An Illinois Institute of Technology Interprofessional Project (IPRO)

Heat-Driven Refrigeration for Developing Nations

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Sponsors: The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and The National Collegiate Inventors and Innovators Alliance (NCIIA)

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Introduction

The world stands at the beginning of the new millennium with a certain confidence and optimism. Mankind has advanced more technologically in the past two hundred years than ever before. Technological advancements have made the current standard of living possible. However, these advancements have not come without a price. Technological and industrial developments require large amounts of continuous reliable energy. The emissions resulting from large-scale energy consumption contribute to many adverse environmental effects such as depletion of the ozone layer and air and water pollution. Furthermore, for the majority of the world's developing countries energy is at a premium. Electricity is often unreliable, limited to certain hours, or altogether nonexistent.

Areas that would benefit greatly from modern refrigeration are developing regions such as those found within the South American, Asian, and African continents where the daytime temperatures reach an average of 40°C or more in the summer months. Due to the extreme heat the local populations face several problems including the wastage of agricultural produce, spoiled food, and the inability to store medical supplies and vaccinations that require cold temperatures. Conventional refrigeration uses a great deal of electricity, a resource scare in developing areas, and as a consequence it is not viable. However if a system that is inexpensive, reliable under local conditions, and operates with only minimal electric power from a solar cell or battery can be introduced it would be a tremendous asset. Faced with such a requirements this project addresses these issues in order to find a solution that is economically and socially feasible.

The solution will take the form of a novel system based on a refrigeration cycle driven by heat. The cycle will be built around a pressure exchanger consisting of a piston and valves controlled by electronics. The heat will most likely be obtained through the combustion of biomass such as plant by-products and animal wastes but will be flexible enough to allow for more conventional fuel types such as kerosene and coal.

This project is currently under development at the Illinois Institute of Technology within the university's Interprofessional Projects or IPRO Program. Under the guidance of Dr. Francisco Ruiz, and with the resources of the Mechanical, Materials, and Aerospace Engineering Department students have collaborated on this project for three semesters. In addition the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) sponsored the project this semester. In the past the National Collegiate Inventors and Innovators Alliance (NCIIA) has also sponsored the project.

Project Background

The Heat Driven Refrigeration Cycle had existed as an IPRO for two previous semesters a few years ago. The first group's main focus was research. They examined the refrigeration cycle being proposed, the possible heat sources, and the different types of refrigerant available. With the theoretical groundwork completed the second group began construction on the prototype of the refrigerator to serve as a proof of concept.

The first incarnation of the IPRO began with the idea of a different type of heat driven refrigeration cycle than what is currently used in absorption cycle refrigeration. This novel design utilizes a pressure exchanger composed of a piston and electronically controlled valves to replace the traditional compressor found in vapor-compression cycle machines used in the industrialized world. This then would allow a refrigerator to be constructed that does not take electricity but instead heat. Possible sources for the heat included burning in a furnace coal, kerosene, agricultural waste, firewood and some currently less viable alternatives like locally produced methane and aquatic biomass. The IPRO did not reach a conclusion on which exactly was the best because location for the refrigerator to be implemented in would determine the quantity and cost of fuel. They did find that the fuel needed to be low in moisture content, less than 60% moisture, and long burning, four hours or more so as to not need constant attention. After evaluating the thermodynamic cycle for multiple refrigerants the group decided on R134-a for several reasons. First, it is relatively inexpensive and easy to obtain through out the world. Also it is environmentally friendly and would be able of producing an estimated COP of 1.5.

The second IPRO team began building a prototype and divided the work into the mechanical subsystems and electrical subsystems. For the mechanical part they built the piston-cylinder apparatus composed of a high and low cylinder and a piston between them, four solenoid valves to control the movement, and magnetic sensors to track the motion of the piston. It is connected to a standard window unit air conditioner that supplies the evaporator, condenser, and expansion coil. Also they began constructing the boiler system but did not finish. The electrical subsystem was a circuit constructed on a breadboard that took input from the magnetic sensors and controlled the solenoid valves. By the end of their portion of the project the piston-cylinder assembly along with the control circuit could be operated with compressed air. The boilers however needed a good deal of work.

Project Purpose

The purpose of this semester’s IPRO was to start where the second group left off and finish construction and begin testing the prototype machine. This goal consisted of many smaller construction and testing goals because of the complexity of the apparatus. Therefore the IPRO group divided up into four smaller groups to work on the boilers, piping, electronic controls, and data acquisition.

The boilers had to be installed with float sensors, thermocouples, resistance heaters, check valves, and piping between them. After that they would have to be tested separately and in tandem for mechanical functions and the ability to withstand the operating temperatures and pressures.

The existing piping was poorly constructed and in some places incorrect so it would need to be removed. New piping of appropriate diameter and correct fittings would then need to be installed between all the components with insulation where necessary. Also the piping would have to contain components capable of taking various pressure readings through out the cycle. A way to fill the system with refrigerant would be needed as well.

The existing electronic system would have to be checked to make sure it still operated and if not repair or replace it.

Data acquisition would use a computer to take data readings from the apparatus while it operates and record them for analysis. Also a program would be designed to control the prototype from the computer and effectively eliminate the previously existing control circuit.

After these construction goals had been completed the next step would be to test the entire refrigerator to see if the theoretical effectiveness calculated in the first IPRO would be attainable. This would complete the proof of concept stage of the ongoing project and open the door for marketing to industry and refinement of design to attain a finished product.

In addition to objectives directly related to the project the group also had to complete all the deliverables required by the IPRO office including the project plan, mid-semester report, meeting minutes, abstract, group presentation, poster, and final report.

Project Research Methodology

The vast majority of the research involved in this project was completed by previous IPROs. Previous IPROs' work consisted of finding the right refrigerant and doing a preliminary marketing study into the feasibility of actually constructing this. Our group's main task was to actually complete construction of the system and get it operational. A summary of the previous research can be found in the Project Background Section.

Team Organization and Individual Assignments

To complete the construction of the refrigerator, we divided the group into four teams: The boiler team, the piping team, the electronics team, and the data acquisition team.

Boiler Team

Alex Callow, Eric Dunaway, Dylan Easley, Sean McCann

Eric was originally brought into the project to develop our webpage and to work with the electronics team. His focus then became designing a control circuit for the operation of the boiler system.

The main objective of the boiler team was to complete construction of the dual-boiler system and test it independently of the rest of the fridge to ensure that it works correctly.

The first task was to understand how the concept was to work. The concept of the boiler system is best understood by going through a cycle of its operation:

1. The pre-boiler starts off with a full charge of the working fluid in liquid form. The float sensors inside the boiler register that the boiler is full and the solenoid valve is closed.
2. The pre-boiler dumps enough energy into the fluid to raise its pressure above the pressure of the main boiler.
3. After the pre-boiler empties, the float sensors register an empty vessel and the solenoid valve opens to the low-pressure cylinder, creating a vacuum that draws in liquid refrigerant from the condenser.
4. The sensors register the pre-boiler as full and close off the solenoid valve.
5. The process repeats.
6. All this time the main boiler is vaporizing the fluid that flows into it and driving it to the high-pressure cylinder.

After understanding the operation of the system, a method for testing the system independently of the rest of the refrigerator was devised. This setup is shown below in figure 1. Water was used as a test fluid because it is cheap and readily available. It also would not discharge all over the lab, creating a hazardous environment. In the setup shown below, the vacuum pump simulates the low-pressure cylinder and the valve is used to maintain a back pressure in the main boiler.

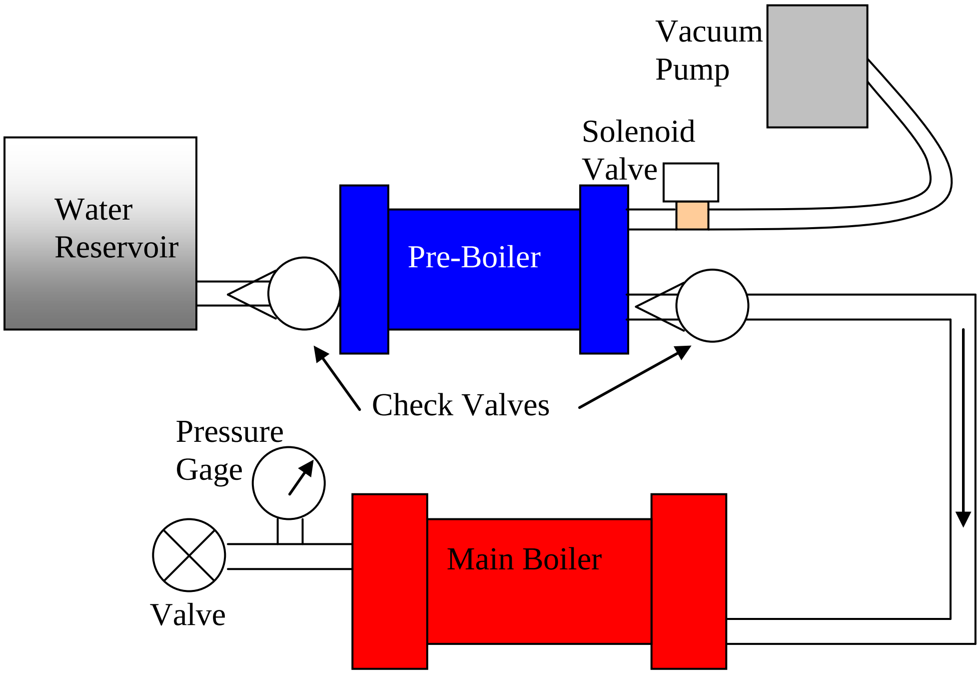


Fig 1 – Independent test setup for boilers

After this system was devised, the team found all the parts necessary to complete construction and testing could commence. The control circuit was not completely done by the time of the first test, however a “sample” circuit was built that could demonstrate control of the solenoid valve with only one sensor providing input to the valve. The second iteration control circuit demonstrated control of the valve with both sensors supplying input to the circuit. The circuit is shown below in figure 2.

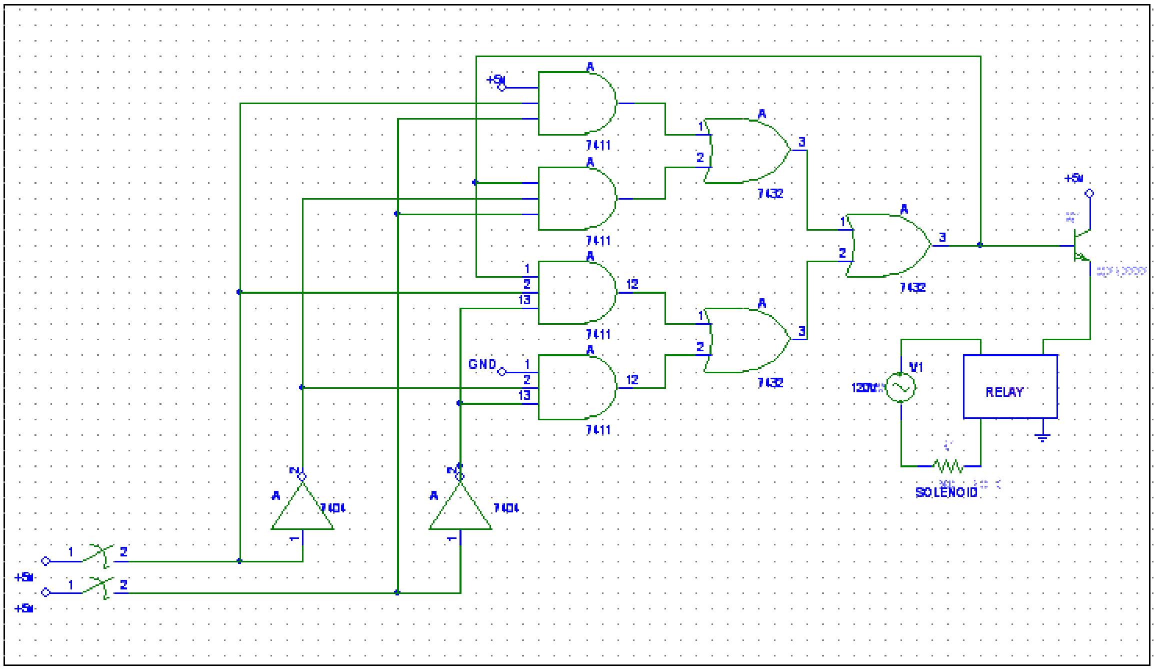


Fig 2 – Control Circuit

The two float sensors serve as switches where each of the four combinations of the switches allows for only one of the four AND gates to enter into a high state. One gate is permanently connected to +5 V, one to ground, and two of them are connected to the output of the circuit. This is to prevent the output from changing when only one of the switches is high or low.

The gate that is chosen sends its data into the OR gates, which determines whether the output is high or low. When the output goes high, the circuit activates a transistor, which powers a relay, allowing a 120 V AC signal to power the solenoid, opening it.

With the control circuit completed, testing the two boilers working together could commence. The first test was with the main boiler empty and at atmospheric pressure. The pre-boiler worked flawlessly. The second test involved applying a back pressure to the main boiler by heating the water inside it. Unfortunately, the main boiler began to leak profusely at 40 psig. This is the point where the boiler system currently stands.

Piping Team

Tom Alworth, Wendell Holmes, Anna Ryu

The main goal of this subgroup was to connect the cycle components correctly so that the cycle can run properly. This goal was achieved by overcoming many obstacles and accomplishing many tasks along the way.

Goal 1: Determine how the cycle components should to be connected, what is needed to connect them, and obtain these supplies.

The first activity after being divided into groups was for the Tubing Group to understand how the system operates and how the tubing is used to connect the various components together. After analyzing the schematic diagram and the T-s diagram of the cycle we connected the components together using metal wire to visualize how the system operates. From this understanding of the cycle we used AutoCAD to draw up a schematic diagram of the components and all of the tubing connections.

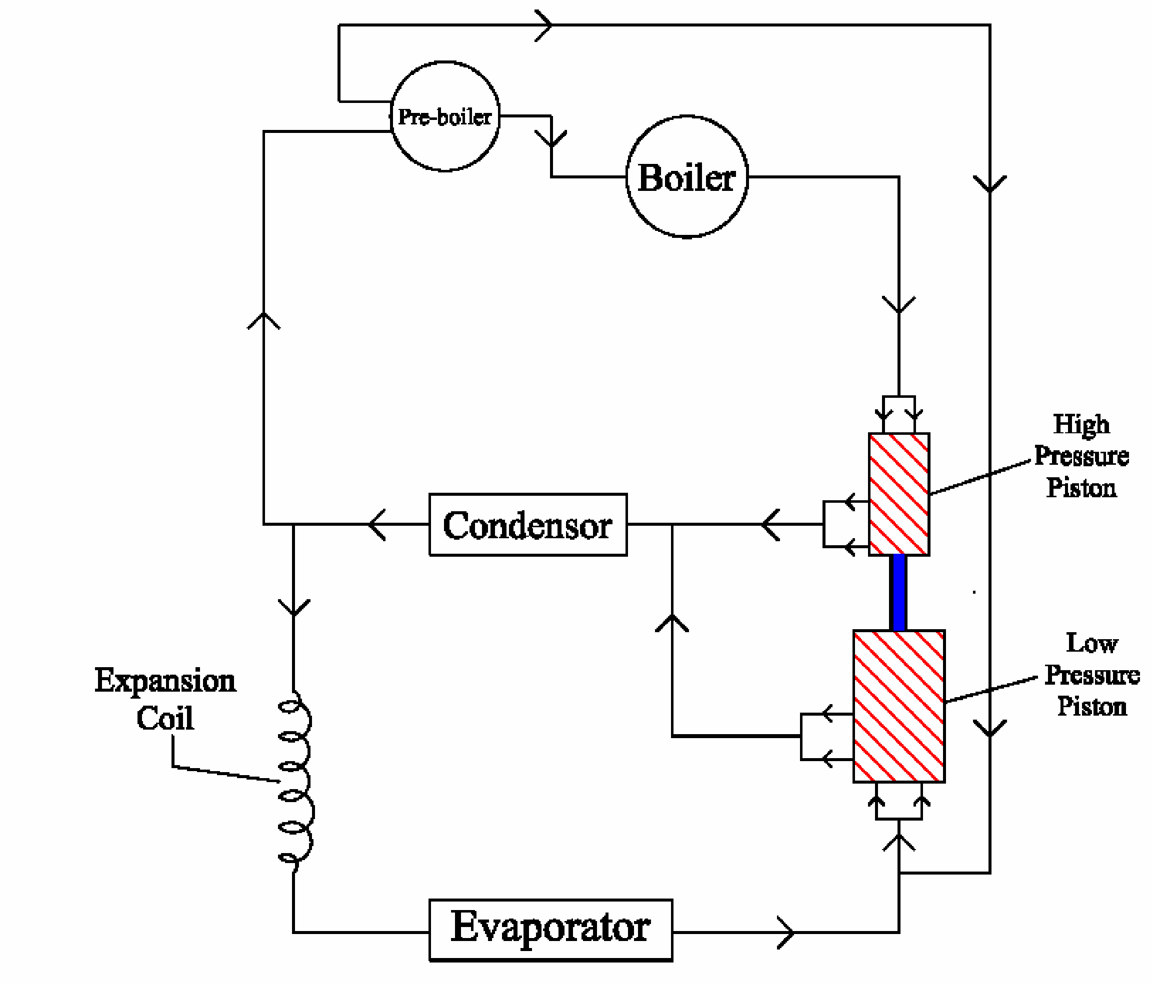


Fig 3 – Flow diagram of the refrigerator

Goal 2: Connect the cycle components.

The same day that we received the correct fittings we were able to bend and install nearly all of the tubing. The tubing from to and from the pre-boiler and main boiler was left undone until the Boiler Group finished testing the boilers. Later on we were able to connect the pre-boiler to the main boiler so the Boiler Group could finish testing the boilers. This proved to be a bit difficult because the Boiler Group had decided to use check valves that were not the correct size for the tubing that we were planning to use.

To solve this we had to use more fittings and reduction couplings to connect the boilers together.

Goal 3: Test the connections for any leakage.

In order to test the system for leaks we closed off all outlets and connected a compressed air line to the inlet. Then we coated the outside of each fitting with soap water. Soap water is used because if a leak is present bubbles will form where the leak is and thus any leakages can be easily identified. In this way we were able to check each fitting and tighten those that indicated air leakage. About 100 psi was used in this pressure check.

Goal 4: Obtain pressures at various points in cycle.

After talking to the Data Acquisition Group we found that they needed to know the refrigerant pressure at a few different places in the cycle—namely the main boiler, the condenser, and the evaporator. Right away we concluded that pressure transducers were too expensive and that there was a simpler way to obtain the pressures. All three of the desired pressures are in the liquid-vapor two-phase region where the temperature remains constant for a given pressure. This being the case, we decided that the most cost effective way to determine the pressures would be to calculate them based on the measured temperatures in the regions in question.

Goal 5: Determine how to charge the system with refrigerant.

We were able to talk with two different air conditioning technicians and we learned that we needed to install a Schrader valve for charging (like the valve used on a car or bike tire). We also learned that the system needs to be evacuated of all moisture before charging and that the refrigerant should be added where the cycle will have low-pressure vapor present.

Electronics Controls Team

Keon Kim, Donghoon Lee

The main objective of the electronic control system was to control the four solenoid valves connected to the pistons in the system. By controlling these four solenoid valves, the piston moves back and forth, acting as a pump and controlling the flow of the refrigerant through the system. A pre-existing circuit was present at the beginning of the semester, however the operation of the circuit was unknown as the circuit diagrams did not match up to what was actually constructed. The last group used flip-flops to control these four solenoid valves. But because we were unsure about the operation of the circuit, we decided to make our own control board, using a programmable microprocessor.

The four solenoid valves in the system are controlled by using magnetic sensors and a programmable microprocessor. The position of the piston in the system is necessary to control the solenoid valve. Therefore, the four magnetic sensors were used to tell the position of the piston. The magnet is attached to the piston and the sensors are fixed to the board just next to the cylinder. The figure below shows the piston and magnetic sensors in the system.

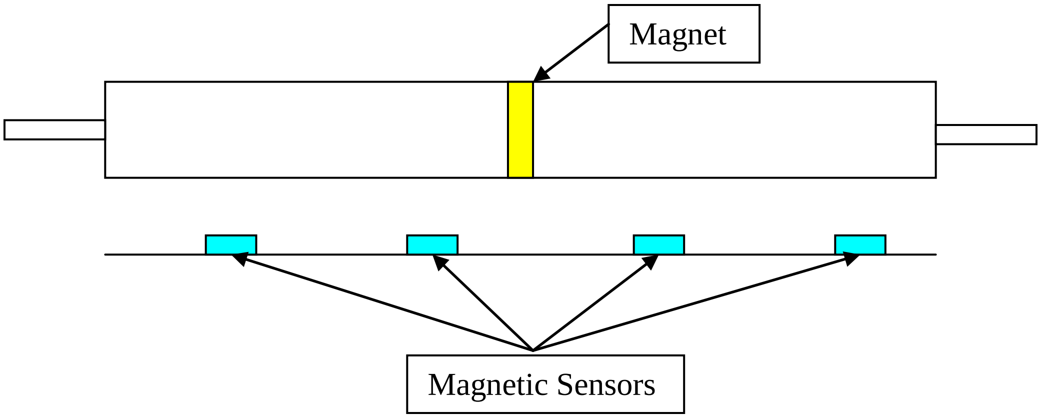


Fig 4 – Piston diagram

When the magnet in the cylinder passes the magnetic sensors, the microprocessor reads the location of the piston. However, the signal from the magnetic sensors is small, thus it was necessary to use an op-amp LM 324 as a comparator. Then connecting the output signal from the op-amp to the microprocessor, the signal for controlling the solenoid valve was made for each cylinder position in the system, using the four relays. Relays are convenient for controlling the power, because of the high voltage necessary (120 VAC) to operate the solenoid valves.

The figure below shows a schematic circuit diagram of the control part for controlling the four solenoid valves.

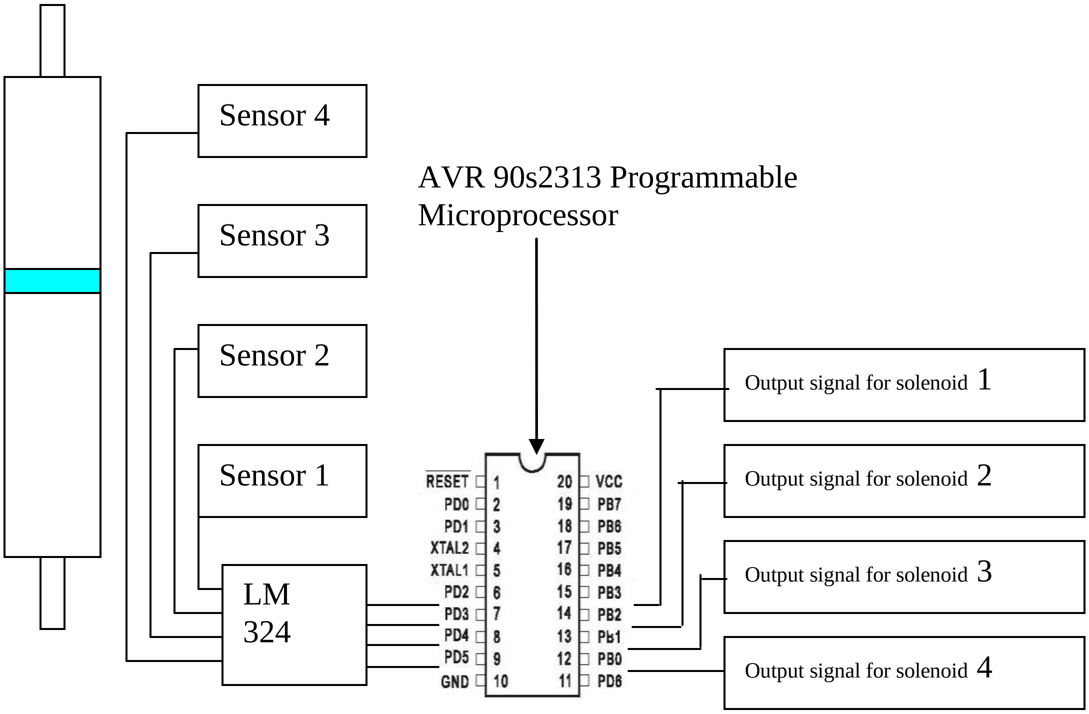


Fig 5 - Circuit diagram for controlling four solenoid valves

The figure below indicates the movement of piston for each case of the position of the piston. The fluid comes through valves 1 and 2, and goes out through valves 3 and 4. So it was necessary to initialize the position of the cylinder first. A switch was attached to the microprocessor for initializing the position of the piston. When the switch is pressed, valves 3 and 4 are activated, thus the piston moves in the direction indicated in the figure below due to the flow from the boiler system.

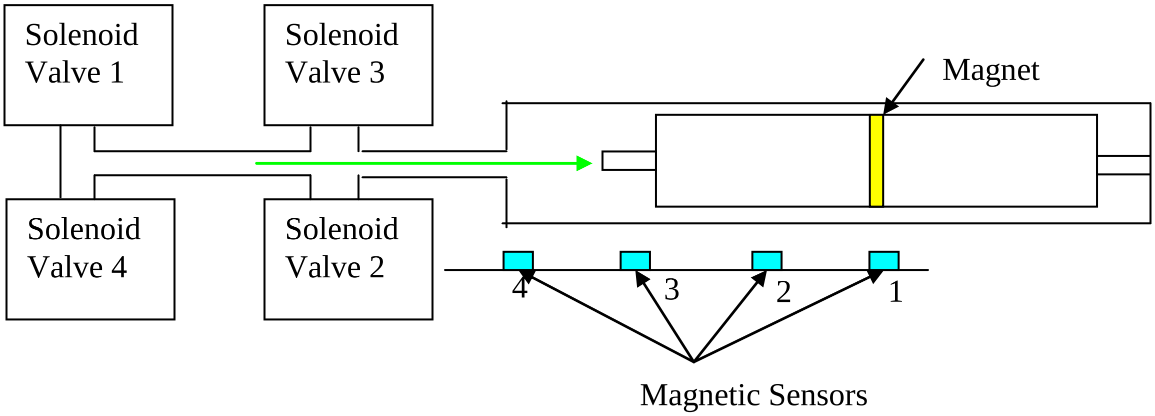


Figure 6 – Piston in the rightmost position

Then, when the piston reaches to the point near at magnet sensor 1, valves 1 and 2 are activated until piston reaches to the point near sensor 3. Thus, the piston starts to move to the left as indicated in figure below. When piston reaches to the point near at magnet sensor 3, valve 1 is deactivated, and only valve 2 is activated until the piston reaches the point near sensor 4. This is done to smooth the motion of the piston.

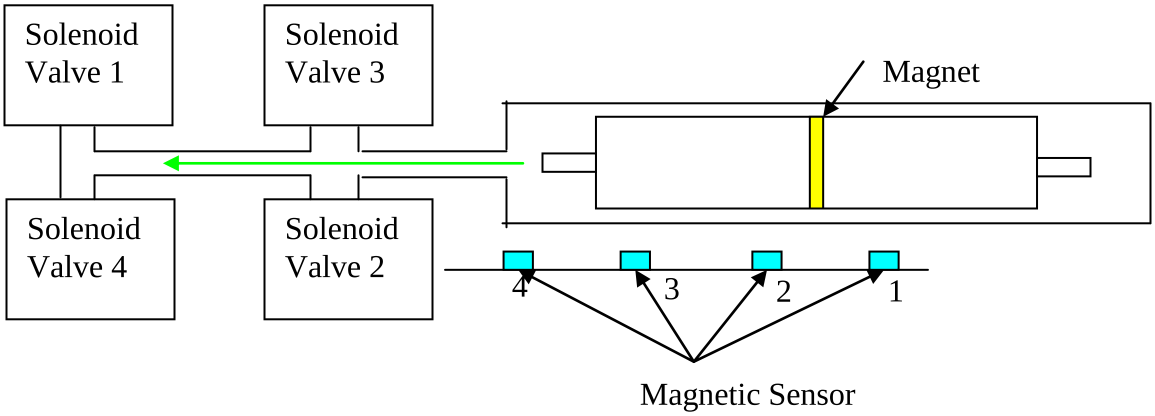


Figure 7 – Piston just starting its transit to the right

When the piston reaches the point near sensor 4, valves 3 and 4 are activated until the piston reaches sensor 2. Thus, the piston starts to move to the right as indicated in figure below. When the piston reaches sensor 2, valve 3 is deactivated, and only valve 4 is activated until the piston reaches sensor 1. Then, the process repeats.

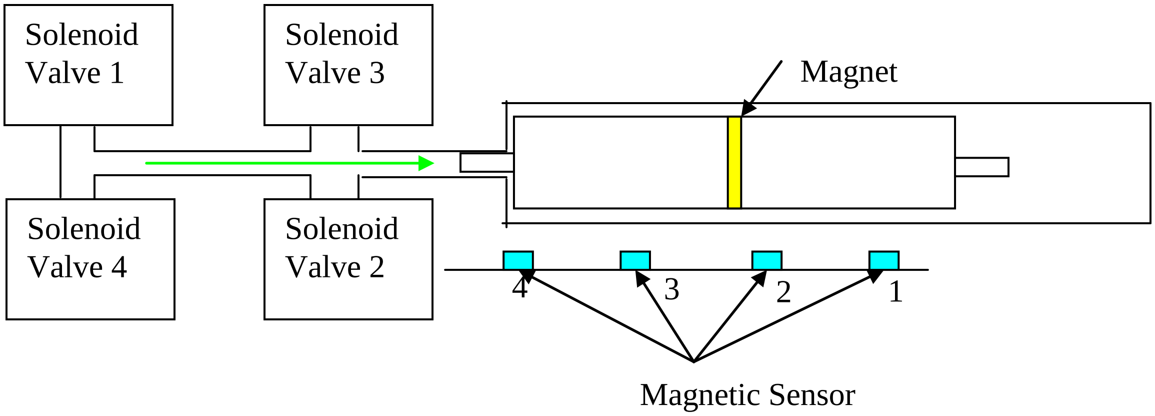


Figure 8 – Piston in the leftmost position

Table 1 below indicates status of the each valve and the signal from the microprocessor when the piston moves to the right. When the signal from the microprocessor is applied to the relay to activate the solenoid valve, the valve opens. Thus the signal from the microprocessor can be seen through the status of the valves.

Position of the piston According to sensor	Valve 1	Valve 2	Valve 3	Valve 4
4	Closed	Closed	Open	Open
3	Closed	Closed	Open	Open
2	Closed	Closed	Closed	Open
1	Open	Open	Closed	Closed

Table 1 - The status of each valve when the piston moves to the right

Table 2 below indicates status of the each valve and the signal from the microprocessor when the piston moves to the left.

Position of the piston According to sensor	Valve 1	Valve 2	Valve 3	Valve 4
1	Open	Open	Closed	Closed
2	Open	Open	Closed	Closed
3	Closed	Open	Closed	Closed
4	Closed	Closed	Open	Open

Table 2 - The status of each valve when the piston moves to the left

Data Aqusition

Anthony Arkwright, John Brandt

This subgroup had to acquire a computer, install and verify a data acquisition (DAQ) board, order a terminal board for the DAQ system, and develop a control system for the refrigeration cycle that can accommodate for optimization.

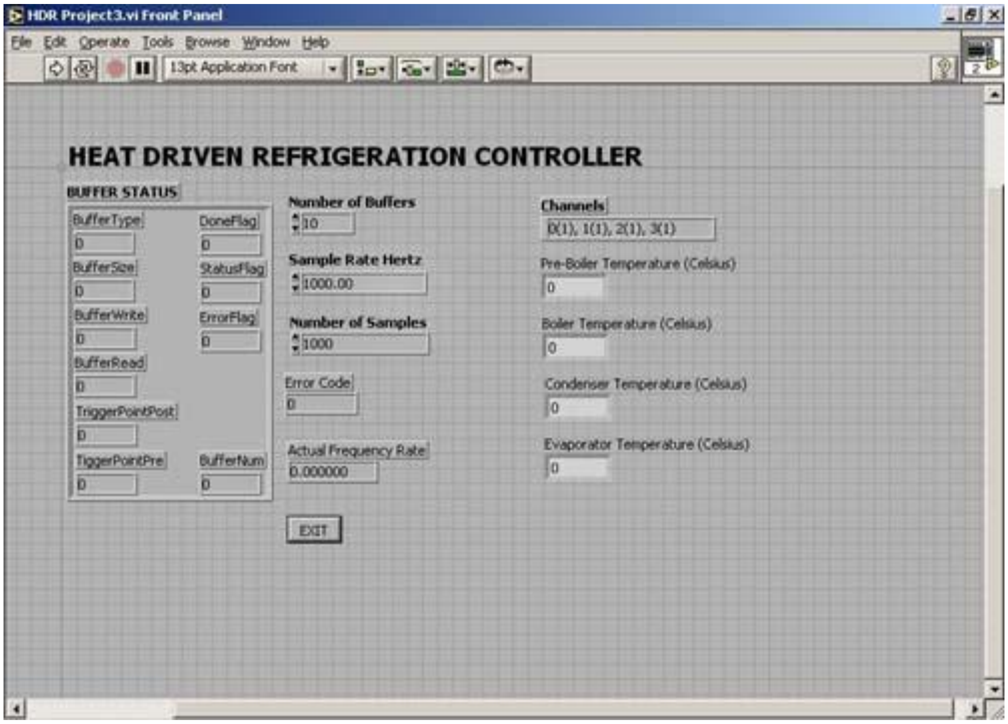
At the beginning of the semester, the team had no computer, but a data acquisition (DAQ) board was available for use. A computer was assembled from spare computer parts found around the lab in Room 067 of E1. However, the only hard drive that was found was too small for the programs and operating systems needed to run the DAQ software (National Instrument's Labview). Therefore, an appropriate hard drive was ordered to fix this dilemma.

The next step was the most frustrating: verifying that our current DAQ board works with Labview. The DAQ board that was available is from a small company, ADAC; the model type is the 5500MF (Figure 1). The company promotes on its website that their cards are compatible with the Labview software. However, software issues arouse. The software packages on their website were missing important VIs (small functions that Labview reads). When they finally sent the missing VIs they were for the wrong version of Labview. Following some more correspondence with the company, the correct VIs were sent and the software problems were fixed. Another problem concerning the DAQ system was that the terminal board (the board that is the interface between the computer and the process supplying data) was stolen from the lab in the beginning of the semester. When it was confirmed that the ADAC acquisition board did work with Labview, a terminal board (Figure 1) and cable was ordered at a cost of $200. Once these items arrived, they were connected to the DAQ card, and it was confirmed that everything worked properly together.

Figure 9 – The ADAC 5500MF DAQ card.

Figure 10 – The new terminal board.

The control program (Figures 3 and 4) that was to be created had to optimize the refrigeration cycle by opening the solenoid valves at the perfect time. In order for this to be done, the pressures of the system had to be known at several points. Measuring pressure could be done through the use of pressure transducers, which tend to be costly, or, indirectly, through measuring temperature. Measuring temperature can be done using thermocouples, which are relatively cheap compared to a pressure transducer. After it was decided to measure temperatures, a Labview program was created that could record the temperatures of the fluid in various places in the refrigeration cycle. The four places chosen for this were: the pre-boiler, the boiler, the condenser exit, and the evaporator exit.



BUFFER STATUS

BufferType
0
DoneFlag
0
BufferSize
0
StatusFlag
0
BufferWrite
0
ErrorFlag
0
BufferRead
0
TriggerPointPost
0
TiggerPointPre
0
BufferNum
0

Number of Buffers
10
Sample Rate Hertz
1000.00
Number of Samples
1000
Error Code
0
Actual Frequency Rate
0.000000

Channels
0(1), 1(1), 2(1), 3(1)
Pre-Boiler Temperature (Celsius)
0
Boiler Temperature (Celsius)
0
Condenser Temperature (Celsius)
0
Evaporator Temperature (Celsius)
0

Figure 11 - Front panel of the initial controller program.

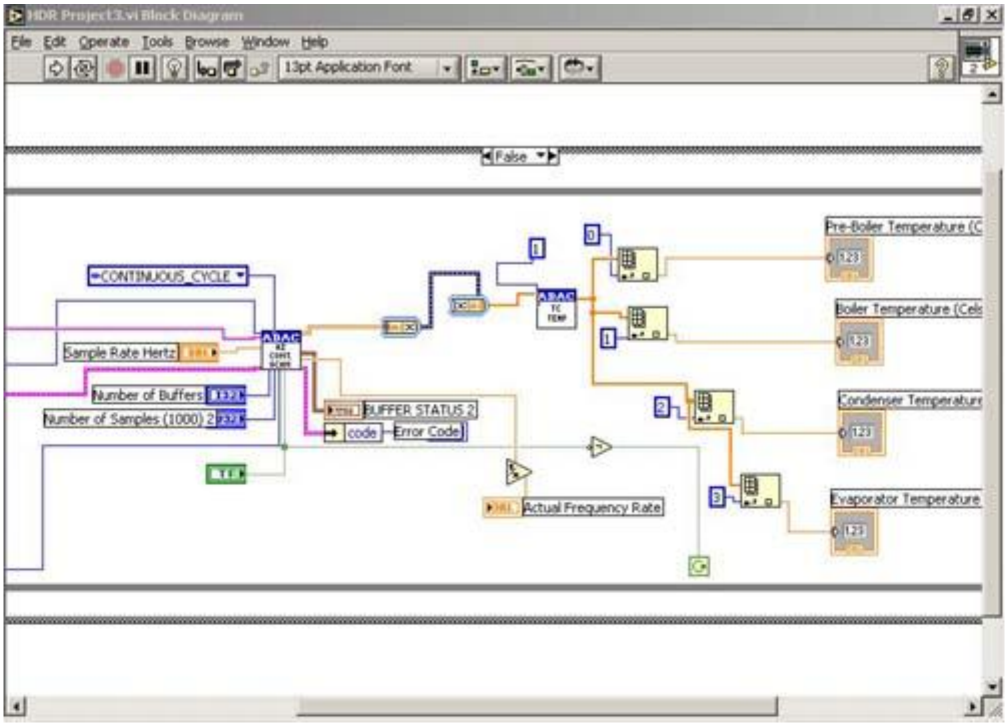


Figure 12 – Block diagram of the controller programming.

Thermocouples output a small voltage, on the range of a couple of millivolts. In order for appropriate conversions, the signal must be amplified before being input into the DAQ board. For the amplification there are a couple of options. Expensive amplification units built specifically for thermocouples are available. Some sources give a cost of $500 for such a device. The other option is to build a homemade amplifier out of op-amps. It was decided for budget considerations that four amplifiers (one for each signal) will be built by the team.

Time ran out in the semester when the amplification problem was being researched. For the future, the amplifiers need to built and hooked up to the thermocouples. The written program needs to then be verified that it works properly. Once this is completed, the program can be expanded to convert the temperatures into pressure readings so that the refrigeration cycle can be optimized.

Barriers and Obstacles

Naturally, while contsructing an untested prototype system of any type, problems are going to come up. This section highlights the barriers and obstacles that each section faced.

Critical Barriers

The first major issue that came up was the unexpected loss of our data acquisition equipment. A few weeks into the project it came up missing and could not be located in the lab. New equipment had to be ordered, which took valuable time.

Another major problem occurred while ordering parts from McMaster-Carr. The purchase order sat in IIT's system for a month before being sent out. As with the missing data acquisition equipment, valuable time was lost.

The biggest obstacle faced though would be the lack of diversity in our IPRO group. The Team consisted of 10 MMAE majors and one from the ECE department. The lack of electronics knowledge hampered our efforts throughout the semester.

Major Obstacles

The biggest problem the boiler team faced was a poorly designed end cap. The float sensors, as shown below in figure 13, need a full range of motion in order to operate properly.

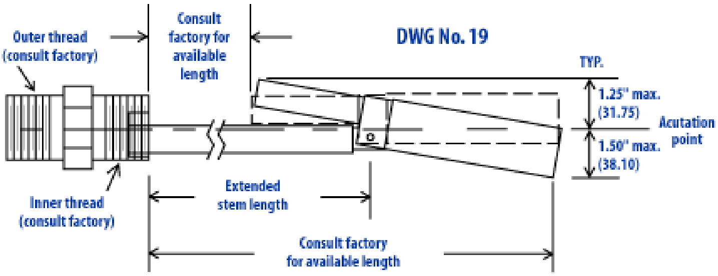


Figure 13 – Float sensor diagram

The end cap we had at the beginning of the semester had an improperly placed hole for one of the float sensors—it was trapped against the edge of the boiler and could not move at all. We had to procure a new end cap from Columbia Pipe & Supply Co. (1120 W. Pershing Rd, Chicago, IL 60609) and get new holes drilled and tapped in the proper location.

A problem the piping team ran into was figuring out how to connect the mangled condensor exit to the pipe system. The MMAE machine shop ended up silver soldering a pipe connection to the exit to rectify the problem.

Another problem for the piping team involved measuring pipe sizes and thread sizes properly. This resulted in an order of many wrong parts from McMaster-Carr and we needed to return the wrong parts and order the proper ones.

A problem the electronics team ran into involved obtaining the proper electronic components. One of the parts had to be specially ordered from Korea.

Additionally the electronics team ran into a problem with finding the optimal location for the magnetic sensors. The sensors are extremely sensitive and need to be placed in the proper position in order to function correctly. Many trial-and-error tests were required to find the optimal location.

Results and Conclusions

After much design and assembly, parts of the system were tested yielding results. The refrigeration distribution team, after assembling the tubing connecting the pressure exchanger to the condenser and evaporator, pressure tested with 100 psi air. The copper tubing is rated to 2000 psi and so are the brass compression fittings, hence neither the tubing nor the fittings should leak at 100 psi. However the some of the compression fittings leaked a little as the fittings were not properly tightened, and by tightening the fittings the problem was solved. Applying a soapy water solution to the fittings and looking for bubbles to grow in size found leaky fittings.

After changing the sensor locations on the pre-boiler and designing a control system for the float sensors, the boiler team began testing the boiler system. The test was conducted independent of the rest of the system. The first test was to determine if the float sensors would trigger at the empty and closed positions, and to determine if the system worked properly in opening the low pressure solenoid valve at the proper time to allow refrigerant to flow into the pre-boiler. After the first try the test was unsuccessful, so the control system was redesigned and on the second time through it worked find. The last test was to determine if the pre-boiler would properly pressurize and push liquid into the main boiler. Because water was easily available, even though it is very different from refrigerant, it was used as the test working fluid. The control system worked effectively to suck water into the pre-boiler, and the pre-boiler was able to pressurize the fluid by enough to cause it to flow into the main boiler. This test revealed several weaknesses in the design. The water was heated to approximately 400° F as saturated steam at a pressure of 100 psig. When the main boiler pressure reached 40 psig, the end caps began to leak. This can most likely be fixed by applying a pipe thread sealant to the end cap threads. The Teflon tape used to hold seal the check valve fitting, the heater mount, and the thermocouple mount, began to smoke as did the rubber on the outside of the both boilers. Because 400° is significantly hotter than the designed max temp using refrigerant of 200° F, this issue will have to be addressed using a working fluid that will operate in the 200°F region. Another issue encountered during this test, was a much faster pressurization of the main boiler than the pre-boiler, but due to the test conditions this does not say much. The reason the main boiler pressurized much faster, is that it was not filled with any water to begin with, so when a small amount of water entered into the extremely hot main boiler from the completely full pre-boiler, it immediately flashed into steam, greatly increasing the main boiler pressure. Since the pre-boiler was full of water, it took a much greater amount of heat to turn it into steam; hence it took longer for the pre-boiler to pressurize. During operation, the main boiler is designed to remain filled approximately half full of liquid at all times. Currently both heaters for the boilers are controlled by the same power source; hence both heaters are either on or off. In the future individual control of the heaters could help to solve this problem, if it still exists when operating under the designed conditions. The key findings of the boiler team are: the boiler control system works and that the boiler end caps leak around 40 psig.

The pressure exchanger control systems team spent a large part of the semester designing and building a control circuit for the pressure exchanger. After completion of the control circuit, the circuit was tested first by running a magnet over the magnetic sensors of the circuit, which proved the design of the circuit worked. Next the magnetic sensors were temporarily attached to the table so they could sense the movement of the magnet on the linkage connecting the two pressure exchanger cylinders. The refrigeration distribution team connected the high-pressure line into the pressure exchanger, which will eventually come from the main boiler, to 100 psig compressed air. After several adjustments of the magnetic sensors, the control system worked properly and pressure exchanger moved as it was designed. Hence the control circuit works. Since the magnetic sensors are very sensitive, their position must be exactly correct. In the testing stage, tape was used to hold the sensors in place, but in the future due to the vibration due to the pressure exchanger, the sensor mounts need to be bolted or firmly secured in some other method to the table.

All current electrical and mechanical systems work. The system is yet to be tested as a whole and refrigerant is yet to be added to the system, so whether it will work as a whole is yet to be determined. After pressure testing, it was found that the boiler end caps leak at 40 psig, and all the tubing that was pressure tested did not leak up to a 100 psig after a few fittings were tightened up.

Recommendations and Next Steps

Now that almost all of the hardware is installed and the different control systems have been built, the design as originally thought up for use in third world countries should be reviewed. By reviewing the original design ideas and taking some time to understand why things were designed as they are, will allow students to ask good questions and figure out for themselves how the system works. Asking good questions and understanding the system will all them to find any large errors or small errors that were made in the construction process. To verify system performance, it is recommended that the system be modeled using thermodynamic equations. As mentioned from the boiler test, the boilers operate at relatively high temperatures, so thread sealants, cords going to the heaters, and thermocouple wires should be researched to find out what temperature ranges they are acceptable to be used within. If the current parts have a maximum operating temperature of less than 200°F, then other components with an acceptable rating need to be found, or a method of shielding the device from the high temperatures needs to be devised.

Although the piping essentially complete, refrigerant still needs to be added to the system. To ensure the system is ready, and to find out exactly what is required to ready the system for refrigerant to be added, a refrigeration mechanic should be brought in.

Typically only refrigeration mechanics fill the systems with refrigerant, therefore you should start working with him early. In order to add refrigerant to the system, a Schrader valve needs to be added, and to find out the location and if more than one is needed talk to refrigeration mechanic. Once the Schrader valves are added, the system needs to be pressure tested again to ensure there are no leaks, since any leak means expensive refrigerant will be lost in the near future.

The pressure rating of the boiler float sensors is 300 psig, and the designed maximum pressure in the pre-boiler is 400 psig, hence float sensors with a higher-pressure rating are needed. Dr. Ruiz suggested the possibility of using some sort of sensor that works off of the fact that refrigerant has a different dielectric constant for liquid and vapor phases. Using a sensor that works like a capacitor, and by measuring the capacitance based on the change in the dielectric constant, the state of the fluid could be determined at the location of the sensor. The pre-boiler mounting is made out of pine, and after taking on and off the table several times, it has become rather worn and should be replaced with a more durable material. As discussed in the results and conclusions, the boiler heater system should be worked with so that the boiler heaters are individually controlled.

The pressure exchanger control circuit designers need to work with the data acquisition team so that the two systems can be used together. The idea is to let the data acquisition team tie the computer system into the pressure exchanger circuit to monitor it and to control it. A LabView program was written this semester to interface the computer with the pressure exchanger circuit, but because the two have not been connected yet, the program is yet to be validated. Computer control will allow the timing of the pressure exchanger to be controlled allowing system optimization, and to optimize the system several system input parameters need to be continuously monitored from the system. The three pressures in the system need to be found, and since these pressures are all two-phase flow at some point, the pressure can be calculated knowing the temperature. To measure the temperature, thermocouples are used. Two K-type thermocouples are being used, and in order to connect their very small signal to the DAC, the signal needs to be amplified; hence an amplification circuit needs to be built.