HUMAN-POWERED REFRIGERATOR

Final Report

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By

Group 3

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Introduction

The refrigerator resides in the corner of your kitchen, quietly plugging away day in and day out. It keeps your ice cream at a freezing point and your carrots crisp and may possibly be the least understood mechanism in your home. The refrigeration cycle is an engineering feat of immense proportion. It is the cycle of a chemical whose boiling point is relatively low to constantly change from a liquid to a gas, alternately giving off heat and absorbing it depending on where it is in the system. The way the system is set up determines if the cycle will heat your home on a wintry day, cool your car in the heat of summer, or keep your favorite flavor of yogurt good all year round.

Our challenge, when we came to Operation Catapult was to design a Human-Powered Refrigerator. The goal was to lower the temperature in the refrigerator to the point where there was an environment cold enough to cool a few cokes. The idea was to power the compressor in such a way that after an aerobic workout of some sort (where the compressor was being turned) it would be possible, after a certain time, to open the refrigerator and be rewarded by a frosty beverage. As we began our journey, we knew neither the extent of research required nor the rocky road we were setting off on.

Mechanics of the Refrigeration Cycle

The refrigeration cycle depends largely on four main components, those being: the compressor, condenser, expansion valve, and the evaporator (See Figure 1). The compressor is the component that takes the refrigerant in a gaseous state at a low pressure and compresses it to a higher pressure. The refrigerant then moves to the condenser where the high-pressured gas becomes a liquid. Once condensed, the liquid moves to the expansion valve where the high pressure refrigerant is moved through a small tube creating friction which causes the liquid to move to an even higher pressure. Once moved through this small tube, it enters into a larger tube thus creating an area of low pressure in the larger tube which allows the refrigerant to expand and evaporate. This evaporation absorbs heat from the air surrounding the larger tube, otherwise known as an evaporator. Once this refrigerant, now a gas, has moved through the evaporator and extracted the heat from the air it then returns to the compressor at a low pressure. From here, the cycle repeats indefinitely.

The refrigeration cycle can both cool and heat depending on the area of the cycle that you harness. If you choose to cool with the refrigeration cycle, then you place the evaporator in the area that you wish to cool. Examples of this are the refrigerator in your home, and the air conditioner in your car. The air conditioner works by applying a fan behind the evaporator to disperse the coolness of the evaporator over an area. The refrigerator works in somewhat of the opposite way. It encloses an area around the evaporator and allows the evaporator to absorb the heat within the enclosed area and remove it to the outside. The only modification you would need to make if you chose to use the refrigeration cycle to heat an area is to place the condenser in to the area that you wish to heat and the evaporator outside of it. The condenser gives off heat as the refrigerant changes from a gas to a liquid.

The Human-Powered Refrigerator

The group began by researching refrigerators in general. It was discovered that there were several options available. A decision had to be made on whether to build a conventional refrigerator or to build an electric refrigerator. The conventional refrigerator works by utilizing the cycle mentioned above. The electric refrigerator, however, works off of the positive and negative charge of two junctions, one hot and one cold. To create the hot and cold junctions, iron or bismuth must be attached to both the positive and negative charge of a source of electricity.

For a human to power an electric refrigerator, although it would be easier to build, would involve the construction of a generator. It had previously been decided that this would be too difficult, and unfeasible in the amount of time allotted for the project. Because of this, the group chose to build a conventional refrigerator with some sort of contraption to allow a human to directly power the compressor.

Once it was decided that the conventional refrigerator would be built, the group then had to find a number of calculations to determine how large the refrigerator could be built. The first of these was the Co-Efficient of Performance. The equation used to find the Co-Efficient of Performance is:

$$\frac{\textbf{Refrigeration Effect}}{\textbf{Work Input}}$$

This equation was necessary so that we could find how much work input was needed to get the area within the refrigerator from room temperature to thirty degrees Fahrenheit. To do this it was decided that a modified equation for the Co-Efficient of Performance would be used. The equation was the following:

$$\frac{1}{\frac{\text{room temp}}{\text{desired temp}} - 1}$$

It was found that if a refrigerator was to have a forty degree difference from a room temperature at seventy degrees Fahrenheit to an inside temperature of thirty degrees Fahrenheit, a Co-Efficient of Performance of 3.8 would be achieved.

Once the Co-Efficient of Performance was found, it was then possible to apply the information to Fourier’s Law of Heat Conduction. This would give us the size of our refrigerator. Fourier’s Law of Heat Conduction is:

$$\frac{\textbf{Heat Flow (BTU's/hr.)}}{\textbf{Unit Area (Sq. Ft.)}} = \textbf{K}\left(\frac{\textbf{DT}}{\textbf{B}}\right)$$

The Heat Flow for this particular equation is the amount of energy created by a human exercising lightly for one hour. With the aid of the biomedical engineering department, it was discovered that a person exercising lightly creates between 1,000-2,000 BTU’s/hr (British Thermal Units). The group decided on 1500 BTU’s/hr, as a n approximation. K stands for the thermal conductivity of the chosen material desired for the construction of the refrigerator, which was a two inch Styrofoam with a R-value of ten. ΔT is the change in temperature between room temperature and the desired temperature within the refrigerator. For this refrigerator there was a desired forty degree change. Finally, B is the thickness of the insulation on the refrigerator, and Unit Area is the variable that is needed, or in other words, the largest space that could be cooled to forty degrees in an hour going at a constant rate of 1500 BTU's per hour in a perfect refrigeration cycle. When all these factors are plugged in, the equation looks like this:

$$\frac{1500\ (\text{BTU's/hr.})}{\text{Unit Area (Sq. Ft.)}} = 0.0.2\ \frac{(40)}{1/6}$$

The end result was that we could build a refrigerator with 31.25 Sq. Ft. of space. It was then decided that we would build a refrigerator with one cubic foot of space inside, or six Sq. Ft. of space. It was chosen to build such a small refrigerator compared to the allowable amount to allow for any inefficiency and to make it easier on the rider of the bicycle that would power the compressor.

Building and Design

Once the size and type of refrigerator was decided upon, the next step was to design the actual refrigerator. To do this it was necessary to look at the parts available, which weren't many, and to look at our options available outside of the campus. There was a restriction on the amount of money allotted, which made it even more difficult to collect the necessary parts. In the end the design chosen was one that would involve a handmade refrigerator box, an Air-conditioner compressor from a GM car, a condenser off of an old refrigerator, and a bicycle that would be used to power the compressor. The bicycle was chosen because it would be easier to power a compressor for a long period of time using the legs rather than the arms.

The actual construction of the refrigerator took only about three days. The real challenge was to find the parts necessary, at a cheap enough price, and to adapt them so that they all went together. This has been a problem throughout the entire process and is still eminent even in the final hours.

To begin, the refrigerator box was built, using two-inch Styrofoam that was put together with adhesive caulk. Once the caulk was cured, the entire box was sealed with duct tape to ensure that everything held together and to add to the insulation (as well as aesthetics). The evaporator coil was made before hand from 5/16 inch copper tubing, and the refrigerator was built around it. The next step in the process was to acquire a bicycle and a compressor, which was done within a number of days. A condenser was already at hand, so that all that was left to do was to put the refrigeration system together.

Copper tubing of various sizes was found to be available for the project. The real trouble shooting came into play when it was necessary to find adapters to fit various sizes of copper tubing, including an odd-sized tubing (the 5/16 inch) as the main part of our system. Once the parts were obtained and the system hooked up it was time to modify the bike. This was done by taking Un-Strut and making a stand to bring the back wheel of the bike off of the ground. The bike was now stationary and able to have a belt attached to it.

To find the size of the belt necessary to hook the compressor to the bicycle there were two options. One of the options was to measure the diameter of each of the wheels and then to measure the distance between the two centers of the wheels. The other option was to take a piece of string and to wrap it around both wheels and then to measure the length of the string. The second option was the one chosen because of ease and simplicity. The belt was found and purchased after several phone calls and the system was constructed and completed. (See Figure 2)

The next step was to evacuate the system. This involved attaching a vacuum pump to the refrigerator; the vacuum ran for approximately three hours removing any air or moisture from the system. Once this was finished, we were able to pressurize our system and add our refrigerant (134-a). This was difficult because the compressor was a R12 refrigerant compressor and had the valves associated with R12 refrigerant. For the system to be run legally, it was necessary to use 134-a and adapters had to be found to adapt the vacuum to the system and to 134-a gauges that would show the amount of pressure in our system. To do all this, although the actual process was relatively simple, finding the appropriate adapters for the system took a number of days. Finally, the system was filled and the refrigerator was ready to be tested.

Testing

When construction of the refrigerator was complete, testing commenced. The refrigerator lowered five degrees in approximately five minutes. The refrigerator started at seventy-five degrees Fahrenheit and it was lowered to seventy degrees Fahrenheit. After the temperature was lowered to seventy degrees, however, the refrigerator temperature quit cooling. Because the temperature leveled off, the pressure was checked. When that was done, it was found that the whole system had been de-pressurized; a leak was somewhere in the system. So, once again testing was delayed while we attempted to find the leak and seal it.

Although the refrigerator has only been tested once, and there was only a small amount of cooling involved before the refrigerator system de-pressurized. Testing will be continued to the best of our abilities until the end to see what improvements can be made to our system to make it more efficient.

Conclusions

Three weeks ago, this group set off to build a human-powered refrigerator. Without knowing how a refrigerator works, or how we would get one to work, we struggled over one obstacle after another to come to the end, where a fully functional human-powered refrigerator lay at our feet. As a result of all our hard work, we made certain discoveries. We found that our finished product, though fully functional, was not efficient. We did lower the temperature inside our refrigerator, but it was only several degrees below room temperature. This was evidence of the difference between the ideal scenario found in Fourier's Law and reality, with complications including leaks and friction. Regardless, we view our project as a success. Though it is not efficient, our refrigerator still works and can lower the temperature of the air within it. In addition, the project proved to be very educational, both in conceptual and practical knowledge. All members of the group were ignorant as to the processes of the refrigeration cycle prior to this project and all leave well versed in what goes on inside a refrigerator. It is for this reason that this project can be classified as a success.

Figure 1

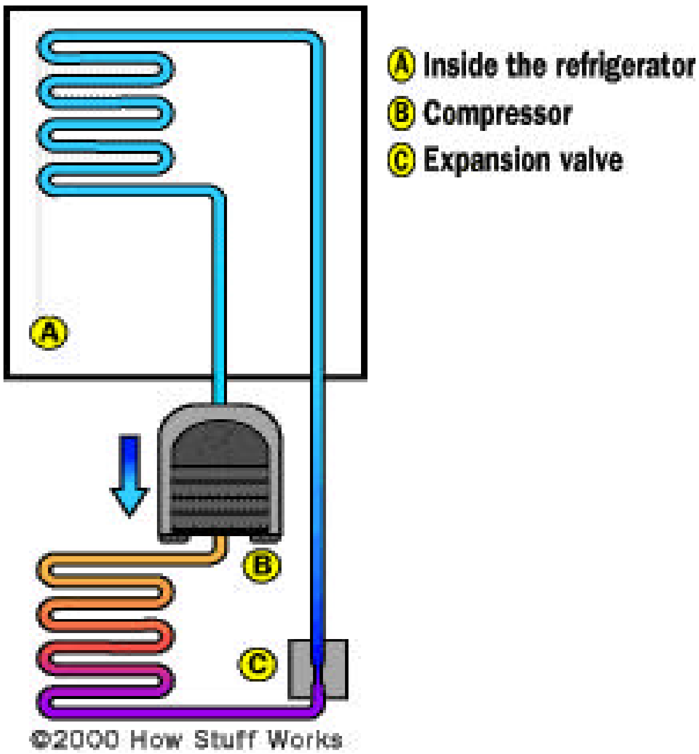

Figure 2