.2
Closed, no air			
	110.0	**7.8**	**22.5**
	110.0	8.0	22.7
	110.0	7.8	22.5
	120.0	**16.5**	**31.2**
	130.0	26.5	41.2
	140.0	40.5	55.2

These results are plotted alongside the temperature-pressure behavior predicted by a steam table in figure 1, attached. The steam table data are listed below.

Table 1a: Steam table data used in figure 1

Steam Sat Table Data	T (°C)	P (bar)	P (psi)
	110	1.433	20.7785
	120	1.985	28.7825
	130	2.701	39.1645
	140	3.613	52.3885

Fugitive heat loss was calculated using the following formula:

$$Q_{out,\ closed} = Q_{in} = E_{rms} I_{rms} \Delta t$$

Where Q is heat transferred, E is voltage to the heater, I is current to the heater, and Δt is heater-on time. The above follows directly from the first law of thermodynamics (see theory section) for a closed system. No work is done on or by the system, so the only heat that can flow out of the system for a steady-state situation is the heat that flows in. The average rate of heat transfer was calculated by dividing the total heat transferred by the total time, 600 seconds. These calculations are summarized in table 2, below.

Table 2: Heat transfer and heat transfer rate for closed systems (Monday data in bold)

	T (°C)	V (V)	I (A)	t (sec)	$Q_{out,\ closed}$ (kJ)	$Q_{out,\ closed}$ rate (kJ/s)
Closed, with air						
	110.0	**210.8**	**10.5**	**211.0**	**467.0**	**0.8**
	110.0	206.7	10.2	150.0	316.3	0.5
	110.0	205.6	10.3	183.5	388.6	0.6
Closed, no air						
	110.0	**208.5**	**10.3**	**181.9**	**390.6**	**0.7**
	110.0	205.8	10.3	183.0	388.0	0.6
	110.0	208.0	10.3	90.2	193.2	0.3
	120.0	**207.7**	**10.3**	**164.4**	**351.7**	**0.6**
	130.0	207.3	10.2	147.7	312.3	0.5
	140.0	206.3	10.2	205.3	432.0	0.7

For the open system tests, again starting from the first law of thermodynamics,

$$Q_{out,\ open} = Q_{in} - \Delta m(h_g - u_f)$$

Here, Q_{in} is calculated as for the closed system tests but the heat transfer out of the system is no longer equal to the heat transfer into the system at a steady state because mass has been allowed to transfer out of the system. In the above equation Δm is mass, h_g is the specific enthalpy of saturated water vapor, and u_f is the specific internal energy of saturated liquid water at the given temperature. The mass of water that leaves is multiplied by the difference in its internal energy when it leaves the system as steam and when it was liquid water before it was heated. The rate of heat transfer is calculated the same as for closed systems.

Heat transfer rate versus temperature for open and closed systems are plotted in figure 2, attached.

Questions

1) The experimental results follow the same general trend predicted by the saturation table, but the variability is high.

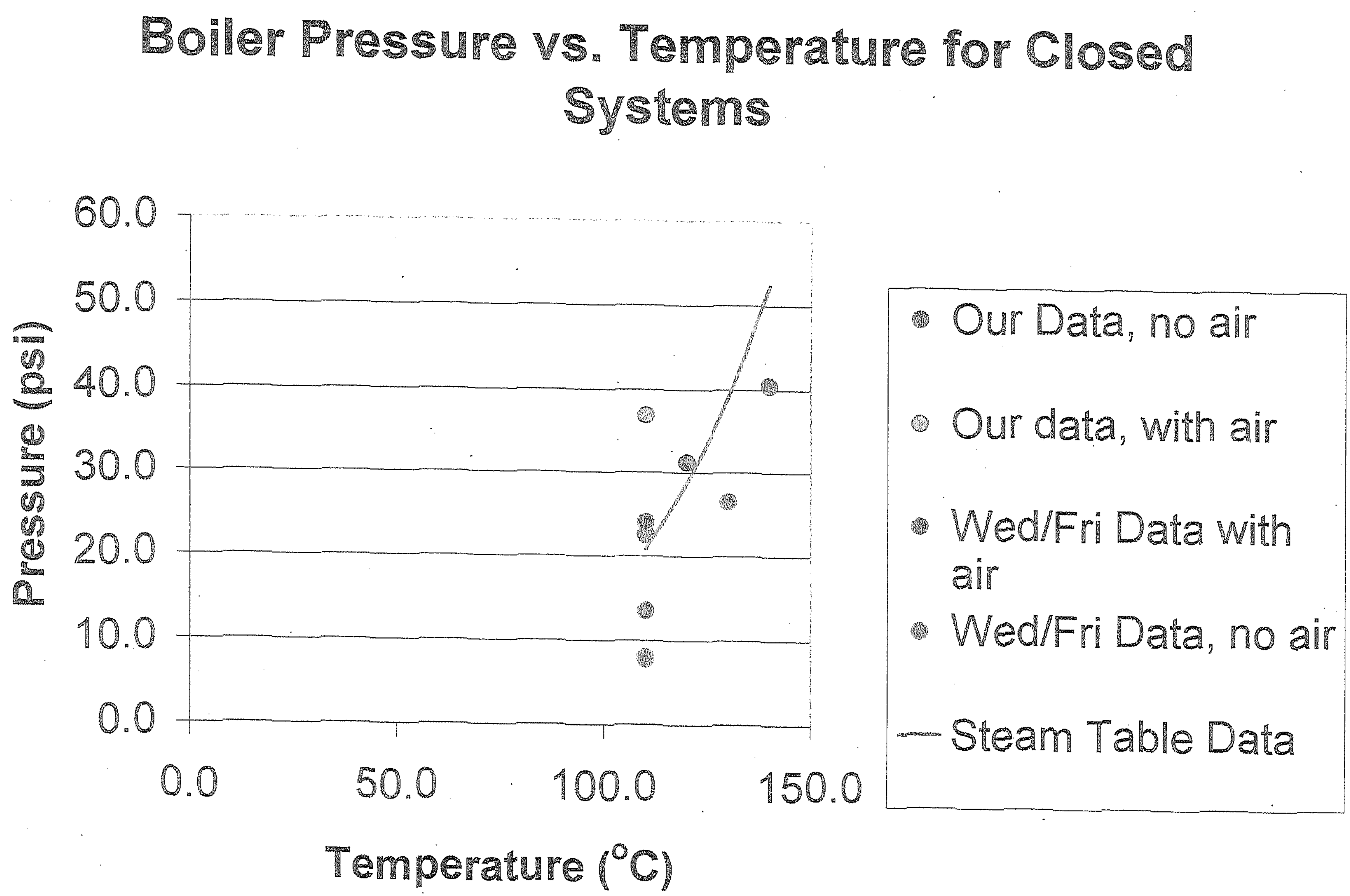
2) The experimental results for saturation pressure and temperature indicate that a large amount of uncertainty must be anticipated when using table data for real life applications.
3) The samples with air trapped in the boiler show even more variability than those without air. This indicates that it is imperative to remove any non-condensable gasses from the boiler when using boilers, condensers and other heat transfer equipment.
4) Fugitive heat loss should increase as a function of temperature by conduction according to Fourier's law and by convection according to Newton's law of cooling, because both give heat transfer as being proportional to the difference in temperature between two things (in this case, the boiler and the air in the room.) This trend is fairly difficult to discern from this study's data, however, due to a high degree of noise.
5) By removing the u_f term from the equation for $Q_{out,open}$, and using excel to calculate, we see the following:

T (°C)	$Q_{out, open}$ (kJ)	$Q_{out, open}$ no uf (kJ/)	$Q_{out, closed}$ (kJ)
120.0	**333.2**	**115.7**	**351.7**
130.0	**264.1**	**11.8**	**312.3**
140.0	**503.1**	**213.5**	**432.0**

The results are closer for $Q_{out, open}$ and $Q_{out, closed}$ when the uf term is included in the calculation. This is evidence that the first law of thermodynamics is valid. V

Conclusion

The experimental results do follow the general trends predicted by the steam tables, but there is a high degree of variability. This variability is more pronounced for the trials with air in the boiler, indicating that if steam table data are to be used the boiler must be purged of air. Similarly, the predictions of the first law of thermodynamics are generally followed but with large variations. These results indicate that the steam table data and the first law of thermodynamics may be used, but a high degree of variability should be anticipated when applying these predictions to real world situations. V



Boiler Pressure vs. Temperature for Closed Systems
Pressure (psi)
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.0
50.0
100.0
150.0
Temperature (°C)
Our Data, no air
Our data, with air
Wed/Fri Data with air
Wed/Fri Data, no air
Steam Table Data

Mary G. Rhoads U36163858 10/10

ME 304 Prelab questions
lab 1

1) What is the purpose of the u-trap in the condensate line?

↳ to prevent steam from escaping as steam (ie, without condensing.) ✓

2) What are Q and $\dot{Q}$ calculated in section 5, step 2?

$Q_{out,closed}$ is the amount of heat energy transferred from the heater to the boiler during the 10-minute sample period. ✓

$\dot{Q}_{out,closed}$ is the rate of heat energy transfer.

$$\dot{Q} = \frac{Q}{\Delta t} = \frac{Q}{600_s}$$ in this case.

3) Rewrite formulae for Q_{out}, Q_{open} in 5, step 3 for the case

saturated liquid H_2O at temp of water in the boiler enters through an inlet pipe at same rate as steam leaves. (constant net mass)

formula is $Q_{out,open} = Q_{in} - \Delta m(h_g - u_f)$
for $\Delta m = 0$, $Q_{out,open} = Q_{in}$ ✓

and $\dot{Q}_{out,open} = \frac{Q_{out}}{600_s} = \frac{Q_{in}}{600s}$