CHE260 PRA0101
Novera Ahmed
Carl Joseph Ancheta
Joaquin Antonio Arcilla

Exploring Path Independency and uses of Ideal Gas Law

Abstract

The purpose of this report is to determine that thermodynamics state properties are path independent and to show how one could use the ideal gas equation to measure the volume of a container. The first experiment had us equalize the pressure of the gasses at two different rates to confirm that the state properties are path independent because at both rates they reached the same thermal equilibrium. The second experiment allowed us to calculate the volume of the container and the initial mass of gas in the tank. These measurements using the ideal gas law are an important tool for scientists and engineers.

Introduction

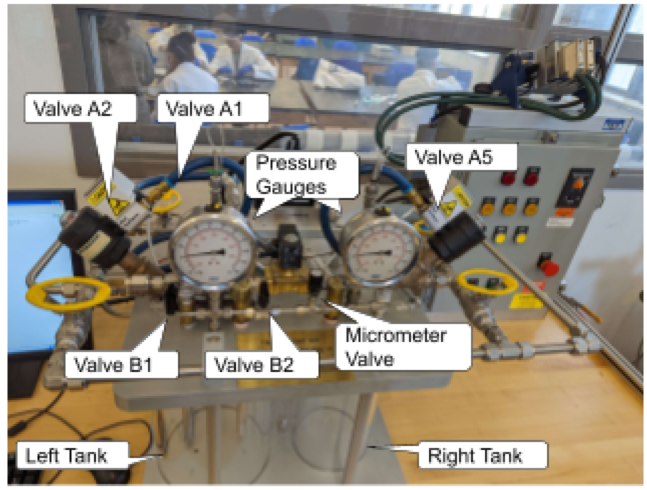
The Ideal Gas Law is a law in thermodynamics that relates temperature, pressure, mass and volume— of an ideal gas together. This equation is used to estimate physical macroscopic properties in gas-based systems and thermodynamic engines. The Ideal Gas Equation can be used to measure the volume of any object by pressurizing a known gas within it.

In this lab, we will be experimenting with the real world phenomena surrounding the ideal gas lab. In the first part, we check whether the final conditions of heat transfer are only dependent on their initial values or if the path it takes in between matters. In the second part, we will apply the ideal gas law to measure the volume of the container in the experiment. These are just two examples of real life applications with the Ideal Gas Law.

Experimental Method [2]

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: Path Independency of Thermodynamics State Properties and Determining the Volume Ratio of the Tanks

5. Click the 'Start Collecting Data' button in LabVIEW to record data on graphs.
6. Pressurize the Tanks.
    a. Pressurize left tank to 40 psi by opening valve A2, opening left solenoid by clicking the 'Left Solenoid' button in LabView, increasing flow rate to 50g/min in LabView, closing the left solenoid by clicking the 'Left Solenoid' Button in LabView when 40psi is reached, closing valve A2, setting flow rate to 0 g/min.
    b. Vacuum the right tank to -6 psig by opening valves A1 and A5, opening right solenoid by clicking 'Right Solenoid' button in LabVIEW, setting flow rate to 50 g/min in LabVIEW, waiting for pressure to read -6 psig, closing right solenoid by

clicking 'Right Solenoid' button again, closing valves A1 and A5, and setting flow rate to 0g/min.

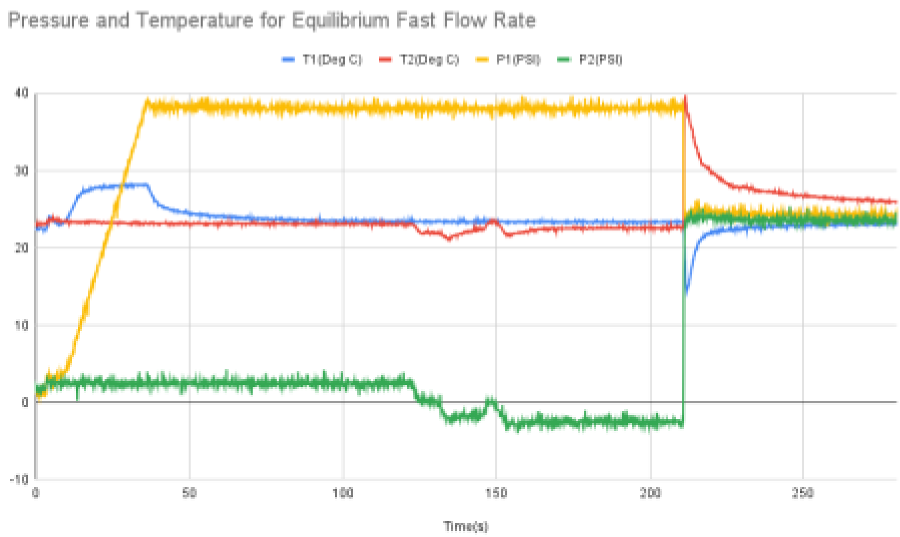
7. *Method 1: using centre solenoid to reach equilibrium*
    a. After pressurizing the 2 tanks, click the 'Center Solenoid' button in LabVIEW and leave it open <u>until the tanks get close to the same temperature</u>.
    b. Click the 'Stop Recording' button and save the data.
    c. Empty the tank by opening Valve B1.
8. Repeat step 6 to pressurize the tanks again.
9. *Method 2: using a micrometer needle valve to reach equilibrium.*
    a. After pressurizing the 2 tanks, open ball valve B2 by turning it counterclockwise 4 times.
    b. Leave B2 open <u>until the 2 tanks are at about the same pressure.</u>
    c. Click the 'Stop Recording' button and save the data.

Experiment 2: Determine initial mass and volume of left tank experiment

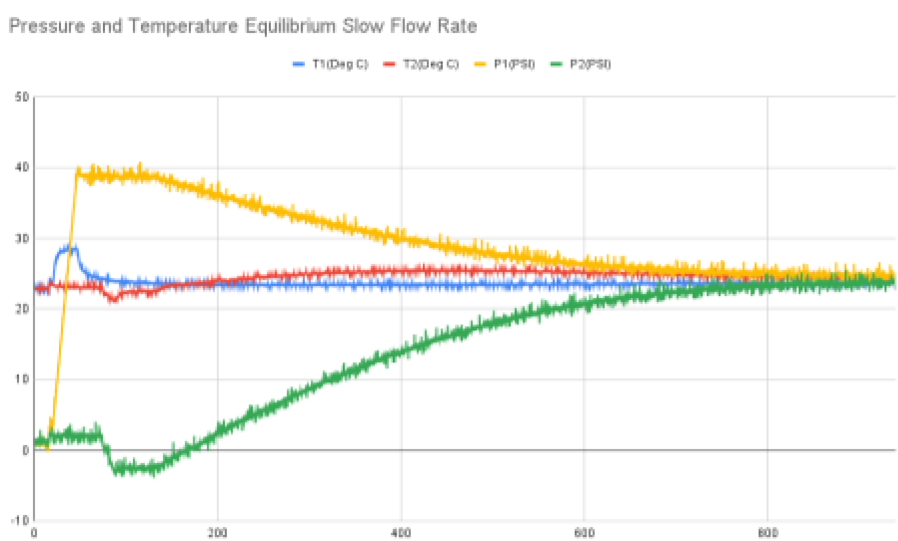
10. Click 'Start Collecting Data' button to record data on graphs.
11. Pressurize left tank to 40 psi by opening valve A2, open left solenoid by clicking the 'Left Solenoid' button in LabView, increasing flow rate to 50g/min in LabView, then closing the left solenoid by clicking the 'Left Solenoid' Button in LabView again when 40psi is reached, close valve A2, set flow rate to 0 g/min.
12. Wait for pressure and temperature to stabilize by watching the graphs in LabVIEW.
13. Once stable, click the 'Stop Recording' button and save the data.
14. Empty the tank by opening Valve B1.

15. Click ‘Reset’ button in LabVIEW.

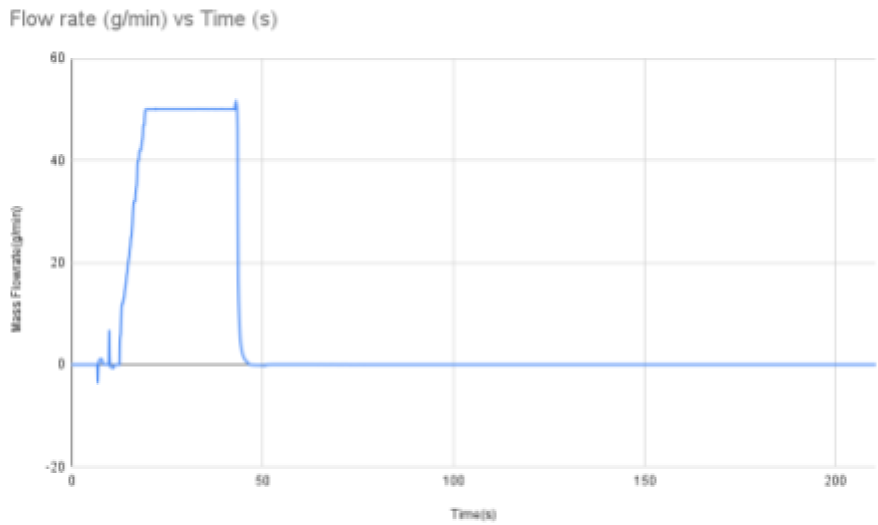
Results & Discussion



(Figure 02, Experiment A with the fast flow rate)



(Figure 03, Experiment B with slow flow rate)



(Figure 04, Flow rate vs Time)

Part 1

For the first part of the experiment, both tanks are brought to the same equilibrium pressure using the valves to restrain airflow accordingly. During this process, both of the tanks experience an almost instantaneous reaction in reaching equilibrium. Through observation, we recognize that when the valve is opened, there is a simultaneous sharp increase of temperature in the right tank (T_2) and there is a drop in temperature in the left tank (T_1). We continued to collect data afterwards for 48 seconds to allow both of the tanks to reach equilibrium. T_1 is a little higher than T_2 after 48 seconds in the analysis as they are both arriving at an equilibrium observed to be 23°C ± 0.5°C.

Given the data for the second part, both tanks were slowly brought to equilibrium through a micrometer needle valve as observed by the downward approximately linear trend of the pressure in the left tank (P_1) and the upward approximately linear trend of the pressure in the right tank (P_2). The equalization process took place over 13 minutes and 46 seconds. T_2 is greater than T_1 at a constant value but both the temperature values are still within reasonable uncertainty of the thermal equilibrium value.

Part 2

In this section, we computed the initial mass and volume of the tanks using flow rate. We initially hypothesized that there would be a negligible amount of mass in the tank since there is assumed to be no “residual gas” in the tank. However, after computing the initial mass using flow rate against time, we were able to use the ideal gas law to find the volume.

Therefore, both sections provided us with different results for our experimental analysis. Limitations of this design include creating several assumptions beforehand, for instance, we are meant to assume that the gas inside the tanks being used is air, whereas it could have a different composition of gas compared to the regular definition of air. It would have also been beneficial for us to receive or be allowed to compute the volume of the tank with a different method to verify our experimental method

Part 1 Discussion Questions:

1. Since there are two methods and two different flow rates to allow the two tanks to reach an equilibrium point, we are calculating the volume ratio with data from both methods, and then comparing the two final values.

For initial temperatures, they are taken from the time the tank has been set to its listed initial pressure after the temperature stabilizes. For method 1, the left tank was <u>23.5°C</u> while the right tank was <u>22.5°C</u>. For method 2, the left tank was <u>24°C</u> while the right tank had <u>22.5°C</u>.

For the final temperature, the two tanks are treated as one tank since the pressure and temperature is uniform throughout both tanks. For the final equilibrium temperature with method 1, it was 25°C while method 2 measured 24°C.

While the initial pressures were listed in the lab manual as 40 PSI and -6 PSI, our lab equipment did not measure these values exactly. For the calculations, we are using the real values measured by LabVIEW. For method 1, the initial pressure for the left tank was 38 PSI, while the right tank was -2.7 PSI. For method 2, the left tank had a pressure of 38.9 PSI and the right tank had a pressure of -2.5 PSI.

Using the ideal gas law and the conservation of mass law, we created an expression to solve for the volume ratio: $\frac{V_L}{V_R} = \frac{T_L(P_{eq}T_R - P_R T_{eq})}{T_R(T_{eq}P_L - P_{eq}T_L)}$

From this equation we calculated the volume ratio between the left tank and right tank to be **1.88** ± **0.5** based on method 1, and **1.98** ± **0.5** based on method 2. These values are relatively close and thus can be experimentally declared to be the same value. This means that the left tank is almost twice as large as the right tank.

2. Net heat transfer is the difference between heat transferred into the system (Q_i) and heat being transferred out of the systems (Q_f). In the case of the first method, the left tank being pressurized caused some increase in temperature since these properties are linearly proportional to one another. The temperature inside the tank is higher than the ambient temperature. Given that the tanks are in a closed system, once the valves are opened to release pressure into the second tank, there is a stark difference in temperature with the fast moving molecules from the left tank transferring into the right one. This causes the temperature to decrease in the left tank and rise in the right tank to reach thermal equilibrium within the range of the ambient temperature.

3. Path independence refers to a value that can be measured without knowing the history of the system. In the case of the experiment, the properties measured for path independence are Pressure and Temperature. As described above, A and B, experiment A had a faster flow rate while experiment B had a slower flow rate, taking longer to achieve equilibrium.

In both experiments (figure 02), when the tanks were connected, the air pressure and temperature transferred from the left tank to the right tank until it reached an equilibrium point. For experiment A (figure 02), the fast transfer rate brought the temperature to around 24.5°C, while the pressure was around 24 PSI. In experiment B (figure 03), the slow flow rate brought the temperature to around 24°C, and the pressure was around 24 PSI.

Since the final values are similar despite the different flow rates, we can conclude that pressure and temperature are path-independent properties.

Part 2 Questions:

1. As described in the lab manual, the difference between the initial and final mass can be found by getting the area under the flow rate vs time graph (Figure 04). We approximated the flow rate curve as a trapezoid and used the trapezoidal area formula to get a mass difference of 24.0737 g (Δm).

Since the volume from the initial state and final state is the same, we can get an equation relating the initial and final values using the ideal gas equation. The initial mass will be a variable $m_{initial}$ while the final mass will be $\Delta m + m_{initial}$. Rearranging the equation, you get:

$$m_{initial} = \frac{\Delta m * T2}{P2 * (\frac{T1}{P1} - \frac{T2}{P2})}$$

Solving this equation, we calculated an initial mass of **9.95 g**. Putting this value into the ideal gas equation to solve for volume at its initial state, we got a volume of **0.00786 m^3**.

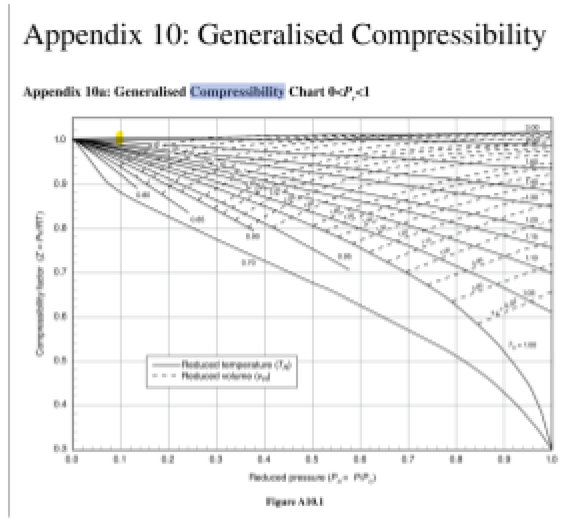
2. The main errors from this lab come from the use of apparatuses that may not be accurate to their gauge display. When we were filling up the left tank to 40 psi, we read the pressure value of 40 psi from the gauge with our eyes. Although the needle would seem close enough to the desired value, on LabVIEW the value wasn't perfectly at 40 psi but was instead close to 38 psi. Each of the gauges suffer this issue of using your eyes to watch the needle.

LabVIEW itself could also have been inaccurate and measured the wrong values. This would make the calculations in the above section inaccurate.

In terms of the calculations, the values of pressure, temperature and flow rate were never perfectly stable. So for the purposes of the calculations, an average of a short span was chosen to represent the values for the formulae. These estimated values could be inaccurate to the real system and thus create inaccurate calculations.

3. Ideal Gas behavior has a compressibility factor (Z) of Z = 1 and deviates as Z decreases. After some time the pressure equalized to P_{abs} = 0.377 MPa, and the temperature equalized to T =

295.15 K. These values give reduced pressure and temperature values of **$P_{reduced}$ = 0.1** and **$T_{reduced}$ = 2.243** [1]. The reduced pressure and temperature values correspond to a compressibility factor that is nearly 1.0 according to Figure 05, which indicates that the compressibility of air does not have a significant effect on our results at these pressures and temperatures.



(Figure 05, Generalised Compressibility Chart [1])

Conclusion

Through this lab, we proved that temperature and pressure are path-independent properties that can be measured at a specific point in time without having any prior knowledge of the system. Furthermore, we used the ideal gas law to find the volume of the left tank without taking any length based measurements. The ideal gas law is a building block for other thermodynamic phenomena and is a basic law that helps builds an engineer's intuition.

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)"