Lab C - Determination of the Identity of an Unknown Gas Through Measurements of Heat Capacity

Principle of method

In order to obtain the heat capacity of the unknown gas, it was subjected to an approximation of an adiabatic expansion, in which the system does not exchange heat with its environment, given how fast its compression takes place. The adiabatic approximation performed at the laboratory then provided the different manometer readings from inside the carboy with the unknown gas.

The obtained readings (P1 and P_3) can then be subtracted from each other and added to the measured room pressure (P_2) in order to acquire the value for pressure inside the carboy. Following these calculations, the heat capacity for the gas (Cv_m) can be determined, as shown by Equation I below:

$$Cv_m = -R\frac{\left(1-\frac{P_3}{P_1}\right)}{(1-\frac{P_3}{P_2})}$$

The result from this equation can then be used in order to obtain the ratio γ ($= \frac{C_p}{C_V}$), which is more often used than the value for Cv_m Therefore, by assuming an ideal gas and an adiabatic expansion, the ratio γ can be calculated through Equation II:

$$\gamma = \frac{R}{Cv_m} + 1$$

Procedure

The experiment was carried on as determined by the lab manual[1]. During the procedure the height of water from the manometer was recorded, along with their respective run number and time necessary for the system to reach equilibrium, the following information is shown below by Table 1.

	Manometer Reading		
Run Number	Left (cmH_2O)	Right (cmH_2O)	Vent Time (s)
1	15.52	70.25	9.24
	37.93	48.2	
2	14.71	70.99	8.32
	37.45	48.57	
3	15.2	70.49	7.28
	37.2	48.59	
4	16.03	69.7	6.34
	37.667	48.51	
5	15.62	70.09	5.21
	37.12	48.91	
6	16.12	69.61	4.28
	37.04	48.98	

Table 1. Left and right water level measurements of the manometer and vent times for the Clement-Desormes experiment.

During the procedure, a room pressure (P_2) of 730mmHg and a room temperature (T_1) of 22 °C were also recorded in order to perform the data analysis for this experiment. The above tabulated results were edited, converted, used in order to determine Cv_m and γ, as described by the following section.

Results and Calculations

The calculation for this experiment started with converting all the raw measurements from cmH_2O into mmH_2O; after this, the left side of the manometer was subtracted from the values taken from the right side. These results were then added to the room pressure value, already converted from mmHg into mmH_2O. The result from the addition was the value for Carboy pressure.

Having obtained the Carboy pressure value, Cv_m was determined through equation I shown in the previous section, and its value was directly used to obtain γ. The sample calculation from the first run exemplifies the data analysis made to the entire dataset and the rest of the values are tabulated in Table 2.

Calculation of Carboy Pressure:

$$P1/P3 = ((\text{Left Value} * 10) - (\text{Right Value} * 10)) + (P_2)$$

$$P1 = ((70.25cmH_2O * 10) - (15.52cmH_2O * 10)) + (9924.423mmH_2O) = 10471.723mmH_2O$$

$$P3 = ((48.2cmH_2O * 10) - (37.93cmH_2O * 10)) + (9924.423mmH_2O) = 10027.123mmH_2O$$

Calculation of Heat Capacity:

$$Cv_m = -(8.3145)\frac{\left(1 - \frac{(10027.123)}{(10471.723)}\right)}{(1 - \frac{(10027.123)}{(9924.423)})}$$

$$Cv_m = 34.11307042 \text{ J/K * mole}$$

Calculation of γ:

$$\gamma = \frac{8.3145}{34.11307042} + 1$$

$$\gamma = 1.243732736$$

P1 (mmH_2O)	P3 (mmH_2O)	Cv_m (J/K * mole)	Gamma (γ)	Vent Time (s)
10471.72	10027.12	34.1	1.24	9.24
10487.22	10035.62	31.9	1.26	8.32
10477.32	10038.32	30.3	1.27	7.28
10461.12	10032.85	31.1	1.26	6.34
10469.12	10042.32	28.5	1.29	5.21
10459.32	10043.82	27.4	1.30	4.28

Table 2. Vent times, initial pressure (P1), final pressure (P3), calculated specific heat (Cv_m), calculated ratio (γ) and intermediate temperature for the Clement-Desormes experiment

All the calculated values were then plotted against their vent time and extrapolated to zero as shown by Figure 1 and Figure 2. This was done in order to obtain the its proper γ and Cv_m values for a true adiabatic expansion of the unknown gas.

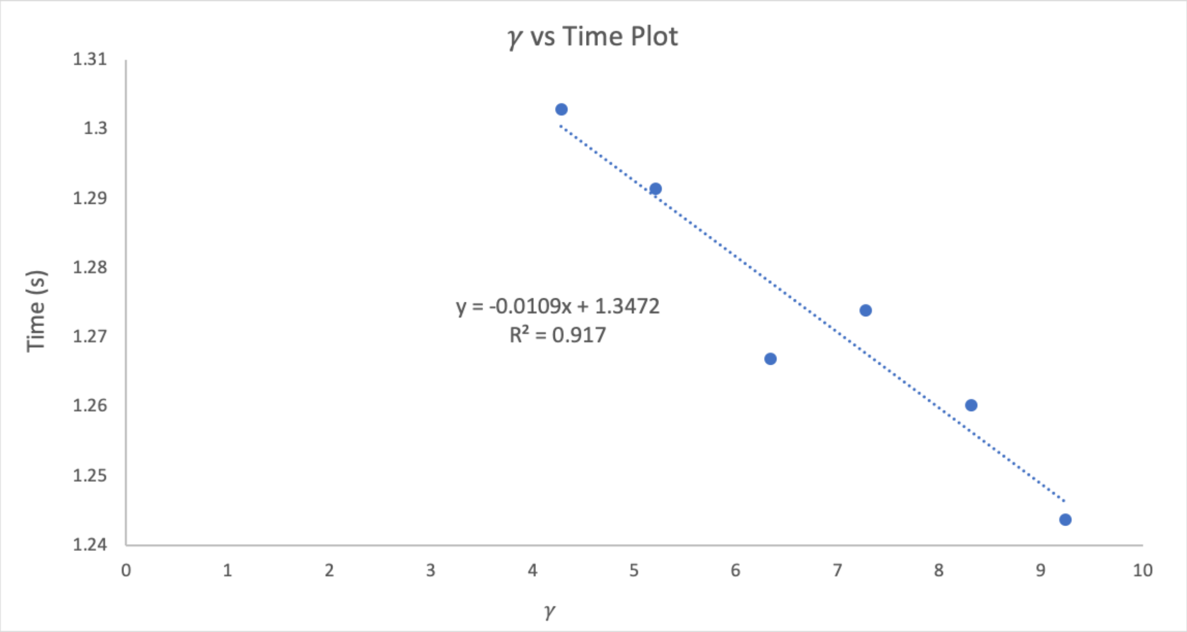

Figure 1. A plot of Gamma (γ) vs Vent time for the Clement-Desormes' experiment

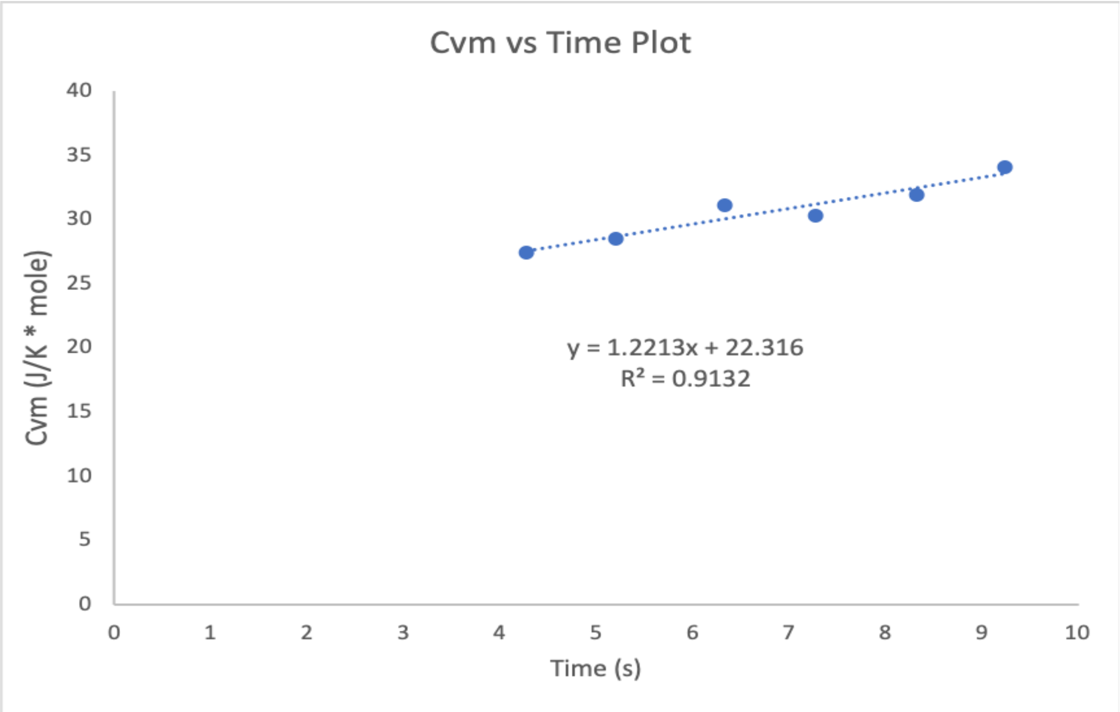

Figure 2. A plot of Cv_m vs. Vent time for the Clement- Desormes' experiment

The determination of both proper Gamma and Specific heat values was done by replacing x for 0 in the equation prevenient from the regression fit of the line. Therefore, it was determined that proper Gamma had a value of 1.34 and that the Specific heat of the unknown gas was 22.316 J/K * mole.

Discussion

In order to derive the necessary formulas for this experiment, it was assumed that the unknown gas inside the carboy was an ideal gas, and that the expansion performed was completely adiabatic.

Despite a slightly inaccurate specific heat value, the information leads to the conclusion that the identity of the gas used for this experiment was N_2, for which the literature values[2] indicate a specific heat of 20.820 J/K * mole (at 300K) and a gamma value of 1.40, as shown by Table 3 below.

	Cvm (J/K* mole)	Gamma (γ)
Experimental	22.316	1.34
Literature	20.82	1.4

Table 3. Experimental and literature values for specific heat Cv_m and Gamma ratios (γ)

It was expected that the data acquired and plotted from the experimental measurements would have clearly pointed out which gas it was present inside the carboy, however the results obtained from the experiment was reasonably inaccurate, to the point of making it hard to distinguish whether the gas' identity was O_2 or N_2.

The sources of inaccuracy in the result have been hypothesized to be from the fact that the assumptions made to derive the formulas were not strictly obeyed, once the gas inside the carboy was not an ideal gas and the expansion that occurred was not truly adiabatic. In order for an expansion to be truly adiabatic, no heat transfer could have occurred between the system and its surroundings, which would require immediate closing of the tap as soon as it is opened, and it was not the case.

It was also concluded that another source of inaccuracy could have come from leaving the tap open for too long, once that would have allowed for entry of the gases present in the surroundings into the system, thereby causing for a mixture of gases inside the carboy and different gamma values than the one established for adiabatic expansion of only one gas.

The values obtained by the end of the experiment allowed for estimation of T2, which was calculated by first deriving a formula from the assumption that for this experiment:

$$T_2 = \frac{P_2 V_2}{nR}$$

And,

$$T_1 = T3 = \frac{PV}{nR}$$

Therefore,

$$nR = \frac{PV}{T_1}$$

And given that,

$$n1P1V1 = n3P_3V3 = n3P_3V2 \quad (\div n3P2)$$

$$V3 = V2$$

Then,

$$T_2 = \frac{P_2\, T_1}{P_3}$$

Using the equation derived above, T_2 was calculated and determined as 291K, which is lower than T1. The reason for this is that in an adiabatic expansion, there’s no heat supplied from the surroundings of this system and therefore the energy required for expansion is going to be retrieved from the internal energy, thereby causing a decrease in internal pressure and, consequently, a decrease in temperature.

Conclusion

An unknown gas was identified as N_2 after being submitted to an experiment that simulates adiabatic expansion and having its specific heat, Cv_m, and Gamma ratio, γ, experimentally determined through manipulation of the manometer's pressure readings. The results were reasonably straightforward in pointing out the gas' identity despite a slight inaccuracy.

References

[1] Exp. C, Chem 201 Manual 2020

[2] Bhattacharjee, S., "TEST: The Expert System for Thermodynamics," Electronic Resource, Entropysoft, San Diego, CA, http://www.thermofluids.net. Last accessed on Feb 10th, 2020