

Week 1

Group F

Experiment Heat Capacity Ratio

Total Score: 92

Title Page – (5 points total)

Score: 5/5

Table of Contents – (5 points total)

The TOC should indicate:

- The various topics described below and the page numbers in which they are contained. (2)
- After each topic, state the person responsible for generating that portion of the work. (3) -3

Score: 2/5

Objective of the experiment – (10 points total)

- State the purpose or the goals of the experiment and what you expect to accomplish by performing the experiment. (4)
- Describe in detail the theory and principle behind the experiment. Include the equations you will be using. (4)
- Properly define all symbols and acronyms. (2)

Score: 8/10

Comments: Next time, please clearly define ALL notations used in the equations as well as their units (-1). Also, please include definitions for key terms like 'adiabatic reversible' (-1). Overall, good objective and summary of theory here.

Equipment – (10 points total)

Score: 9/10

Comments: Clearly indicate the precision of the measuring devices (in this case, the software) (-1). Next time, please note the precision of the gauges while you are performing your experiment.

Experimental Procedure – (15 points total)

Score: 14/15

Comments: Write in past tense (-1) because you ran the experiment and you are not telling someone how to run it, but rather explaining what you did. Here you should also be indicating any deviations that you made from the lab manual.

Experimental Results – (15 points total)

Score: 14/15

Comments: Include definitions in table 1 and equations in objective. Make sure to show work for calculations in table 2 (not needed for each run, just one example) (-1)

Discussion of Results – (15 points total)

Score: 15/15

Lab Guide Questions – (10 points total)

Score: 10/10

Conclusion – (10 points total)

Score: 10/10

References – (5 points total)

Score: 5/5

Comments: Next time please use in text citations for paraphrasing, images, etc from outside sources.



SAN DIEGO STATE UNIVERSITY

ME 495 – Mechanical and Thermal Systems Lab

HEAT CAPACITY RATIO – EXPANSION
PROCESSES OF A PERFECT GAS (TH5-B)

Group F

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1. Objective

The objective of this experiment is to experimentally determine the heat capacity of air at ambient temperature. The heat capacity is extremely important to be able to quantify the amount of heat that passes through the fluid. This experiment exposes the students to a variety of thermodynamic properties including adiabatic processes as well as the characteristics of an ideal gas.

This experiment will be using the TH5-B equipment, seen in Figure 2 below, which allows a chamber to be pressurized above atmospheric pressure. Once the chamber has been pressurized, a small amount of air is released from the chamber in an adiabatic and reversible process. During this process, the temperature of the remaining air in the chamber will change. After the valve has been closed, the fluid will then return to the ambient temperature at a constant volume process. The temperature and pressure are recorded by the TH5-B to an excel spreadsheet.

There are a variety of equations that are required to be utilized in order to determine the heat capacity for a fluid.

For a perfect gas $C_p = C_v + R$ where C_p is the molar heat capacity at constant pressure and C_v is the molar heat capacity at a constant volume. We will need to utilize the two types of processes, adiabatic expansion and constant volume temperature change, to determine the relationship between these two. For air at ambient temperature the ratio $\frac{C_p}{C_v} = 1.4028$ [1].

The process of obtaining this ratio will require the derivation of the equation in terms of pressure or temperature as these are the two quantities that we are measuring. The following derivation is from the document “Heat Capacity Ratio – Expansion Processes of a Perfect Gas (TH5-B)” written by Dr. Kassegne [2] for the ME495 Laboratory.

For a reversible adiabatic expansion, $dq = 0$

From the first law of thermodynamics, $dU = dq + dW$

Therefore during the expansion process, $dU = dW = -pdV$

At constant volume, the heat capacity ratio relates the change in temperature to change in internal energy:

$$dU = C_v dT$$

$$\text{Thus, } C_v dT = -pdV$$

Substituting in the ideal gas equation and then integrating gives:

$$C_v \ln \frac{T_f}{T_i} = -R \ln \frac{Vol_f}{Vol_i}$$

Now, for an ideal gas,

$$\frac{T_i}{T_s} = \frac{P_i Vol_i}{P_s Vol_s}$$

$$\text{Therefore, } C_v = \left(\ln \frac{P_i}{P_s} + \ln \frac{Vol_i}{Vol_s} \right) = -R \ln \frac{Vol_i}{Vol_s}$$

Rearranging and substituting we get:

$$\ln \frac{P_i}{P_s} = - \frac{C_p}{C_v} \ln \frac{Vol_i}{Vol_s}$$

During the return of temperature to the starting value,

$$\frac{Vol_i}{Vol_s} = \frac{P_s}{P_f}$$

$$\text{Thus, } \ln \frac{P_s}{P_i} = \frac{C_p}{C_v} \ln \frac{P_s}{P_f}$$

Re-arranging gives the relationship in its required form:

$$\frac{C_p}{C_v} = \frac{\ln P_s - \ln P_i}{\ln P_s - \ln P_f}$$

The relationship above will be used in experimentally determining the ratio of specific heat capacities. We note the large reliance on the initial and final pressures of this formula. The experiment will rely heavily on the accurate recording of these pressures.

2. Equipment

The equipment comprises of:

- Two floor standing interconnected rigid vessels on a common base plate, the larger vessel is for operation under pressure and the smaller vessel is for operation under vacuum. Both can be seen in Figure 3 below.
- A free-standing electrically operated air pump (in combination with ball valves on top-plate also allow for vacuum)
- 3 larger quarter-turn ball valves, shown in Figure 2 below
- 3 smaller quarter-turn ball valves, shown in Figure 2 below
- Associated tubing and fittings to connect pump to vessels
- Electrical console with current protection devices and an RCD for operator protection
- PC for data collection
- IDF5 interface device

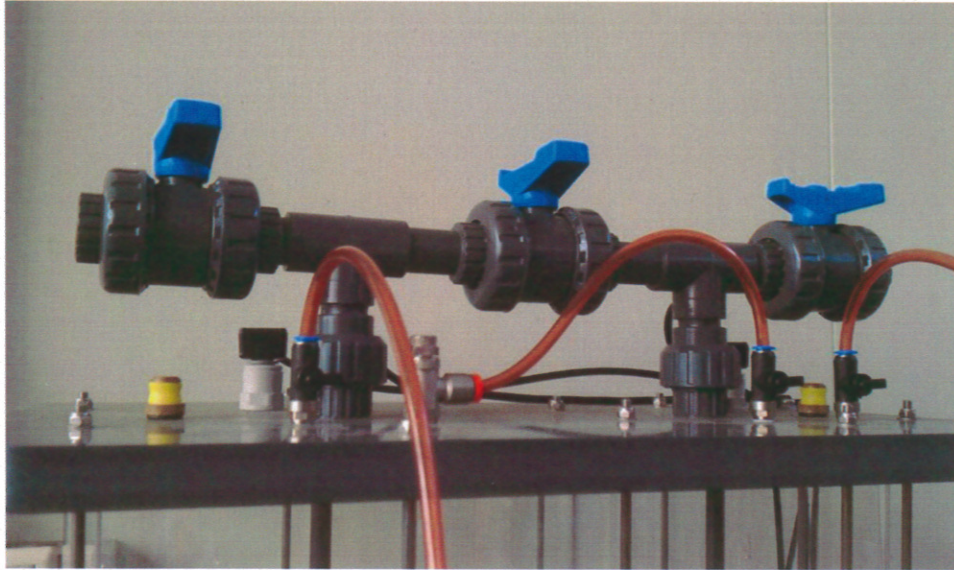


Figure 1 Valve assembly located on top-plate

Each vessel incorporates the following features:

- connection to the air pump via an isolating valve to allow the vessel to be pressurized/evacuated
- connection to a piezo-resistive sensor to measure the pressure/ vacuum inside the vessel (range of both sensors $\pm 34.5 \text{ kN/m}^2$)
- connection to a large bore pipe and valve to allow depressurization/ pressurization of the vessel to/from the atmosphere (the valve is rapidly opened and closed to provide a small step change in pressure)
- interconnection between the two vessels via a large bore pipe and valve (fast change) and small bore pipe and needle valve (gradual change).
- fast response thermistor (T1 and T2) to monitor air temperature inside the vessel
- relief valve to prevent over-pressurization



Figure 2 Rigid vessels with base and top-plates and associated valves and tubing

The Vessel Assembly has the following dimensions:

- Height:800mm
- Width:460mm
- Depth:280mm

The Electrical Console has the following dimensions:

- Height:220mm
- Width:220mm
- Depth:300mm

The two vessels shown in Figure two above are what are responsible for the entire experiment. The vessel on the left will be pressurized to approximately 30psi by the pump immediately to the right of the vessels. An electronic box immediately to the right of the pump will be responsible for capturing all data required for the experiment using an Armfield Interface Device (IFD-5).

3. Experimental Procedure

The following is the procedure that our group completed by following the guidelines outlined in the document “Heat Capacity Ratio – Expansion Processes of a Perfect Gas (TH5-B).” We found that we did not have to deviate from the established procedure.

Before beginning the experiment, make sure all of the equipment is working properly. This is done by opening all of the valves and checking that all tube connections are secure. Also turn on

the pump to verify that the valves work properly, verifying that the pressure does not change after the pump is switched off. Next check that the computer and the pump are plugged in. When everything is ready to be used, turn on the computer. Open the experiment program and set P_{atm} to be 760mm of Hg.

Close all the valves except V1 and V3 to allow air into the vessels. This starts the experiment at atmospheric pressure. Close V1 and V3 while opening V4. Turn the air pump on to pressurize the large vessel. Watch the electrical console to note the pressure. Wait until the pressure passes 30 kN/m^2 . When it reaches about 32 kN/m^2 , turn off the air pump. Close V4 immediately and wait until the pressure in the vessel stabilizes to a number that does not fluctuate more than 1 kN/m^2 . Record the pressure as the starting pressure, P_s .

On the computer, click the “Configure” button. Type in “1” for the sample interval length in seconds. Click “Start” to begin the data logging. The computer will start collecting data on a table.

Open and close the valve V1 rapidly and watch the electrical console. The pressure will drop immediately. Record this pressure as P_i . Wait for the pressure to rise and stabilize at a pressure that does not fluctuate more than 1 kN/m^2 . Record this final pressure as P_f . Click “Stop” on the computer program. Save the data table and repeat the experiment for a total of five runs.

4. Experimental Results

PARAMETER	SYMBOL/EQUATION	UNIT
Atmospheric Pressure (Absolute)	P_{atm}	101325 N/m^2
Intermediate Pressure (Measured)	P_i	N/m^2
Intermediate Pressure (Absolute)	$P_{absi} = P_{atm} + P_i$	N/m^2
Final Pressure (Measured)	P_f	N/m^2
Final Pressure (Absolute)	$P_{absf} = P_f + P_{atm}$	N/m^2

Table 1. Units and definition of various pressure readings.

Equations used for calculations:

$$\gamma = \frac{C_p}{C_v} = \frac{\ln(P_{atm}) - \ln(P_{absi})}{\ln(P_{atm}) - \ln(P_{absf})}$$

$$E_\gamma = \frac{|\gamma - \gamma_0|}{\gamma_0} \times 100\%$$

Trail	Measured Pressure (N/m ²)			ABSOLUTE PRESSURE (N/m ²)			$\gamma = \frac{c_p}{c_v}$	γ_0	ERROR (E _v)
	P _s	P _i	P _f	P _s (P _{atm})	P _i (P _{absi})	P _f (P _{absf})			
1	29290	26440	27030	101325	127765	128355	0.980516	1.64	40.21%
2	29320	24400	25690	101325	125725	127015	0.954825	1.45	34.15%
3	29420	19620	22020	101325	120945	123345	0.90008	1.29	30.23%
4	29400	25580	26750	101325	126905	128075	0.960828	1.49	35.51%
5	29420	23270	24730	101325	124595	126055	0.946655	1.32	28.28%

Table 2. Experimental Data

Each run had an error around or above 30%. The average error was approximately 34%. This high error indicates some sort of operator or equipment error.

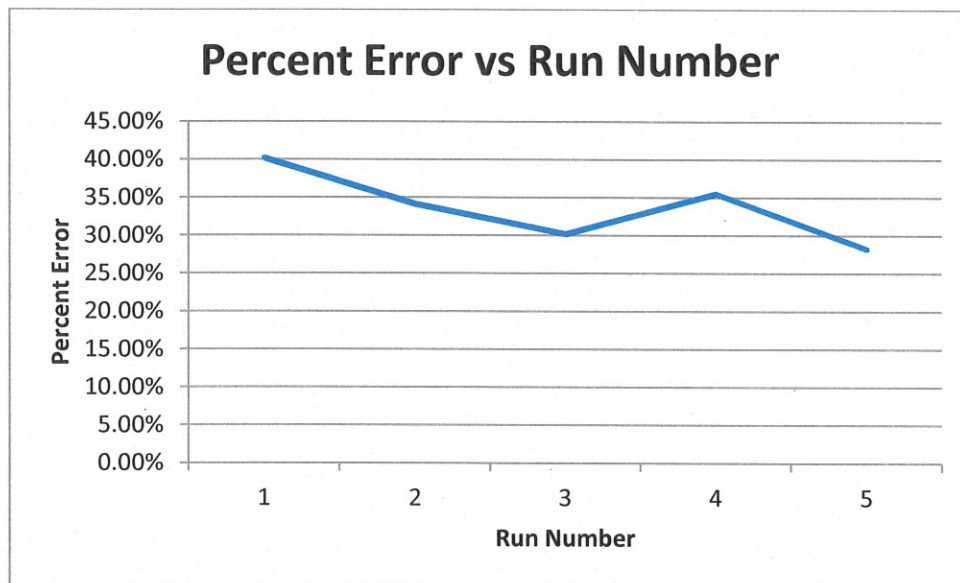


Figure 3. Graphical representation of the Percent Error for each run number. It is interesting to note the decreasing trend.

5. Discussion of Results

After the completion of the experiment, we have obtained five runs of reliable data that is shown in Table 2 above. As the run numbers continued, we had an overall decreasing error, starting at approximately 40% error and finishing at a 28% error. This indicates that as we ran the experiment we became more accustomed to the procedure and became more accurate with our measurement. It is interesting to note that there appears to be a correlation between the pressure difference between P_s and P_i and the percent error. For example, run number 3 and 5 had the largest pressure differences, and they contained the two lowest percent errors at 30.2% and 28.3%, respectively. This correlates with our prediction in the Objective of the Experiment

section in that the results are highly sensitive to the intermediate and final pressures. It may be worth exploring if the magnitude of the pressure difference has a correlation on the specific heat capacity.

The error percentage is still rather high for standard operating procedure. This was induced by a variety of factors. The primary reason for this high error would be due to operator error. While recording the data, we had to rely on viewing the electronic readout to obtain our data used for calculations. This refreshed extremely fast, and it is well within reason that this caused slight number misreading. Other errors could have been caused by improper calibration of the equipment, as evident by the percent error of all runs being at least 30%. Had it been only operator error, the error would have varied more significantly. Additionally, the temperature outside was that above ambient conditions, which could have contributed to the rather large error percentage.

Overall, the results are very consistent in relation to one another. This indicates that the experiment was consistently run across all runs. With a note of the large error percentage, the data can still be used as a reliable indication of the ratio of the heat capacities.

6. Questions

1. Why can the initial expansion process be considered as adiabatic?

An adiabatic process means that no heat transfer occurs between a system and its surroundings [4]. Normally a change in pressure is associated with a change in temperature, but since the pressure was not very high and when releasing the pressure through the valve V1, the release in pressure was so rapid that the temperature change can be considered negligible. Due to these the initial expansion was adiabatic.

2. Explain what you mean by C_p and C_v .

When we use the variables C_p and C_v we are referring to the specific heat capacity under different conditions. When using C_p we consider the specific heat capacity under constant pressure, whereas C_v is the specific heat capacity under constant volume. [3]

3. How well do the results obtained compare to the expected result? Give possible reasons for any difference.

Our results yielded a significantly high percent error for each run, but after speaking with a teaching assistant, we learned our results were similar to the results obtained by previous groups doing this experiment. Our average percent error for the five recorded trial runs was 33.68%. We conducted a number of different runs in an attempt to get the most accurate results possible and fix any potential errors we may have had in the first few test runs. Runs 1, 2 and 4 gave us a higher value of γ_o than we would have liked. Runs 3 and 5 gave us our closest results to the actual value of γ_o . Our high error percentage

is possibly due to human error. During the experiment we were required to quickly get a read off of the LCD monitor on the IFD5 after the pressure was rapidly released. Reading off the display may have resulted in the wrong data being recorded. The experiment also took place on a very hot day which had different ambient conditions than the theoretical testing conditions. Based on our initial Ohm reading from the IFD5, we could conclude the room was around 28°C where the theoretical conditions were measured at 25°C. This was figured out by using the chart provided by Dr. Kassegne in the lab instructions [2].

4. Comment on any differences in the transient responses of the pressure and temperature sensors.

The transient response of the pressure and temperature in the experiment were observed in two ways. The first way was on the IFD5, where a small LCD display would present the readout of the pressure or temperature depending on what setting the device was set to via the frontal knob. The second and more accurate was seen and recorded by the computer hooked up to the IFD5. The transient response of the pressure was set up on the computer to take and record a reading every second. The data from the pressure readings fluctuated and slowly dropped until stabilizing once the system came to equilibrium. The temperature did not fluctuate very much over time due to ambient conditions, although hot, remaining constant throughout the experiment. The pressure sensor fluctuated more than the temperature sensor due to the increase of air being pumped in and out of the pressure chamber. The pressure would slowly drop over time due the air inside the chamber trying to reach equilibrium. In an ideal situation, both the pressure and temperature sensors would respond in the same way. In this experiment, the pressure drop is significantly larger than the temperature drop, so we neglected the temperature change over time.

7. Conclusion

This experiment completed all required objectives. It successfully exposed the group to the practical aspects of the first law of thermodynamics, adiabatic processes, and constant volume temperature changes. After completing the experiment by following the prescribed procedure, we had consistent error percentage of at least 30%. This error was contributed primarily to user error, however because of the consistency of the data; it can be considered a successful lab. Future labs should examine how strong the correlation between the pressure difference and the ratio of heat capacities.

8. References

- [1] Air Liquide. *Air Properties*. Air Liquide Online Encyclopedia, 11 Sept. 2011.
<encyclopedia.airliquide.com>
- [2] Kassegne, S. "ME495 Lab - Heat Capacity Ratio of Perfect Gas - Expt Number 6." Mechanical Engineering Department. San Diego State University. Fall 2011.
- [3] Moran, M. J., & Shapiro, H. N. (2008). *Fundamentals of Engineering Thermodynamics* (6th ed.). USA: Wiley.
- [4] Incropera, F. P. (2007). *Fundamentals of Heat and Mass Transfer* (6th ed.). USA: Wiley.