CHE260 PRA0101
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Exploring Applications of the First Law of Thermodynamics

Abstract

The purpose of this report is to explore the applications of the First Law of Thermodynamics. In the experiments, we heat pressurized air to a certain temperature and maintain the temperature using heaters. The first law would be applied by calculating the heat added to the air in the tank and the heat lost to the surroundings. The impact of the work done by the fans which provide air circulation for this process is also explored in terms of the first law. The results of these experiments show that the first law of thermodynamics is an accurate theory proven throughout experimental data at a macro scale and hence further proves that energy is conserved.

Introduction

The first law of thermodynamics states that according to the conservation of energy, the sum of the heat transfer and work done on a system is equal to the change in internal energy of a gas: $Q + W = \Delta U$ (1). Through this formula, we want to show that the amount of heat lost to the surroundings and the work done on the system can be found through this governing equation. For part 1, the mass of the left tank will be determined by manipulating the ideal gas law using the formula to help us in further sections of the report:

$$m_{left\ tank} = m_{added\ to\ tank}[1 + \frac{1}{(\frac{P_2T_1}{P_1T_2}) - 1}] \qquad (2)$$

In part 2, the PID controlled heaters are used to heat the tank until a specific temperature. Once the tank reaches the desired temperature, the PID controller sends pulses of heat into the tank in order to maintain temperature. We determine the heat loss in the left tank using:

$$Q_{total\ added} = 2P_{heater}\Sigma t_{on} \quad (3)$$

As well as the Volume Specific Heat Capacity using:

$$Q = mc_v\Delta T \rightarrow c_v = \frac{Qm}{\Delta T} \quad (4)$$

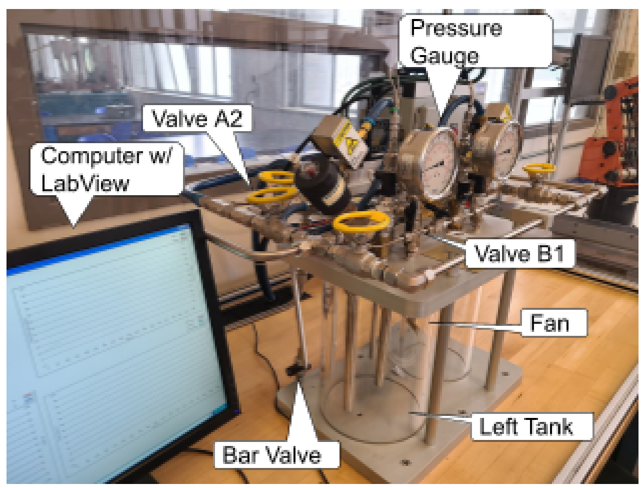
In part 3, the work done by the propeller in the tank is determined through the work done by the propeller being equal to the change in internal energy for an adiabatic system. The work done is determined by using the equation for the fan blade performance using pump and fan similarity equations through:

$$\frac{P_2}{P_1} = \frac{\rho_2}{\rho_1}\left(\frac{n_2}{n_1}\right)^3\left(\frac{D_2}{D_1}\right)^5 \quad (5)$$

Experimental Method

Materials

- Safety Goggles
- Manometer
- Experiment Apparatus - Figure 01
- LabVIEW Software



(Figure 01, Experimental Apparatus with utilized parts labelled)

Setup Procedure

1. Before starting the experiments, put safety goggles on.
2. Turn the computer on and open LabVIEW software.
3. Close all valves if any are open.
4. Record ambient pressure by reading off a manometer.

Experiment 1 (Determining the Mass in the Left Tank)

5. Click the 'Start Collecting Data' button in LabVIEW to record data on graphs.

6. Pressurize the Left Tank.

    a. Pressurize left tank to 40 psig by opening valve A2, and then open left solenoid by clicking the ‘Left Solenoid’ button in LabView, and increasing flow rate to 50g/min in LabView slowly. When 40psig is reached, close the left solenoid by clicking the ‘Left Solenoid’ Button in LabView, closing valve A2, setting flow rate to 0 g/min.

7. Wait for pressure and temperature values to stabilize on the graphs.
8. Click the ‘Stop Recording’ button and save the data. Do not empty the tank.

Experiment 2 (Determining the Heat Loss in the Left Tank and Specific Heat Capacity)

9. Reset the data by clicking the ‘Reset’ button.
10. Click the ‘Start Collecting Data’ button in LabVIEW to record data on graphs.
11. Raise the temperature of the air in the tank to 40℃ by setting the temperature in the ‘Target Temperature’ box in LabView and clicking the ‘Hold’ button.
12. Wait for the temperature to reach 40℃ and then wait for 5 minutes for the temperature to stabilize.
13. Click the ‘Stop Recording’ button and save the data.
14. Turn off the heaters by clicking the ‘Hold’ button.
15. Cool the tank down but running air through it

    a. Click the ‘Start Collecting Data’ button in LabVIEW to record data on graphs (this data does not need to be saved)

    b. Open the Left Solenoid by clicking the ‘Left Solenoid’ button in LabView, open the Bar valve by lifting it.

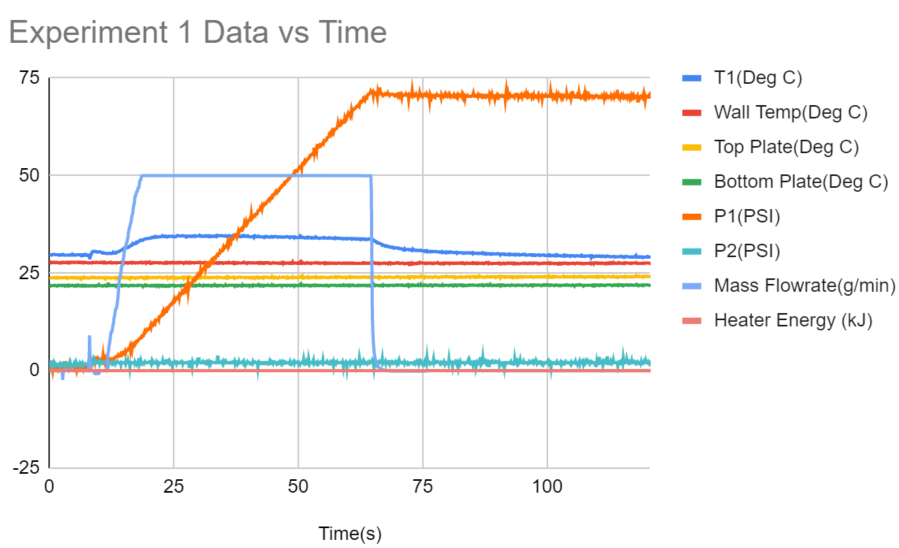
c. When the air has cooled to 30℃ close the Left Solenoid by clicking the 'Left Solenoid' button. If the temperature climbs to above 30℃ again, repeat opening the Left Solenoid. Repeat this step until the temperature has stabilized at or below 30℃.

d. Close the Bar valve by lowering it, evacuate the tank by opening valve B2.

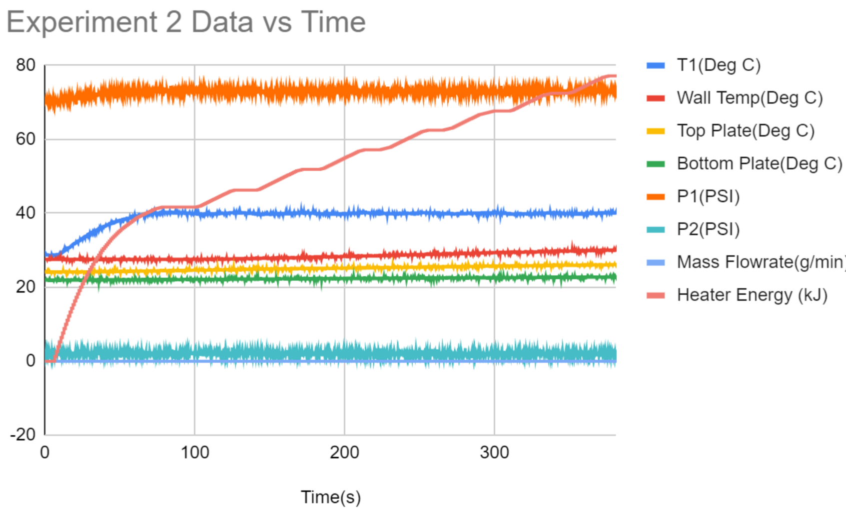
e. Reset data by clicking the 'Reset' Button.

16. Repeat steps 5-16 for each pressure, starting temperature, and end temperature: 70 psig & 40°C cooled to 30°C, 40 psig & 60°C cooled to 40°C, and 70 psig & 60°C cooled to 40°C

Results & Discussion



(*Figure 02, Example Data collected for Part 1 — Determined mass under mass flow rate graph)*



(*Figure 03, Example Data collected for Part 2 — DeterminEDheat added and heat loss)*

Mass in each tank:

Experiment	Mass (g)
A	33.71
B	50.16
C	29.53
D	45.07

(Table 1, Mass in tank for each experiment)

Q totals from experiment A, B, C, D:

Experiment	Q Total (J)
A	607,200.0
B	621,000.0
C	500,800.0
D	628,400.0

(Table 2, Total Heat Loss to maintain temperature)

Q_{lost} through the Top and Bottom plates from experiment A, B, C, D:

Experiment	Q of Plates (J)
A	566,451
B	578,466
C	435,488
D	543,839

(Table 3, Heat Loss through the Top and Bottom plates)

c_v of air from experiment A, B, C, D:

Experiment	c_v of air (J/kgK)
A	0.285
B	0.251
C	0.414
D	0.141

(Table 4, Volume Specific Heat Capacity of Air)

Work of the fan from experiment A, B, C, D:

Experiment	Work of Fan on system (J)
A	25.19
B	25.83
C	21.15
D	26.39

(Table 5, Work done on system by fan)

Energy ratio between heat and work of experiment A, B, C, D:

Experiment	Work added / Heat Added

A	0.0041 %
B	0.0042 %
C	0.0042 %
D	0.0042 %

(Table 6, Ratio between Work and Heat Added)

Rate of Temperature increase based on the fan work of experiment A, B, C, D:

Experiment	Rate of Temperature Increase (K/t or C/t)
A	0.0086 K/t
B	0.0066 K/t
C	0.0069K/t
D	0.013 K/t

(Table 7, Rate of Temperature Increase)

Part 2 Discussion Questions

1. Heat added by the heater is given by $Q_{Total\ Added} = 2P_{heater}\Sigma t_{on}$.

When the mechanical heater heats up the tank, most of the power is used to actually heat up the tank. Once it's at the set temperature the heater only turns on in a pulsing interval in order to maintain the temperature. At this point, the tank is at steady state, and therefore the heat added is the same as the heat lost. So the total heat loss when trying to maintain the temperature will equal the energy output from the heater. None of the heat is transferred to the tank itself. *Values found in Table 2.*

2. Heat conduction Equation for Cylindrical Walls can be calculated by $\dot{Q} = 2k\pi l\,\frac{\Delta T}{ln(\frac{r_2}{r_1})}$,

and the total heat entering and exiting the tank are equal, $Q_{total} = Q_{cylindrical} + Q_{top+bot}$.

The total amount of heat leaving the tank through the top and bottom plates (Table 3) can be expressed by the difference between heat added by the heaters and heat lost through the cylindrical walls, $Q_{top + bot} = Q_{total} - 2k\pi l \frac{\Delta T}{ln(\frac{r_2}{r_1})} (\Delta t)$ (6) *Values found in Table 3*.

Sources of error in this process include the apparatus and the uncertainties in the constants provided for the equation. The apparatus does work on the air in the tank by the fan spinning which is not exactly accounted for in the total heat added by the heaters here. The heat transfer coefficients for aluminum and acrylic also vary so numbers will vary depending on what value is used here. The equation also assumes that the temperature of the surroundings will be at a constant room temperature directly on the other side of the wall, which we cannot guarantee.

3. Using the change in internal energy and the values of heat loss previously calculated we can calculate the specific heat capacity of the air. In this case, we will be calculating the specific heat capacity for air with constant volume (*Values found in Table 4)*:

$$Q = mc_v\Delta T \rightarrow c_v = \frac{Qm}{\Delta T} \quad (7)$$

Part 3 Discussion Questions

1. We are given the fan blame performance using a pump and fan similarity equations using equation 4. Rearrange to solve for experimental power:

$$P_2 = P_1 \frac{\rho_2}{\rho_1} (\frac{n_2}{n_1})^3 (\frac{D_2}{D_1})^5 \quad (8)$$

By using the ideal gas law, we can repurpose the question to be provided in the terms that are given to us in the question.

$$\rho_1 = \frac{m}{V} = \frac{P}{RT} \quad (9)$$

In order to find the work done by the propeller,

$$W_{propeller} = P_2 * t \qquad (10)$$

Finally, to distinguish the rate of rise in temperature due to work done by propeller,

$$W = \Delta U = mc_v \Delta T \qquad (11)$$

$$P = \frac{W}{t} = \frac{mc_v \Delta T}{t} \qquad (12)$$

$$\frac{\Delta T}{t} = \frac{\frac{W}{t}}{mc_v} = \frac{P}{mc_v} \qquad (13)$$

Given Variables (Manufacturer Test Conditions)	**Experimental Variables (Directly from experiment)**
T_1 = 40°C , 40°C , 60°C , 60°C	T_2 = 40.01°C, 39.96°C, 59.36°C, 59.27°C
*P_1 = 40Psig, 70Psig, 40Psig, 70Psig	*P_2 = 41.66Psig, 72.78Psig, 42.56Psig, 73.76Psig
ρ_1 = 4.17518071 kg/m^3, 6.47665483 kg/m^3, 3.92453201 kg/m^3, 6.08784169 kg/m^3	ρ_2 =4.30239156 kg/m^3, 6.69077941 kg/m^3, 4.11704351 kg/m^3, 6.35126032 kg/m^3
*$D_2 = D_1$	*$D_1 = D_2$
n_1 = 4200 RPM	n_2 = 2000 RPM
Power_1 = 0.746 J/S	Power_2 = Need to find

(Table 8, Manufacturer vs Real Values)

**Values were converted to Pa for calculations*

***Assumed to be 1 since ratio between the impeller diameter is same for manufacturer test condition and experiment*

Rate of rise in temperature due to work done by the propeller values found in Table 7.

2. The ratio of the work done by the propeller and the heat added to the gas (Table 6) is very small. The work done by the propeller on the gas does not have a significant effect on the heat of the gas so we can neglect this in our analysis. The fan is an essential part of the apparatus however since air is a poor conductor; circulation makes sure heat is evenly distributed and the heater heats all air through convection.

Conclusion

Through this lab we successfully used the First Law of Thermodynamics, $Q + W = \Delta U$, to show how the conversation of energy applies to a heated gas in a constant volume tank. In part 2, equation [3] is used to determine the energy added by the tank's heaters, and equation [6] is used to determine the heat loss through the top and bottom plates. This part of the experiment concludes that the total amount of heat loss can be equated to the total amount of power that went into maintaining the heat of the tank. In part 3, the work done was determined by using equations [8] and [10] to compare the fan performance to the manufacturer's values, we found that the work done in the system due to the fan has negligible impact on the energy added and hence is not considered in the first law equation and won't change our earlier values. Thus, the First Law of Thermodynamics has proven to be of great importance in real-life experiments regarding the study of Thermodynamics.

References

[1] Chandra, S. *Energy, Entropy and Engines: An Introduction to Thermodynamics*. Wiley, West Sussex, 2016.

[2] CHE260. *Lab 1 – Ideal Gas Law*. "Year Accessed (2022)"