The Effects of Decreased Pressure on the Rate of Cooling

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Physics 212

Purpose

In class we have had the opportunity to investigate the laws of thermodynamics. We preformed several experiments to reinforce the validity of these laws which were learned. Relations between work and thermal energy transfers, pressure and volume, isobaric, isothermal, isovolumetric, and adiabatic processes, were all defined through a series of observable examples to carve out definite understandings of nature's occurrences. Oft times we found that some results were different from what our common intuitions lead us to believe, for example the possibility to "heat" a given object (add thermal energy) and not observe a temperature change. Results like these lead us to query whether our understanding of the relation between pressure and temperature change are as correct as we believe them to be. The question we present in this project is if the rate at which the temperature of a gas will cool will depend on the pressure of the gas and how. Experimentation with this issue should lead us to a definite or satisfying answer that, perhaps, will also provide a better understanding as to how variables such as pressure affect temperature and the cooling rates of objects. Even in the principal steps of considering this project we noticed how the different factors of the problem made us question what may happen, so a good clarification will be an objective of this paper.

Hypothesis

Our hypothesis is that when we decrease the pressure on a system while an object cools, the time it takes for it to cool to a certain temperature will increase. This assumption leads much to what we consider to be common knowledge. For example, pressure cookers have an oven with a high internal pressure to increase the effectiveness of its cooking. Reversely, a low internal pressure should do just the opposite. However, our hypothesis was also formed by what we have learned about the theoretical behavior of particle movement according to the temperature and pressure of a system. The higher the pressure, the more frequently particles will collide with each other and transfer energy. The higher temperature, the faster the particles will move.

The first theoretical consideration for our experiment and hypothesis that we will use is proportionality of pressure and temperature towards each other. When all other factors are held constant, pressure will go up to the same degree that temperature will and vice versa. This relation at first made it a bit more difficult than expected to choose how we were going to set up our experiment. Originally we thought that the best way to carry this out would be to hold the pressure constant and try to cause some sort of temperature change then we realized that we would be having other variables change such as volume or moles of gas. The equation for the Ideal Gas Law that follows will be the first of our theoretical guidelines.

$$PV = nRT \tag{1}$$

Any change we make to any of the above variables of pressure, volume, moles, and temperature should affect each other. Notably, time is not represented in this equation and since our experiment is centered around cooling *rates*, we will need to use Newton's Law of Cooling as our second theoretical equation to guide our experiment:

$$T(t) = (T_i - T_s)e^{-\alpha t} + T_s \tag{2}$$

Our experiment will primarily deal with what the constant α represented in the above equation and if our hypothesis is correct, pressure must somehow affect the value of α. Judging by what we stated about the theoretical movement of particles, a low pressure must make them collide less frequently, thus making them exchange energy less frequently, which all leads to a slow cooling rate.

We decided that we did not want to have to deal with changing volumes; this leaves us with only the pressure on the left hand side of the equation to change as temperature changes. With that on the right hand side of the equation we wished to observe how temperature changes so we will be keeping our moles constant during each experiment. The project at hand will then be observing how when we begin with specific pressures of gas the temperature changes of the gas with respect to time. Pressure and temperature will both change through out the observation, but we will be able to determine whether the moles of gas involved or the initial pressure of our gas at a certain temperature will have an effect on how quickly a gas gains or losses thermal energy.

Experimental Procedure

Extremely cautious and careful experimental procedures were necessary in order to determine exactly how cooling rates are affected by pressure. I will begin by discussing the instrumentation and hardware required to collect the necessary information to reach conclusions on this project. Our initial project called for the testing of cooling rates at different pressures. In order to accomplish this we used a small hand-operated vacuum pump. This particular pump is capable of creating a 30 inches of Mercury vacuum. This pump made it possible for us to collect six different sets of experimental data at six different pressures. This indeed was a great help to ensure the accuracy of our conclusions. As in all experimental work, the more opportunities to observe a phenomenon, result in more concrete and confident conclusions.

The pump was connected to an intricate system consisting of sensors and containers. A 249 ml erlenmeyer flask was plugged with a rubber stopper. The stopper contained two holes in it. Through one of the holes was inserted a piece of tubing connecting an electronic pressure sensor to the flask. This particular piece of tubing contained a tee in it which also accommodated for the connection of the vacuum pump to the system. Inserted through other hole in the rubber stopper was an electronic temperature sensor as pictured in figure 1.

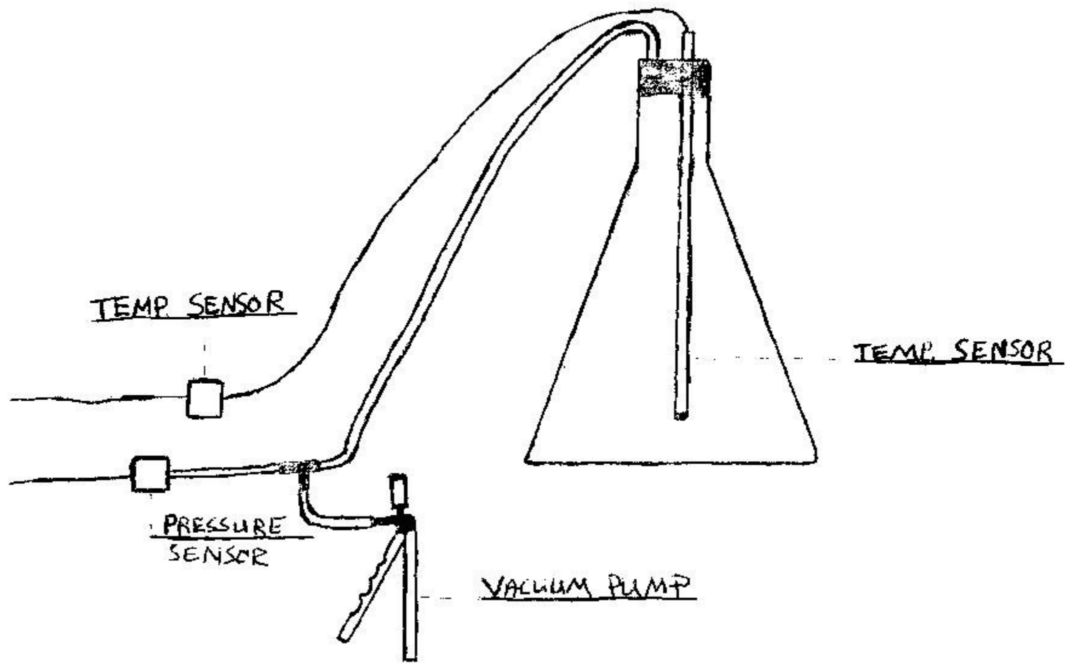

Figure 1.1: Apparatus layout

One of the main challenges that we foresaw before we began the project was the task of eliminating all air leaks in the system. It is important to note that we used a special lubricant at any and all joints of the closed system to lubricate and eliminate any possible seepage which could ultimately alter the results of the experiment. After lubricating all joints we then connected the electronic temperature sensor and the electronic pressure sensor to Lab-pro software.

The Lab-pro software allowed for the collection of pressure versus time and temperature versus time data. Precise calibration of the temperature and the pressure sensor was required at the beginning of experiments each day. After assembling the experimental system, we then began the experiment. For the first run we started the system at the atmospheric pressure for Salt Lake City on March 29, 2005 which was 101 KPa. In order to create a situation in which the air substance contained in the flask could experience cooling, we had one insulated mug containing hot water and one mug containing ice water.

We first submersed the flask to a predetermined level in the hot water mug and allowed the gas inside the flask to reach a temperature of 60˚C. After the gas inside the flask reached this level we then immediately moved the flask to the mug containing the ice water. As in the hot water, the flask was only submersed to a predetermined level to keep the contact between the flask and the two reservoirs constant in each experiment. Agitation of the mugs was employed throughout all six experimental runs.

On the first day of testing two experimental cooling runs were made. Four more runs were completed over two more days. Respectively, the six experiments were conducted at 101 KPa, 91 KPa, 60 KPa, 50 KPa, 30 KPa, and 24 KPa. With each experimental run we endeavored to keep each step of the run consistent and constant only allowing the pressure to vary. With pressure as the only variant, we could then determine how pressure affects cooling rates.

Results

We set our first experiment up so that the pressure within our apparatus would begin at the same pressure as the room (the normal atmospheric pressure). This pressure would be our control to measure against the results in our subsequent experiments where the pressure would be decreased. The first experiment yielded us these results.

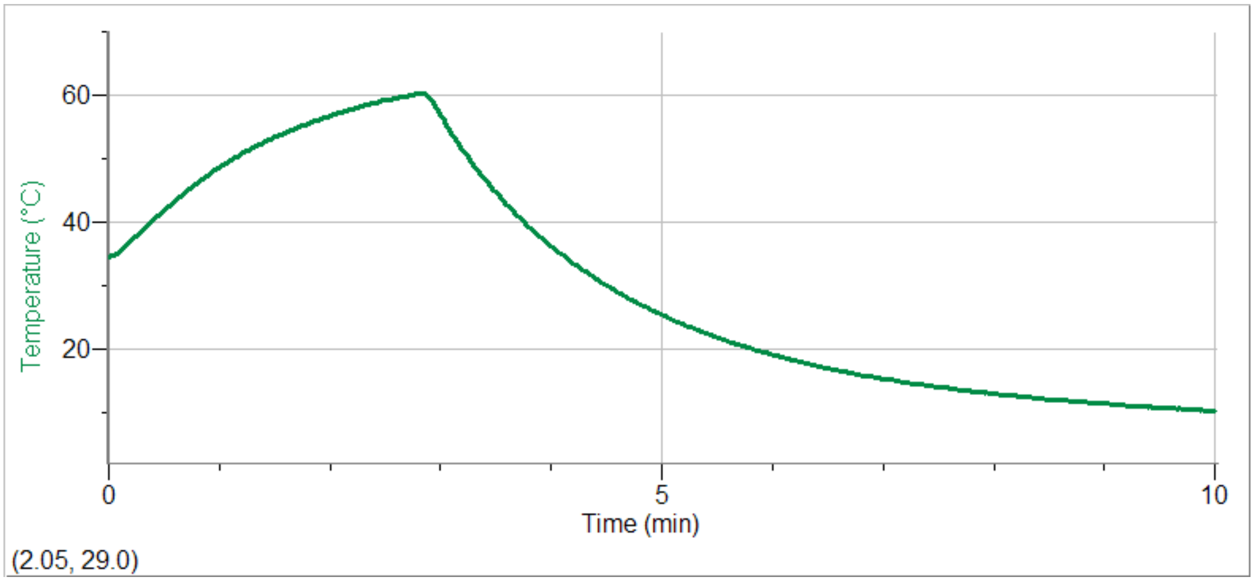

Figure 2.1 (Temperature): T_i = 60.0°C (at peak) , Temperature reaches 15°C after 4.2 minutes

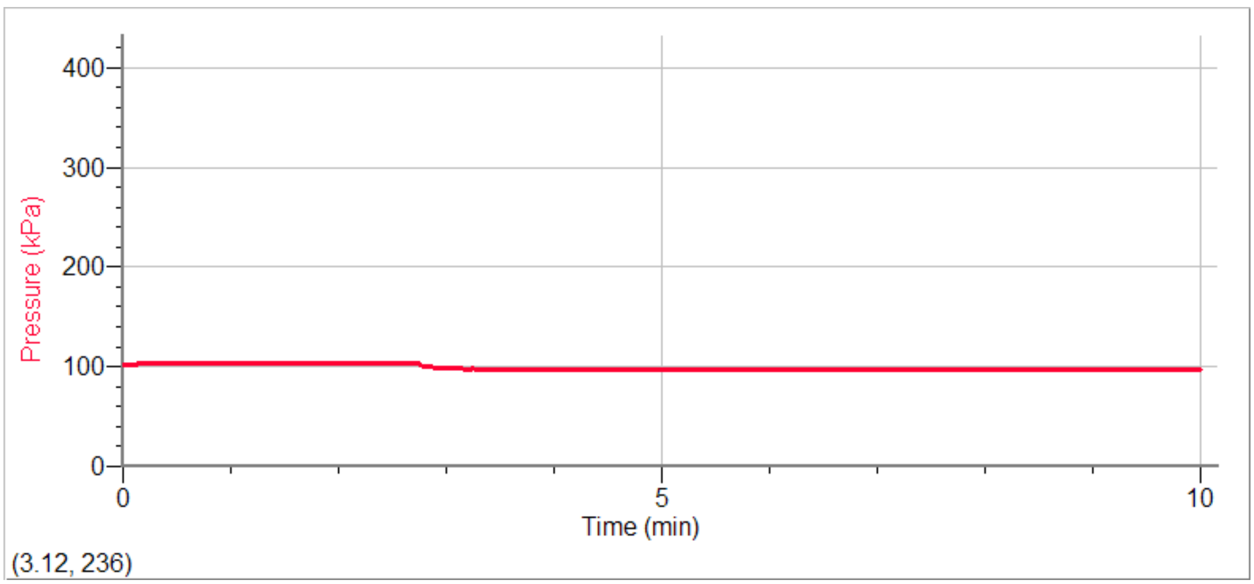

Figure 2.2 (Pressure): Pressure peaks at 102.9 kPa, drops to 97.5 kPa

First the details of the graph: The first aspect of our results that we were pleased with was the stability of the pressure data. Since our experiment relies upon the pressure as the variable, the pressure would need to be as constant as we could make it. The second aspect we found pleasing was the smoothness of the temperature data. We needed to make the cooling process as consistent as possible to make the interpretation of data simpler. However, the pressure here is unusually constant; the sudden drop in pressure when the flask is first immerged in the cold reservoir and then its constant afterwards means that the gas is no longer changing its pressure and therefore it must no longer be changing its temperature either. This came as a surprise to us as our objective was to measure the cooling rate of the *gas*. But if the gas is changing too quickly to be noticed by the temperature sensor then we are merely graphing the change in temperature of the sensor itself. Fortunately, this would not affect the primary objective of our experiment which is to measure simply the effects of varying pressure on cooling rates. We simply need to change our focus from the cooling of the *gas* to the cooling of the *sensor*. Since the sensor is the same in all experiments we do not need to address this further.

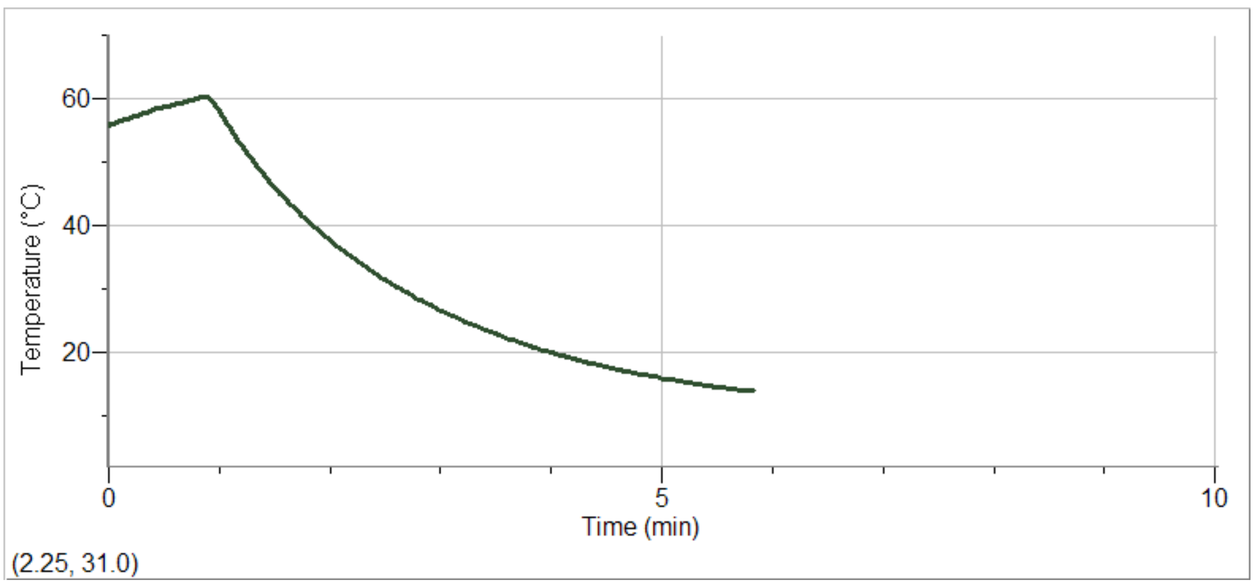

Figure 3.1 (Temperature): Temperature reaches 15°C after 4.4 minutes

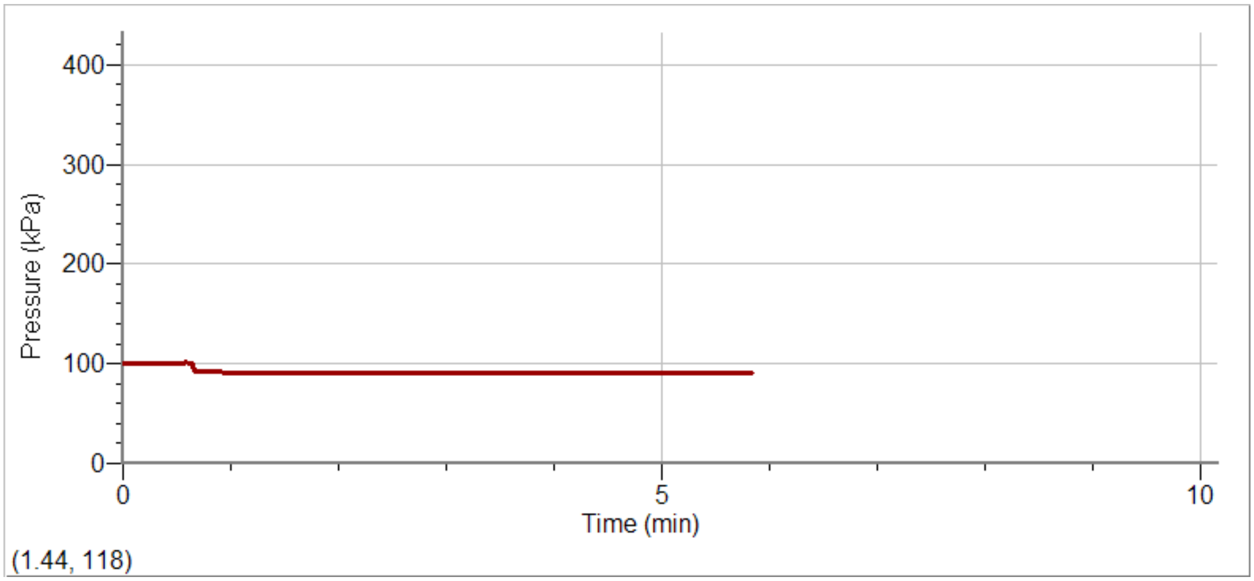

Figure 3.2 (Pressure): Pressure drops and settles to 90.7 kPa

This second run shows a slight decrease in the time it takes for the temperature to cool to 15°C which is what expected given that pressure decrease from the last one is relatively small (about 6.8 kPa difference). Again, we attribute the smoothness of the temperature graph to steady agitation within the cold reservoir as well as proper maintenance of the cold reservoir's temperature.

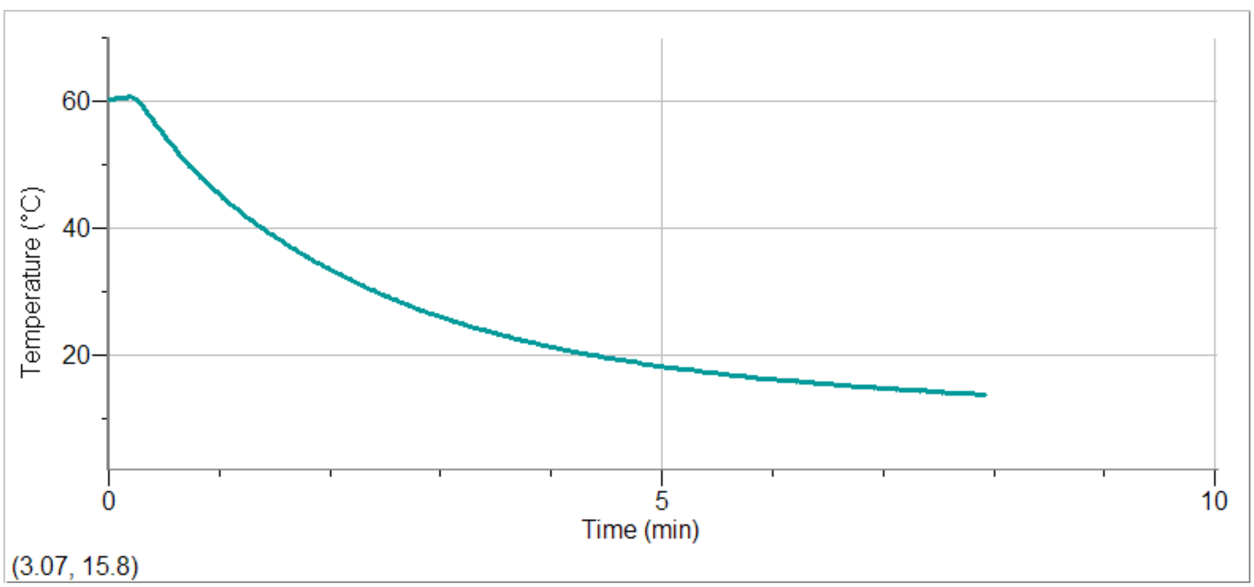

Figure 4.1 (Temperature): Temperature reaches 15°C after 6.5 minutes

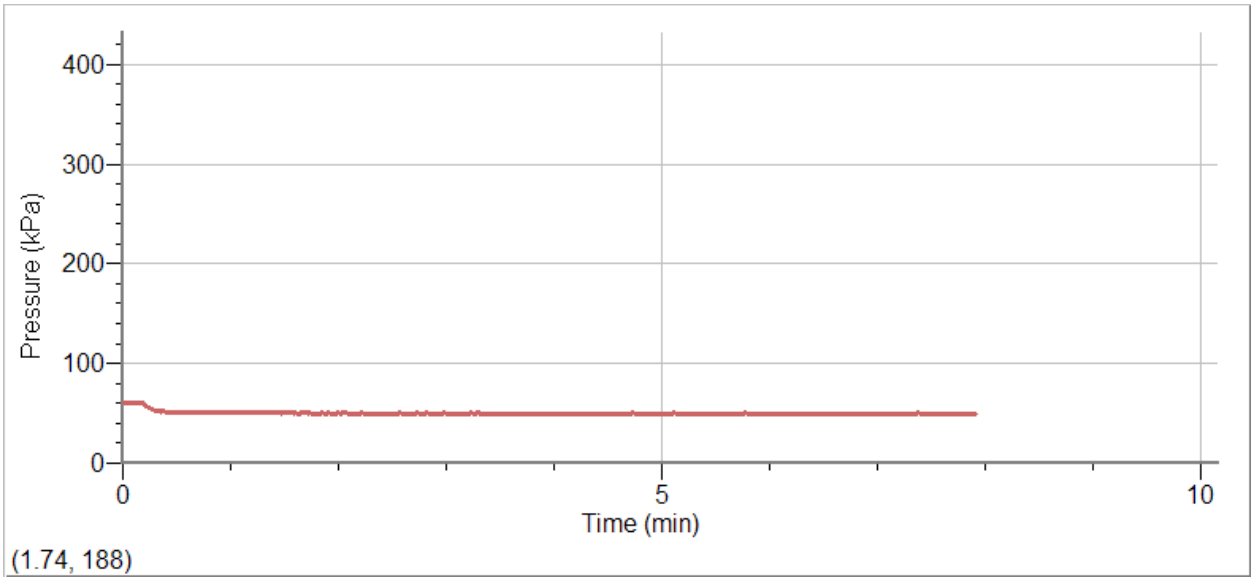

Figure 4.2 (Pressure): Pressure drops and settles to 49.7 kPa

By this point we were very pleased with the consistency of the drop in cooling rate as a result of the drop in pressure. The pressure was 41 kPa lower than the last run and the rate of cooling increased by 2.1 minutes to 6.5 minutes which is a sizeable increase when the relatively large decrease in pressure is considered. Our results so far show that the cooling rate is *not* directly proportional to pressure which is what we figured since the cooling constant found in Equation 2 instead must be what pressure directly affects and therefore how it affects the cooling.

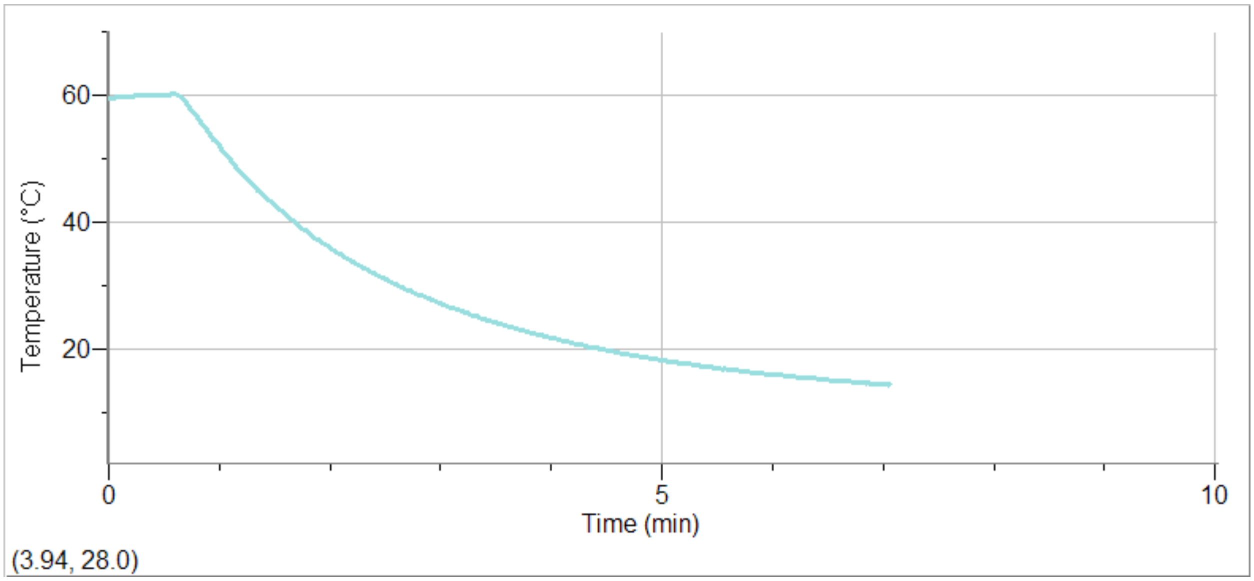

Figure 5.1 (Temperature): Temperature cools to 15°C after 6.0 minutes

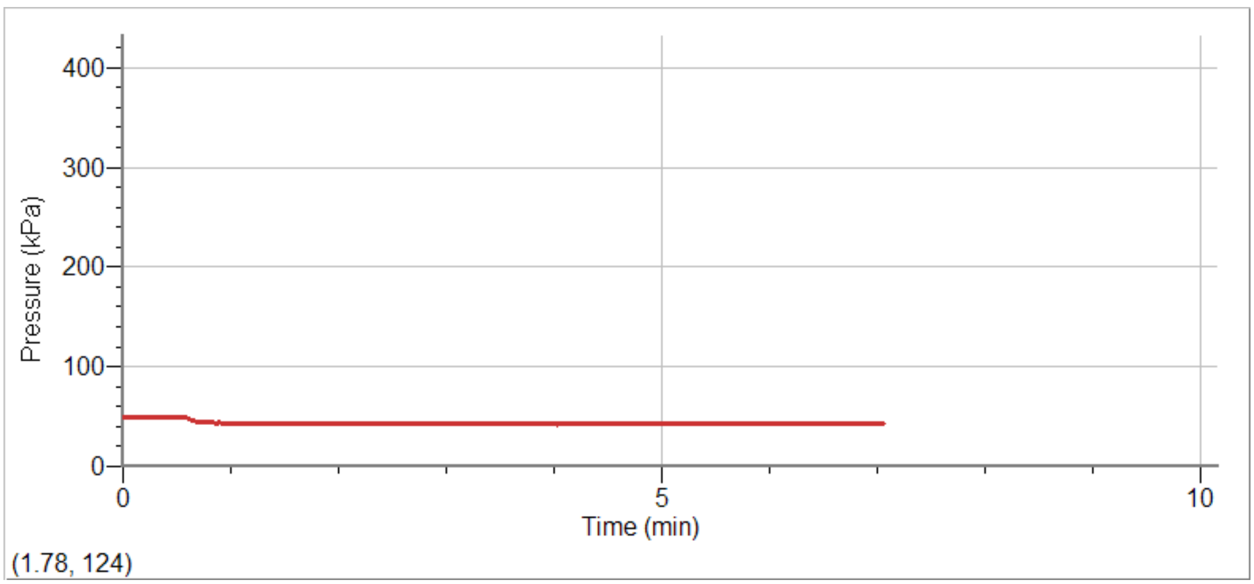

Figure 5.2 (Pressure): Pressure drops and settles at 42.6

At this point our data becomes surprising. We decreased the pressure by 7.1 kPa from the last run but the time it took for the temperature to reach 15°C *increased* by half a minute. The solidity of the results for our first three runs makes us confident that this discrepancy must be caused by a change in how we set up our experiment for the experiments were performed in pairs on separate days (e.g. the first two one day, the second two another, and so on). To identify this source of error will require further experimentation and our first step would be to redo at least several of our runs on the same day to make sure the error wasn't in how we set up our experiment (albeit, our the processes of our experiment is fairly systematic and should be consistent over most areas).

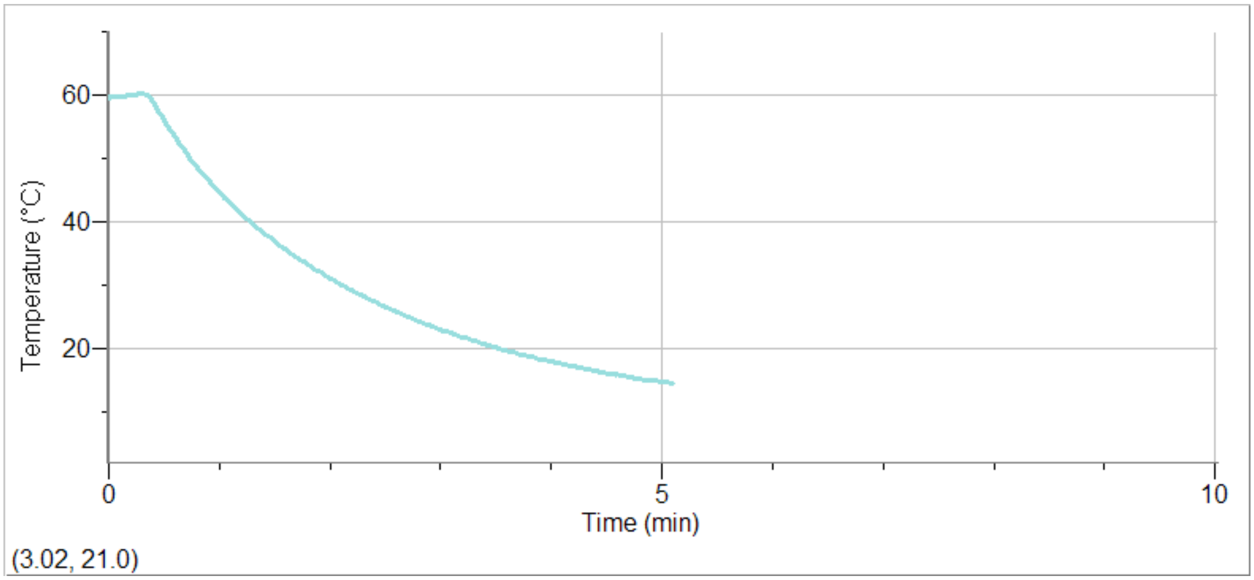

Figure 6.1 (Temperature): Temperature reaches 15°C after 4.5 minutes

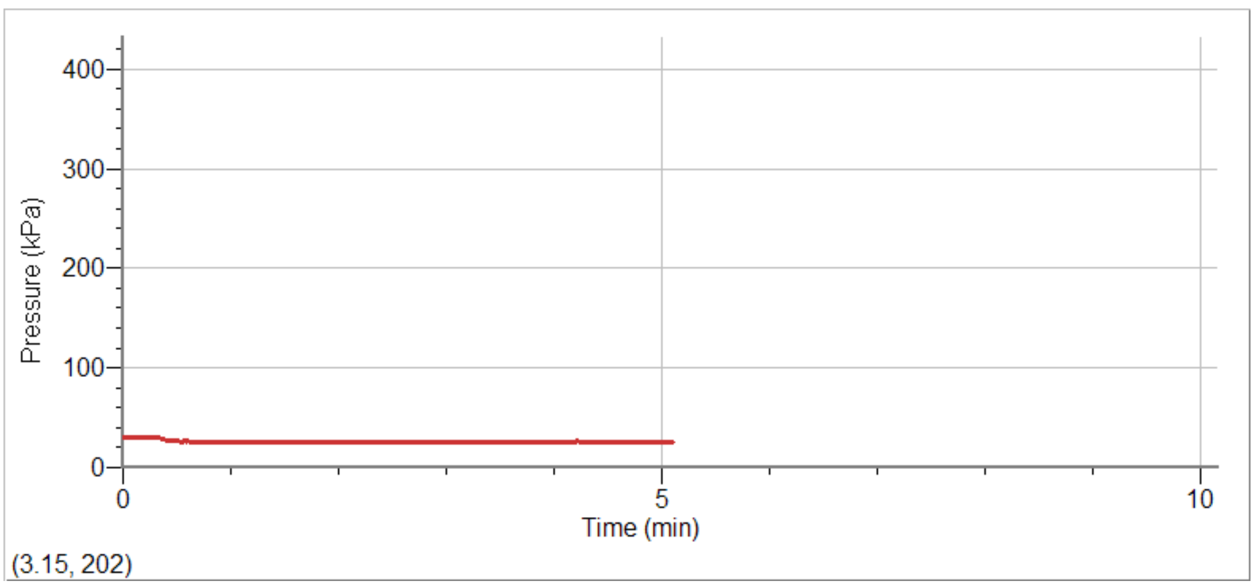

Figure 6.2 (Pressure): Pressure drops and settles at 25.8 kPa

Although this and the last run are consistent each other according to our hypothesis they are not consistent with the other runs, so this strengthens our hypothesis that the source of our is likely a change in how we set up the experiment in the days we did it. Here, we decreased the pressure by 16.8 kPa from the last run and the temperature took one and half minutes less to cool to 15°C.

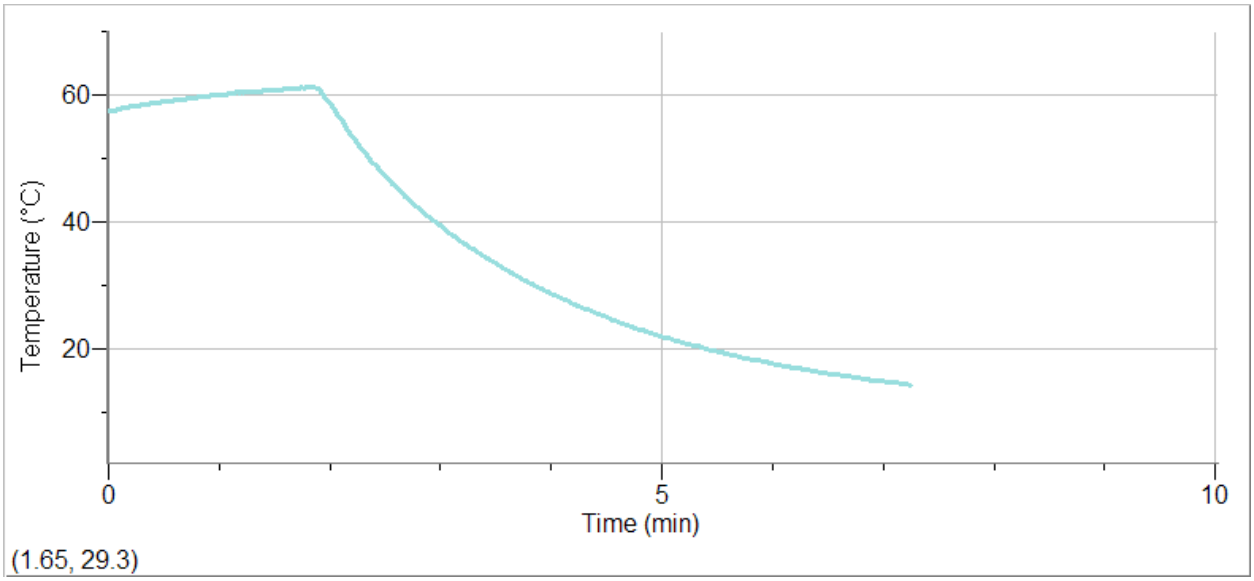

Figure 7.1 (Temperature): Temperature cools to 15°C after 5.0 minutes

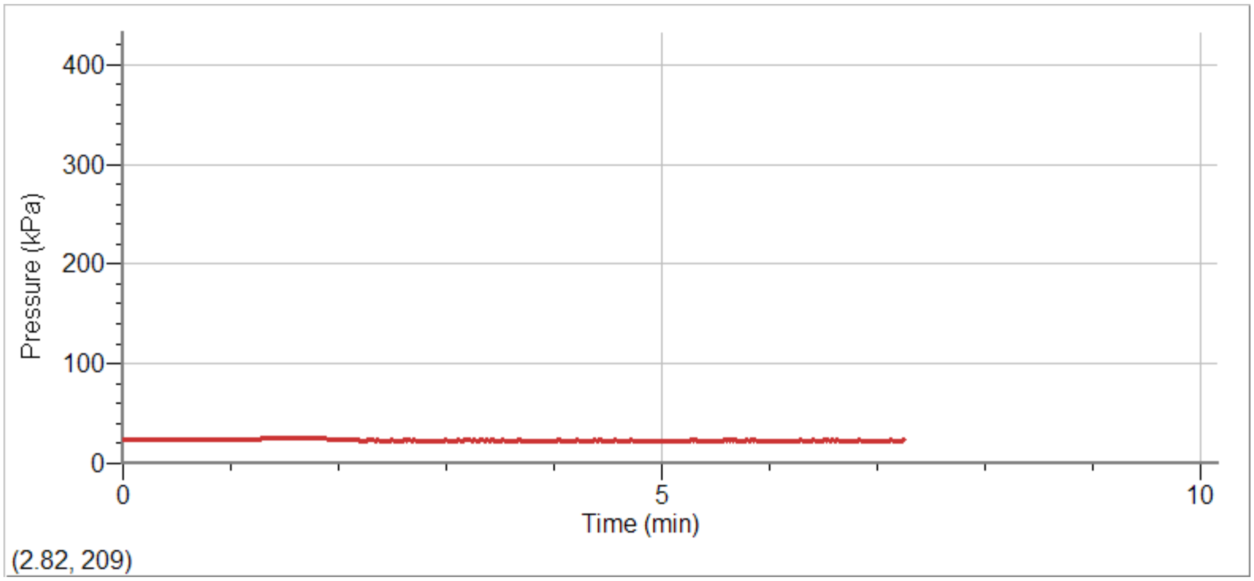

Figure 7.2 (Pressure): Pressure drops and settles around 22.8 kPa

In this run we decreased the pressure by 3.0 kPa and the temperature took half a minute longer to cool to 15°C. Once more, this run is fairly consistent with the last run, though the cooling rate seems to have a relatively dramatic change. The cooling rate increased by 10 seconds for every 1 kPa decreased. As a comparison, in the first two runs the change in cooling time compared to the change in pressure was 1.2 seconds for every 1 kPa. Finally, we've included all the data from our runs into two separate graphs:

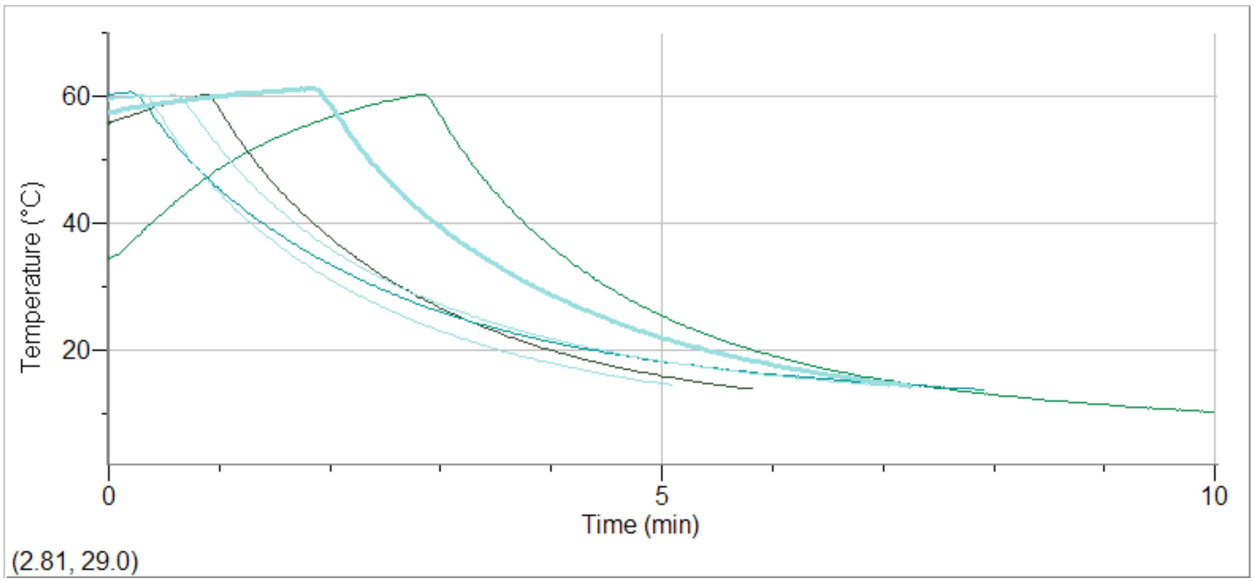

Figure 8.1 (Temperature): Colors correspond to the colors in the previous graphs

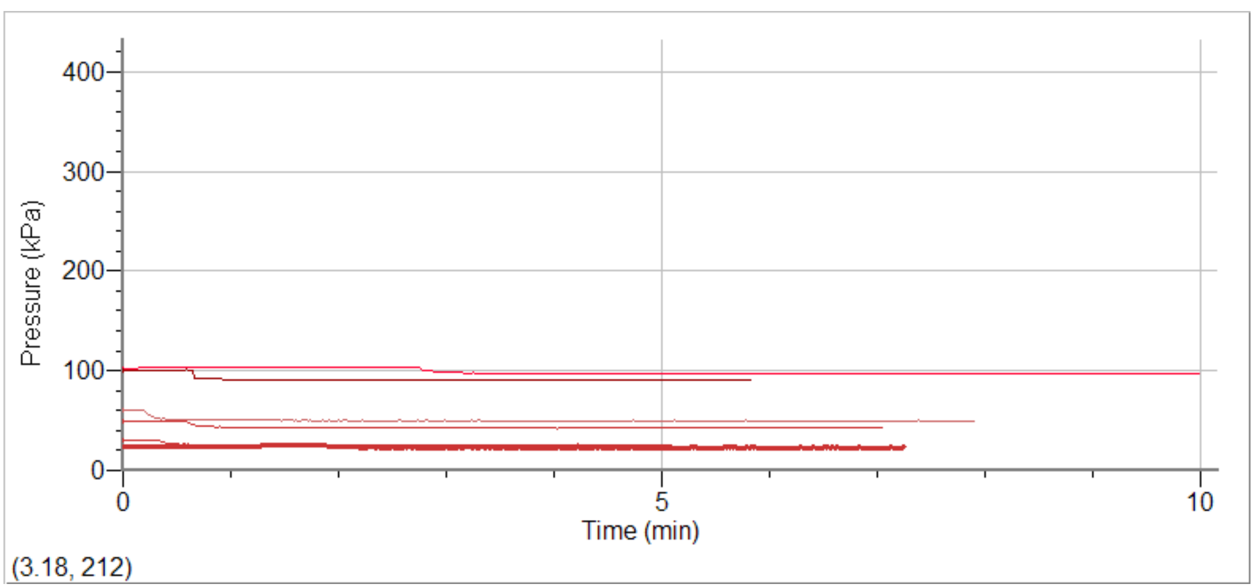

Figure 8.2 (Pressure): Colors correspond to the colors of the previous graphs

Lastly, to more simply compare the graphs in our individual runs we've compiled just the data along with the constant α calculated for each run.

Day 1				
	Run 1:	t = 4.2 minutes	P = 97.4 kPa	$\alpha_{exp} = 0.33$
	Run 2:	t = 4.4 minutes	P = 90.7 kPa	$\alpha_{exp} = 0.32$
Day 2				
	Run 3:	t = 6.5 minutes	P = 49.7 kPa	$\alpha_{exp} = 0.21$
	Run 4:	t = 6.0 minutes	P = 42.6 kPa	$\alpha_{exp} = 0.23$
Day 3				
	Run 5:	t = 4.5 minutes	P = 25.8 kPa	$\alpha_{exp} = 0.31$
	Run 6:	t = 5.0 minutes	P = 22.8 kPa	$\alpha_{exp} = 0.28$

Figure 9.1: Compilation of experiment data

Conclusion

Though the decrease in the rate of cooling did not turn out as consistently as we would have like, the overall smoothness of all the graphs show that at least each time we take measurements the system itself is not loosing air or pressure or cooling itself unevenly. The theoretical background in which we based our hypothesis we've judged to be fairly solid and our results seem to show at least some correspondence between pressure decreasing and cooling rates increasing. The primary problem for our results is consistency.

Day 1 and Day 3 at least show results that when viewed separately seem to support our hypothesis if not when they are viewed together. The first run of Day 2 also seems to transition nicely from the last run of the first day, but the second run gives us trouble. Since each day we did the experiment we had to put back together the apparatus and recalibrate both the temperature sensor and the pressure sensor, the source of error must be located somewhere within those processes.

The second issue is that we set out to find the cooling rate of air only to discover that the sudden drop in pressure at the begin of each run seems to show that the air immediately cools to freezing when placed in the cold reservoir, which would mean that the temperature sensor is recording the temperature of itself. Again, this discrepancy does not alter the primary objective of our experiment which is simply pressure vs. cooling rates, not necessarily cooling rates of gasses. In theory, the cooling rate is still being affected by the pressure and movement of the gaseous particles they must act like a secondary cooling reservoir for the sensor since they quickly drop to the temperature of the actual cold reservoir. The Ideal Gas Law and our observations with the sudden decrease of pressure at the beginning of each run taken together support this idea.

Finally, the constant α should be the key into finding how pressure relates itself to the cooling rate quantitatively. When we decreased the pressure decreased and the cooling rate increased as we expected, α also decreased. Though we can explain through the Ideal Gas Law pressure being proportional to temperature, we know just by our results (taking only the runs we believe to be most acceptable) pressure and cooling rate are not proportional to each other though they affect each other somehow. This leads us to believe that it is the pressure and the constant α that are somehow proportional to each other, but we will first need to provide more support for our first hypothesis. Our hypothesis still shows strength, however, and elimination of what we perceive to be the sources of error may be the solution for fixing our data.