Lab 2 – First Law of Thermodynamics

CHE 260 • Thermodynamics and Heat Transfer

There Are 3 Parts To Complete In This Lab.

Before Beginning this Lab:

- Know that the first law of thermodynamics is stated as follows:

$$Q + W = \Delta E$$

Safety Warnings for this Lab:

- Use the flow meter control in LabVIEW to ramp up the flow of air GRADUALLY from zero. For example, DO NOT set the flow rate to maximum and open all the valves to fill a tank or to create a vacuum, instead, ensuring that the flow rate is set to zero initially, open all the desired valves and then ramp up the flow rate in increments to the maximum flow. This ensures that the flow controllers do not get a large surge of flow through them
- Do not allow pressure to exceed 80 psi (always keep P<80 psi)
- Do not allow temperature to exceed 70^{0}C (always keep T<70^{0}C)
- Always wear safety glasses when operating this system

Nomenclature for this Lab:

T_1:	Left Tank Temperature [°C]
T_2:	Right Tank Temperature [°C]
P_1:	Left Tank Gage Pressure [Psig]
P_2:	Right Tank Gage Pressure [Psig]
[Psig]	Gage Pressure [Psi], Pressure reading that you actually see on the gages
[Psia]	Absolute Pressure [Psi], $Psia = Psig + P_{atm}$

Part 1: Determining the Mass in the Left Tank

Introduction

Part 1 is similar to Lab 1 – Part 2. The purpose of Part 1 is to determine the total amount of mass in the left tank. For this system, the ideal gas law can be manipulated in order to find the mass of the system, as follows:

$$m_{left\ tank} = m_{added\ to\ tank}\left[1 + \frac{1}{\left(\frac{P_2 T_1}{P_1 T_2}\right) - 1}\right]$$

To begin a lab:

1. Turn the computer on and start LabVIEW (or click 'Reset' button if LabVIEW is already running)
2. Make sure all valves are closed.

*Note: Recall from the introductory lab that the **regulator pressure** will be preset to 80 psi.

Procedure

1. Record the ambient pressure using the manometer in the lab.
2. Click the 'Start Collecting Data' button in LabVIEW to begin recording the results on the graphs.
3. Pressurize the left tank to 40 psi and wait for P and T to stabilize. To do this:
    a. Open Valve A2.
    b. Open the Left Solenoid valve by pressing the 'Left Solenoid' button in LabVIEW once.
    c. Using LabVIEW, set the Flow Rate to 50 g/min.
    d. When the pressure reaches 40 psig in the left chamber, close the left solenoid valve by clicking the 'Left Solenoid' button in LabVIEW once.
    e. Close Valve A2
    f. Using LabVIEW, set the Flow Rate to 0 g/min.
    g. Wait for P and T to stabilize (wait for the values of pressure and temperature on the graphs in LabVIEW to remain constant with time).
4. In LabVIEW, click 'Stop Recording' and save your data in the method requested by your TAs – labeling it **Lab 2 – Part 1a**
5. In LabVIEW, click 'Reset'
6. Do not empty the tank!

No discussion questions for Part 1; Proceed to Part 2

Part 2: Determining the Heat Loss in the Left Tank and Specific Heat Capacity

In this section we use two PID controlled heaters to heat and maintain the left tank at a specific temperature. The PID controller pulses power to the heaters in order to increase temperature. It uses the instantaneous temperature in the tank as a feedback and adjusts the number and duration of power pulses. The heaters cannot be left on for an extended period of time due to the high heat capacity of the heaters. Once the desired temperature is reached, the heater would be pulsed regularly in order to maintain the temperature and account for heat loss through the tank walls. The total heat added in a specific amount of time is given by:

$$Q_{Total\ Added} = 2P_{Heater}\sum t_{on}$$

Where:

- P_{Heater} is the power of each heater (~1000 W)
- $\sum t_{on}$ is the total time the heater is powered on for

The top-right graph given in LabVIEW presents the cumulative thermal energy input to the system. The software automatically uses the above equation to calculate the cumulative thermal energy input.

Procedure

1. Click the 'Start Collecting Data' button in LabVIEW to begin recording the results on the graphs.
2. In LabVIEW, set the temperature to 40°C in the box 'Target Temperature'.
3. Turn on the Heaters by clicking the 'Hold' button once.
4. Wait for the temperature in the left tank to reach 40°C. Do not turn off the heaters yet.
5. Wait for 5 minutes.

SAFETY WARNING: CONTINOUSLY MONITOR THE TANK TEMPERATURE IT SHOULD NEVER REACH 70°C. THE GLASS TRANSITION TEMPERATURE FOR CAST ACRYLIC RANGES FROM 85 TO 165°C. ONCE THE ACRYLIC ENTERS THIS STATE IT WILL NOT BE ABLE TO HOLD PRESSURE AND WILL START DEFORMING. IN SUCH A CASE TURN, OFF THE ELECTRICAL CONTROL BOX AND ENSURE THE HEATER INDICATING LIGHTS ARE OFF. INFORM YOUR TA IMMIDIATELY.

6. In LabVIEW, click 'Stop Recording' and save your data in the method requested by your TAs – labeling it **Lab 2 – Part 2a**
7. Turn off the heaters
8. Run air through the tank to allow the tanks to cool down. To do this:
    a. Start Collecting Data (you don't need to save what's collected, this is just so that you can read the temperature off of Lab View).
    b. Open Left Solenoid valve.
    c. Open the "Bar" valve behind the left tank.
    d. When the left tank has cooled to *X*°C (*see table below*), click the 'Left Solenoid' button in LabVIEW once to close the left solenoid. **NOTE:** We want the temperature to be at or below *X*°C once the temperature has stabilized after closing the Left Solenoid valve. This takes around 5-10 minutes of air circulation and 1 minute for the temperature to stabilize after closing the valves, if you close

the valve and the temperature climbs back above X°C just open the valve back up again for a minute or two more.

e. Close the "Bar" valve.
f. Evacuate the left tank by opening valve B1.
g. Close valve B1.

9. Repeat Steps 1-8 for tank pressure and temperatures of 70 psig at 40°C, 40 psig at 60°C, and 70 psig at 60°C. **Note that Part 1 of the lab will have to be done 3 more times.**
10. When you are finished, ensure the system has cooled down and all components are off.

Trial	Pressure & Temperature	After trial, cool temperature to:	Save results as:
a	40 psig & 40°C	30°C	Lab2 – Part 1a Lab2 – Part 2a
b	80 psig & 40°C	40°C	Lab2 – Part 1b Lab2 – Part 2b
c	40 psig & 60°C	40°C	Lab2 – Part 1c Lab2 – Part 2c
d	70 psig & 60°C	40°C	Lab2 – Part 1d Lab2 – Part 2d

Discussion (3 Questions)

1. Calculate the heat loss from the tank using the input power required to maintain the temperature.

2. Calculate the heat loss through the top and bottom plate by first calculating the heat loss through the acrylic walls using the heat conduction equation (given below) for cylindrical walls. What are the sources of error?

Heat Conduction Equation for Cylindrical Walls:

$$\dot{Q} = 2k\pi l \frac{\Delta T}{\ln\left(\frac{r_2}{r_1}\right)}$$

Where:

- k is the conductive heat transfer coefficient $[w/mK]$. For acrylic, it is ~0.17-0.2 $[w/mK]$ and for aluminum it is ~200-250 $[w/mK]$
- l is the length of the cylinder [m]. The length of the cylinder is 11 ¼"±0.001"
- ΔT is the temperature drop across the wall [K]. The inside wall temperature can be assumed to be the same as the gas temperature inside the tank due to uniform temperature distribution inside the tank as a result of vigorous mixing.
- r_1 and r_2 are the inner and outer radiuses of the cylinder [m]. The outer diameter of the cylinder is 8"±0.045" and wall thickness is 3/8"±15%.

3. Calculate the constant volume specific heat capacity of air by looking at the rate of temperature rise.

Part 3: Determining the work done by the Propeller in the Left Tank

The work done by the propeller is equal to change in the internal energy for an adiabatic system. The other approach to calculate work done by the propeller is to look at the fan blade performance using pump and fan similarity equations, which is given by:

$$\frac{Q_2}{Q_1} = \frac{n_2}{n_1}\left(\frac{D_2}{D_1}\right)^3$$

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

Where:

- Q is the volumetric flow rate
- n is the pump shaft speed
- D is the impeller diameter
- P is the fan power
- ρ is the gas density

Subscript 1 refers to the manufacturer's test conditions, and subscript 2 refers to operating conditions (aka. The values you are going to get from this part of the lab). According to the manufacturer, the fan is 2.5" in diameter, with $10\ blades$ with a pitch of $45°$, and would output $25\ cfm$ at $4200\ rpm$ and $0.001\ hp$ at standard conditions.

Discussion (2 Questions)

1. Calculate the work done by the propeller using the above mentioned method. What would be the rate of rise in temperature due to work done by the propeller?
2. How significant is the work done on the system versus the heat added?