ME 495 - Mechanical and Thermal Systems Lab

Department of Engineering

Lab 9: Refrigeration System

**Group E**

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Objective of the Experiment

The objective of this experiment was to gain knowledge and understanding of how a vapor-compression cycle works. For the experiment an Armfield RA1 Refrigeration Unit was utilized and adjustments were made to the units expansion valve to determine the effects on the compression, condensation, expansion, and evaporation of the cycle. The system records temperature differences between each component and allows the cycle to be analyzed through the amount of heat and energy absorbed by the cycle which directly affects the efficiency of the evaporator.

The expansion valve has three forces acting on it: a bulb pressure, an evaporator pressure, and a spring pressure. This device controls the flow of the refrigerant that goes into the compressor. As the bulb pressure increases, more refrigerant is allowed to go into the cycle. Once there is too much, as the temperature decreases, the bulb pressure also decrease, closing the expansion valve.

The following formulas from Professor Nourollahi’s, “ME-495 Laboratory Exercise - Number 9 - Refrigeration System” were needed to find the best performance of the different sections of the vapor-compression cycle.

Table 1: Key Terms

<table>
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<th>VALUE</th>
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<tr>
<td>m</td>
<td>Mass flow rate of the refrigerant (kg/s)</td>
</tr>
<tr>
<td>Heat_in</td>
<td>Heat absorbed by refrigerant (Watts)</td>
</tr>
<tr>
<td>h1</td>
<td>Enthalpy of refrigerant at outlet of the evaporator (kJ/kg)</td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>h4</td>
<td>Enthalpy of the refrigerant at the inlet of the evaporator (kJ.kg)</td>
</tr>
<tr>
<td>Q_in</td>
<td>Energy absorbed by evaporator (Watts)</td>
</tr>
<tr>
<td>F2</td>
<td>Water flow rate through evaporator (L/min)</td>
</tr>
<tr>
<td>T8</td>
<td>Temperature of water at inlet of evaporator (K)</td>
</tr>
<tr>
<td>T9</td>
<td>Temperature of water at outlet of evaporator (K)</td>
</tr>
</tbody>
</table>

Heat to refrigerant

\[
Heat_{in} = \dot{m} \times (h_4 - h_4) \times 1000
\]

Heat to evaporator

\[
Q_{in} = \frac{F_2}{60} \times 4200 \times (T_9 - T_8)
\]

Efficiency

\[
Efficiency = \frac{Q_{in}}{Heat_{in}} \times 100
\]

Equipment

- RA1 Refrigeration Unit
- Compatible PC with Armfield Software
- Flat Bladed Screwdriver
Specifications:

Refrigeration system Vapour-compression type: Refrigerant R134a

Compressor speed range: 2000 to 4400 rpm

Compressor supply: 24V DC to speed controller of brushless 3 phase DC motor
Compressor rating: 7.11 cm³ (0.434 cu in) for high evaporator temperature with 7.2°C rating point

Condenser: Brazed plate heat exchanger using water as heat transfer medium

Evaporator: Brazed plate heat exchanger using water as heat transfer medium

Water reservoir: Working capacity 400 litres

Temperature sensors: NTC Thermistor

Refrigerant flowmeter: Variable area flowmeter

**Experimental Procedure**

To set up the refrigeration apparatus one shall connect the USB connection and make sure the device is on. The device may be run when the circuit breakers and RCD device on the back left of the unit are in the up position, and the power switch is turned on.

With the RA1 software open, set both the condenser and evaporator water pump speeds to 90%.

Remove the cap from the adjusting screw, and turn the expansion valve clockwise until it is closed, then turn the screw ¼ way counter-clockwise. After this set the compressor speed to 65%, and adjust the expansion valve ¼ turn every minute. This shall be repeated until the coefficient of performance remains constant, or for approximately 5 ½ minutes. Stop the recording data, and save it to a location to be analyzed later. Repeat this procedure with the compressor set at 75%, as well as 85%.
To shut down the system, set the compressor motor speed to 80%, the condenser water pump speed to 50%, and the evaporator water pump speed to 70%. Allows the refrigeration device to stabilize until the temperature difference between T3 and T7 is about 4-6 degrees C. After this the equipment may be switch off.

**Experimental Results**

![Figure 3. COP Box and Whisker Plot](image3)

![Figure 4. Compressor Work vs time](image4)
Discussion of Results

The data seen in Figures 3 and 4 is the data accumulated from the experiment for the compressor set at 65%, 75% and 85%. It displays the work done by the compressor over time. Sources of error are from this experiment may have come in the form of the refrigeration system, refrigerant, and the measurement software. The refrigeration system did have 2 failures on the 65% compressor run until we were able to get a good run recorded. Also, the system failed again with minutes for the 75% trial was underway. This was due to a depleted refrigerant in the system. Data for the 75% and 85% trials were given by the TA. Human error can be factored in when starting and stopping the recording software and the exact quarter turn increments that were supposed to be made on the valve.

Lab Questions

1. How does the temperature change as the expansion valve is adjusted? Explain.

The temperature and pressure of the system are directly related. As you adjust the spring pressure of the expansion valve, the superheat value follows because the superheat is proportional to the spring force.

2. How does the pressure vary across the expansion valve? Explain.
There are three forces acting on an expansion valve; bulb pressure (F1), evaporator pressure (F2) and spring pressure (F3). If the pressure at F1 is greater than F2+F3 then the valve would open to allow for additional liquid refrigerant to flow to the evaporator. If F2+F3 were to be greater than F1, this would indicate that the pressure at the evaporator is greater than that of the bulb and the expansion valve would close to discontinue the flow of liquid.

3. Use the equations provided to calculate the efficiency of the evaporator during each reading. Use Excel, and provide a graph for each compressor speed.

Given equation 2 we are able to find the energy absorbed by the evaporator (Q_in), the software collects this data automatically. To finish solving for efficiency with equation 1 we require both the enthalpies of the refrigerant at 2 points, given that we do not have this information it would be difficult to solve. Except the software gives us energy released (Q_out) by the water which would be equal to the energy absorbed by our refrigerant, giving us what we need. Plots are as follows.
Figure 5: 65% Run Efficiency vs. Time

Figure 6: 75% Run Efficiency vs. Time

Figure 7: 85% Run Efficiency vs. Time
4. What happens to the system when the expansion valve is adjusted? Why?

As the expansion valve is adjusted, the flow of refrigerant changes. Since the flow of refrigerant increases while opening the valve to the expansion valve, more flow causes an increase in the energy absorbed by the evaporator and heat absorbed by the refrigerant.

5. Why does the expansion valve need to be adjusted?

An expansion valve controls the rate of liquid refrigerant flowing to the evaporator. This is necessary to maximize the efficiency of the evaporator while also regulating any excess liquid refrigerant from going back to the compressor.

6. Is there an optimum expansion valve position for greatest performance?

Yes, the optimum expansion valve position would be where the refrigerant entering the evaporator is exactly the amount that is being boiled off. The greatest performance would have the refrigerant entering the compressor fully saturated.

7. What happens to the system when the compressor speed is changed? Why?
When the compressor speed is changed, more refrigerant needs to flow through the evaporator. Increasing the compressor speed will increase the pressure in the condenser and increase the mass flow rate through the apparatus.

8. Is there an optimum compressor speed for greatest performance?

Yes, there is an optimum compressor speed for greatest performance. However, the performance is related to the expansion valve. In our case we saw the best COPs when the compressor was running at 65%.

9. What was the average range of values at each compressor speed?

**Conclusion**

The results from the experiment were what were ultimately expected for the refrigeration system. As the compressor speed percentage rose the coefficient of performance increased with it. The possible sources of error may have affected our data and the performance levels of the system. Even so, this lab showed the process and inner workings of a refrigeration system. It also brought about an understanding of ensuring that systems must be checked prior to running to achieve desired performance, safety and results.
Acknowledgements

We would like to acknowledge professor Nourollahi for providing the lab pdf which included the lab procedure and how to operate the unit, as well as providing the equations use in the analysis of our data. Additionally we would like to acknowledge our TA for his assistance in priming the unit as well as setting the unit back to normal operating procedures.

References

[1] Nourollahi, ME-495 Laboratory Exercise - Number 9 - Refrigeration System - Vapor Compression Refrigeration. ME Dept, SDSU