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Objective of the Experiment

The objective of experiment 10 was to find the ratio of volume for air in two vessels. In the experiment an isothermal expansion process was being utilized to give us experience with the properties of an ideal gas, the adiabatic process, the first law of thermodynamics, and measurements of the thermodynamic process using P-V-T data. TH5-B equipment was used as the two vessel system and air was used as the working fluid.

The main idea of this experiment is that the mass of the air in the system will be conserved between the two vessels. The pressure in one vessel will be raised to 30 KPa while the other vessel will be a slight vacuum. By the end of the procedure, the mass will be evenly distributed between both vessels. All the while the process must remain isothermal, to prevent any temperature change in the vessel system.

According to Professor Nourollahi’s “ME-495 Laboratory Excercise - Number 10 - Ratio of Volumes”, the following equations were needed for the calculations:
\[
m_1 = \frac{V_{ol1} P_{1 abs}}{RT} \quad \text{for the volume of the first vessel,}
\]
and \[
m_2 = \frac{V_{ol2} P_{2 abs}}{RT} \quad \text{for the volume of the second vessel.}
\]
Substituting in to equation 1 then gives:
\[
P_f = \frac{V_{ol1} P_{1 abs} + V_{ol2} P_{2 abs}}{V_{ol1} + V_{ol2}}
\]
Cancelling \(R\) and \(T\), and rearranging gives:
\[
P_f = \frac{V_{ol1} P_{1 abs} + V_{ol2} P_{2 abs}}{V_{ol1} + V_{ol2}}
\]
Dividing top and bottom by \(V_{ol2}\), we get:
\[
P_f = \frac{V_{ol1} P_{1 abs} + V_{ol2} P_{2 abs}}{(V_{ol1} + V_{ol2})}
\]
This can be rearranged to give the equation for the volume ratio of the vessels.
\[
\frac{V_{ol1}}{V_{ol2}} = \frac{P_{2 abs} - P_f}{P_f - P_{1 abs}}
\]

**Table 1: Key Terms**

<table>
<thead>
<tr>
<th>TERM</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vol1</td>
<td>Volume in vessel 1 (m^2)</td>
</tr>
<tr>
<td>Vol2</td>
<td>Volume in vessel 2 (m^2)</td>
</tr>
<tr>
<td>p1abs</td>
<td>Initial absolute pressure in vessel 1 (N/M^2)</td>
</tr>
<tr>
<td>p2abs</td>
<td>Initial absolute pressure in vessel 2 (N/M^2)</td>
</tr>
<tr>
<td>pabsf</td>
<td>Final absolute pressure (N/m^2)</td>
</tr>
<tr>
<td>ps</td>
<td>Initial pressure in vessel 1 (N/m^2)</td>
</tr>
<tr>
<td>Vs</td>
<td>Initial vacuum in vessel 2 (N/m^2)</td>
</tr>
<tr>
<td>plabsf</td>
<td>Final pressure in vessel 1 (N/m^2)</td>
</tr>
</tbody>
</table>

**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.
- 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.
  - 3 smaller quarter-turn ball valves.
- Associated tubing and fittings to connect pump to vessels
- Electrical console with current protection devices and an RCD for operator protection. The electrical console can measure pressure in increments as sensitive as 10 Pa and temperature as sensitive as 1 Ohm (resistance is inversely proportional to the temperature).
  - PC for data collection
  - IDF5 interface device
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 ±34.5kN/m²)
- 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: Valve Assembly
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 2 above are what are responsible for the entire experiment. The vessel on the left will be pressurized to approximately 30 psi 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).

**Experimental Procedure**

Begin the experiment by opening only valves V1 and V3 to ensure each chamber is at atmospheric pressure. Once this is completed close valves V1, V3, and V5 while opening V4 and V7.

Next, switch on the air pump and begin pressurizing the large vessel to slightly above 30KN/m^2. After this is reached turn off the pump and close valves V4 and V7 allowing the pressure to settle to 30KN/m^2.
Allow the pressure in the large vessel to stabilize and record the initial pressure and ambient temperature. Now, allow the software to begin recording measurements. Keep valve V5 closed while opening the isolating valve V6. Now slightly open V5 so air begins to leak to the other vessel. Allow the pressure to fall while maintaining the same temperatures.

As the experiment continues V5 can be opened more to allow the pressure and temperature in the vessel to stabilize. Once this happens record the final pressure and press stop on the software program. Finally, save and export the data [1].

**Experimental Results**

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL/EQUATION</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant temperature for both vessels</td>
<td>T</td>
<td>° C</td>
</tr>
<tr>
<td>Atmospheric pressure</td>
<td>$P_{atm}$</td>
<td>101.325 kN/m^2</td>
</tr>
<tr>
<td>Initial pressure for vessel 1 (measured)</td>
<td>$P_s$</td>
<td>kN/m^2</td>
</tr>
<tr>
<td>Initial pressure for vessel 1 (absolute)</td>
<td>$P_{1abs} = P_{atm} + P_s$</td>
<td>kN/m^2</td>
</tr>
<tr>
<td>Initial vacuum for vessel 2 (measured)</td>
<td>$V_s$</td>
<td>kN/m^2</td>
</tr>
<tr>
<td>Initial pressure for vessel 2 (absolute)</td>
<td>$P_{2abs} = P_{atm} - V_s$</td>
<td>kN/m^2</td>
</tr>
<tr>
<td>Final pressure (measured)</td>
<td>$P_f = V_f$</td>
<td>kN/m^2</td>
</tr>
<tr>
<td>Final pressure (absolute)</td>
<td>$P_{1abs} = P_f + P_{atm}$</td>
<td>kN/m^2</td>
</tr>
</tbody>
</table>
Table 3: Results

<table>
<thead>
<tr>
<th>TRIAL</th>
<th>INITIAL PRESSURE</th>
<th>FINAL PRESSURE</th>
<th>R=</th>
<th>R_o</th>
<th>ERROR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$P_s$</td>
<td>$P_{1abs}$</td>
<td>$V_s$</td>
<td>$P_{2abs}$</td>
<td>$P_f$</td>
</tr>
<tr>
<td>1</td>
<td>29.82</td>
<td>129.82</td>
<td>34.46</td>
<td>65.54</td>
<td>109.8</td>
</tr>
<tr>
<td>2</td>
<td>30.41</td>
<td>130.41</td>
<td>34.46</td>
<td>65.54</td>
<td>99.5</td>
</tr>
<tr>
<td>3</td>
<td>30.47</td>
<td>130.47</td>
<td>34.46</td>
<td>65.54</td>
<td>109.0</td>
</tr>
<tr>
<td>4</td>
<td>31.15</td>
<td>131.15</td>
<td>34.46</td>
<td>65.54</td>
<td>110.6</td>
</tr>
<tr>
<td>5</td>
<td>29.41</td>
<td>129.41</td>
<td>34.46</td>
<td>65.54</td>
<td>110.1</td>
</tr>
</tbody>
</table>
Discussion of Results

For trials one through five the following ratios were recorded: 2.21, 1.09, 2.02, 2.19, 2.31. These results are fairly consistent with the calculated theoretical ratios at 2.35, 1.14, 2.12, 2.32, 2.45 respectively.

Overall, the results gathered show a reasonable amount of experimental error. Trial 2 showed the least amount of experimental error at 4.39%. The largest error was trial 1 with 5.95%. The rest of the trials had error percentages values within this range. These error values are far from exorbitant and display the theory of ratio of volumes to a reasonable degree.
The error recorded can be attributed to various sources. For instance, error could be present in the sensing equipment of the experiment. However, more likely, the error occurred because we allowed the temperature to change slightly. This process should have remained isothermal but it was difficult to adjust the valve to maintain this. This explains why the results have varying error amounts and not just a consistent biased error.

**Lab Questions**

1. **Why is this an isothermal process?**

   An isothermal process is when the temperature for an ideal gas remains constant during a process. If the internal energy is proportional to the temperature for an ideal gas, the internal energy remains constant if there is no change or variation in temperature. In this experiment, a single vessel of the TH5 Expansion Processes of a Perfect Gas Apparatus was pressurized, and once the process stabilized, air was slowly let out into the second vessel through the needle valve, V5, until the pressures of both vessels equalized. And because air was released from the first vessel very slowly, the temperature of the gas remained constant, thus concluding that the process is isothermal.

2. **How well does the result obtained compared to the expected result? Give possible reasons for any difference.**
We had an average error of 5.27%. This amount of error is not significant and the error did not fluctuate a large amount between the trials. If we assume that the equipment was in perfect working condition, human error is most likely the cause for discrepancy. We had to slowly release the air from the vessels. Where releasing air too fast would cause a bad reading, but how fast is too fast? This could have been an issue as well as not knowing exactly how much air was being released while turning the knob.

3. Comment on the effect if the rate of change of pressure was sufficient to affect the temperature of the air inside the vessels.

When a system is pressurized, the molecules of a perfect gas move more slowly due to the decrease of space for gas molecules to move freely around. Because this experiment was an isothermal process, air was slowly released through the needle valve, therefore the air molecules did not move rapidly enough to cause a significant change in the temperature. The temperature variation recorded by the computer did not vary more than 1 degree Celsius, illustrating that the flow of air interchanged between the cylinders, was in fact, slow enough to neglect any temperature changes in the system, defining an isothermal process.

Conclusion

After conducting this experiment, the final ratio of volumes that came out to be were 2.21, 1.09, 2.02, 2.19, and 2.31. These values, when compared to their theoretical ratio of volumes values, had percent errors of 5.95%, 4.39%, 4.72%, 5.60%, and 5.71% respectively. The percent error that emerged most likely arose from a potential leak in
the valves or pressurized vessel. Also, not waiting for the system to find its actual
stability point may be a reason error may have occurred also. Even so, this experiment
demonstrated how an isothermal system should balance out in pressure readings after
exposed to a vacuum and given a certain amount of time. It also brings forth thought
about how this process can affect certain systems that need to maintain certain
pressure volumes.

Acknowledgements
Thanks to SDSU Engineering Department for letting us borrow and use the necessary
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Perfect Gas (TH5-B) experiment. In addition, thank you professor Hamid Nourollahi for
creating the experiment and supervising the lab.

References

Mechanical Engineering Department. San Diego State University. Spring 2018