Lab 1

MEAM 2480

Dr. Yim

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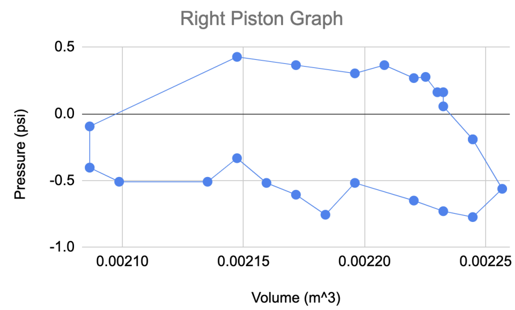
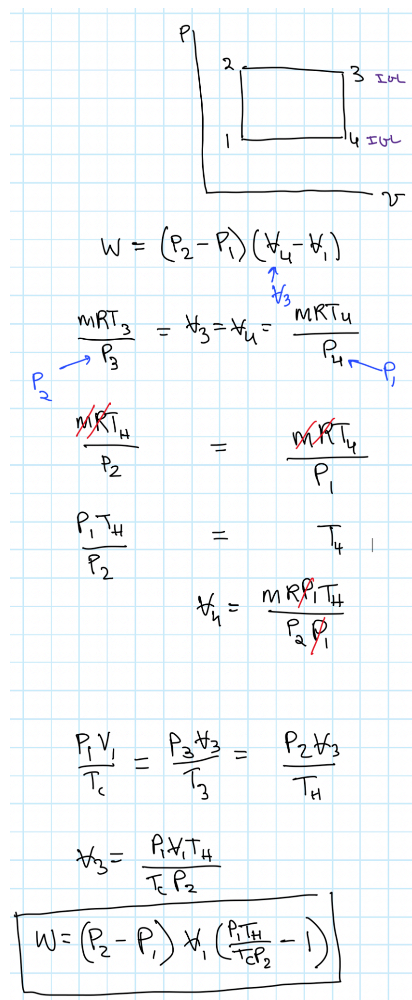
Model



Based on initial calculations, we got a value of 675 J, which we found unreasonable. We then decided to use data from another group when estimating our predicted work calculations.

Now, as indicated in both graphs, the curve somewhat resembles the shape of a rectangle, which is an ideal graphical representation of this process. However, factors such as friction cause the shape of the graph to change. The diagonal slope in the left side of the graph is due to the friction force against the piston as it moves, after the bottle is placed into the cold bath in the beginning. Similarly, this also causes the diagonally slanted curve on the far right side, as the piston moves when the bath is switched again from hot to cold. Then, instead of a perfectly horizontal line, the graph has a slight downward curve, which could be due to losses, such as a gas leak.



When calculating work, if we assume a completely idealized cycle, with no friction losses, we can find a general equation for the work done during the cycle in terms of the pressures, temperatures, and starting volume. (Source: problem 4 on MEAM 2030 homework #3, solved by Ashna Khemani). Then, we can account for factors such as friction, which reduce the total work that can be done on the mass.

Because we are working with a physical system, we know the work actually outputted will be less due to things like friction and air leaks. We measured the force of friction by placing the entire piston/ratchet system on a weighing scale, and lifting it by the piston shaft until the piston started expanding. This allowed us to determine the force of static friction to be about $F_f = 40[N]$. The work due to friction is $W_f = F_f d = F_f \frac{\Delta V}{A}$. We know F_f and the area of the piston A can be measured. ΔV can be found by using the ideal gas law and/or empirical data of the piston stroke. Alternatively, if we are simply observing the piston stroke, we can directly find d by measuring how far the piston moves each stroke.

Therefore, our final formula for the work output is:

$$W_{net} = (P_2 - P_1)V_1\left(\frac{P_1 T_H}{T_C P_2} - 1\right) - F_f d$$

We can use this formula to choose the optimal spool diameter and mass. For example, if we know the total work that can be done, we can relate this to the formula for torque,

$\tau = rFsin\theta$ by substituting this into the equation for work because $W = \int \tau \, d\Theta$.

Performance

Using our model, we decided to choose the larger diameter spool and smaller mass during our tests in class. With bath temperatures of 1 °C and 45 °C, our estimate using the model above yielded a negative number, which is not ideal. Therefore, when we were in the lab for the final week, our group chose to instead estimate the amount of work done by taking the area under the PV diagram curve, and we eventually obtained a value of 0.14 Joules. Unfortunately, this value was an overestimate of the actual work done by the pistons, which amounted to 0.044 Joules in 60 seconds (0.0067 Watts). There were many potential reasons as to why our calculated value was higher than the actual value.

We believe a fault with our performance was our strategy. To maximize the temperature difference and use as much of it as possible to generate work, we developed the following strategy:

1. Put both bottles (A and B) in the cold bath with their caps off
    a. Cold temperature → Pressure drop → more air enters the bottle.
    b. This means when we put it in the hot bath, there will be more air to expand → higher pressure → more work!
2. Put the cap on Bottle A, connecting it to only Piston A, and switch it to the hot bath
3. Once Piston A is not moving anymore (Bottle A is not heating up anymore), connect Bottle B (which is currently in the cold bath) to only Piston B.
4. Switch Bottle A into the cold bath, and Bottle B into the hot bath.
5. Repeat, just switching the bottles between the hot and cold baths.

As expected, this plan produced a decent amount of height for the mass. We produced a total amount of 0.044 J of work, which was the greatest amount produced by our classmates in our lab section. However, there is much more our group could have done to maximize the performance.

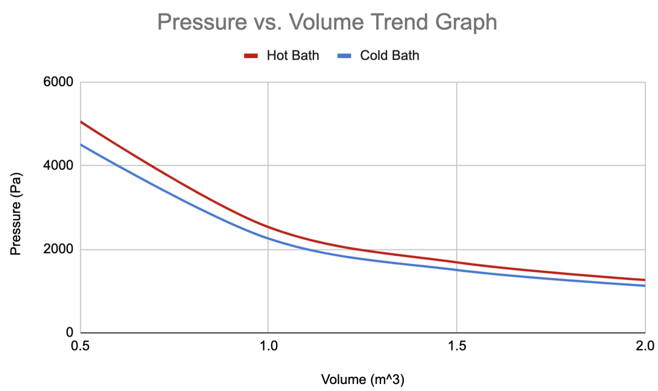
One misconception we had was that the ratchet would hold the gear in place after each "click"; however, we did not account for the fact that there would be slipping in the ratchet in between "clicks." As the pressure stopped increasing in the piston, the gear would turn the opposite direction, lowering the weight.

In addition, when we switched a bottle back into the cold bath, we kept it connected to the piston. This caused a huge pressure drop and since the ratchet didn't hold as we expected, the mass started falling very quickly. Because of this, the measured work from $W = Fd$ was lower than expected during the experimentation; the measured height of the mass came to be much lower than what it would have been with an ideal ratchet, leading our measured amount of work to be much lower as well.

Due to the fact that there were major losses since the ratchet was falling, in this revised approximation for work, we predict that the amount of work that is done would be 25% of the amount of work that we previously calculated, which implies that 75% is lost. As such, with our previous model predicting 0.14 J of work, we now would predict 0.035 J of work, which is closer to our calculated 0.044 J, while still being less than the amount of work done in class.

Improvements

After week 1, we used trendlines to find the equation for the Hot Bath, in red, as $y = 2527x^{-1}$, and the equation for the Cold Bath, in blue, as $y = 2253x^{-1}$. This graph somewhat resembles a cycle, but our group did not track the data in between baths, which made it more difficult to estimate work.



Based on our calculations, we got a value of 675 J, which we knew was unreasonable and significantly greater than expected. This error is likely due to the fact we used m = 1 for ease of calculations with PV = mRT. In turn, our estimated values for volume are far greater than the actual volume. Instead of observing ΔV, we were solving for total volume. In turn, we were encouraged to use data from another group when estimating our predicted work calculations. The graphs shown in the Model portion of the lab were created with data taken by Section 102, one of the Tuesday 1:45 PM lab groups. As previously stated, however, our mathematical model was still inaccurate. We derived it from a problem from MEAM 2030 that involved an extremely idealized system, and was likely not applicable to our real-life system that had losses like friction and leaks.

There are many major points of improvement our group identified. The first one was accounting for the imperfections of the ratchet system. Our strategy for changing the bottles between the baths relied on the functionality of the ratchet system. We had assumed that no work would be lost in between ratched clicks, which was incorrect. Furthermore, we believed we would be able to switch a bottle into the cold bath without it affecting the height of the mass; the pressure drop would cause the piston to drop, but the ratchet would prevent the movement from actually turning the spool. However, when we ran our system and put a bottle in the cold bath, the ratchet did not engage and our mass dropped significantly. Another source of error is that our group created our model only using data from one piston, and we assumed they would have the same performance. In reality, this is not the case.

To correct for these misconceptions, our group could have unscrewed the bottles each time we took them out of the hot bath, such that the pressure would only be raised by the bottle attached to the system, and less would be lost. However, repetitive screwing and unscrewing of bottles of course leads to a tradeoff between pressure and leaks. Even if we may be able to achieve a greater pressure by unscrewing the bottles when they are in the cold bath, if our group sought to improve our performance by unscrewing the bottles in between each switch, it may be even more difficult to prevent losses due to leaking. Lastly, we could have used data from both pistons to improve our calculations.

Of course, if our group successfully created a new method with these improvements, such as ensuring that the bottles are successfully sealed and there are no losses while in the cold bath, more work could be produced. In turn, our revised model may change, as there would be fewer losses in our system. This would in turn cause our predicted value to be higher, which would make it more accurate.