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REFRIGERATION CYCLE: Our Design & Findings

Dear Dr. Osborne-Lee,

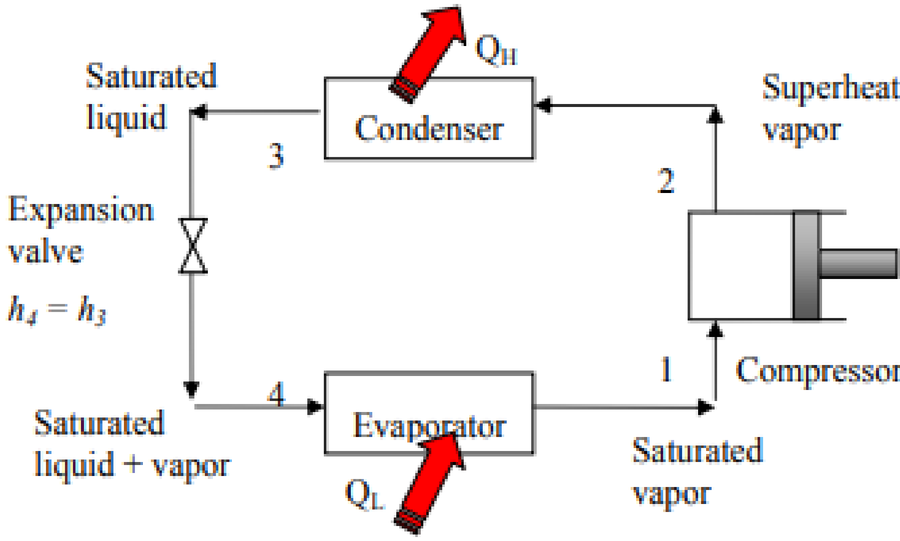
We are writing in reference to the course project posted to Canvas: Refrigeration Cycle Design Project. As a group we were asked to:

- Design a refrigeration system to maintain our ranges
- Choose a safe and suitable refrigerant
- Determine temperatures and pressures at different states
- Show the cycle on a temperature entropy *(P-H or T-S)* diagram
- Determine the coefficient of performance value
- Determine the mass flow rate of the working fluid

Before we started the project we had to first understand how a refrigeration cycle works.

BACKGROUND

In a refrigeration cycle, there are four significant parts: a compressor, a condenser, a thermal exchange valve, and an evaporator. For cooling to occur, the refrigerant passes through all 4 components. As engineers we know heat transfer occurs from areas of high temperatures to areas of low temperatures, this is also true for the refrigeration cycle. Let's break down what happens in each component:



COMPRESSOR

The cycle requires input of power to increase the pressure of a gas. The refrigerant enters at low pressure and low temperature in a gaseous form. It cannot operate on liquids, the working fluid must leave the evaporator and enter the compressor at least as saturated vapor. This is an adiabatic process and is Isentropic, therefore entropy is zero.

THERMAL EXPANSION VALVE

Controls the amount of refrigerant flow into the evaporator and controls the superheating at the outlet of the evaporator. Two phases occur here: saturated liquid and saturated vapor. There's no change in enthalpy and pressure is constant.

CONDENSER and EVAPORATOR

Both are heat exchange devices and transfer heat between two different fluids. The Evaporator removes heat from the interior of the refrigerator compartment by exchanging heat between the air inside the refrigerator and the refrigerant passing through the tubes of the evaporator. The condenser is used to remove heat gained from the refrigerant through the evaporator and the compressor. The transfer of heat to the ambient air must be at a lower temperature than that of the refrigerant exiting the condenser.

Now with our knowledge of the refrigeration cycle, it's time to start the project.

PROBLEM STATEMENT:

A refrigeration system is to be designed to maintain the temperature in the range -25°C to -15°C, while the outside temperature varies from 15°C to 25°C. The total thermal load on the storage unit is given as 20 kW. Obtain an initial design for the vapor compression refrigeration system shown in Figure 1. Choose a safe and suitable refrigerant. For safe operation and other factors, such as additional energy transfer, design the system using a safety factor of 1.3. The compressor efficiency could range from 60 to 80 percent.

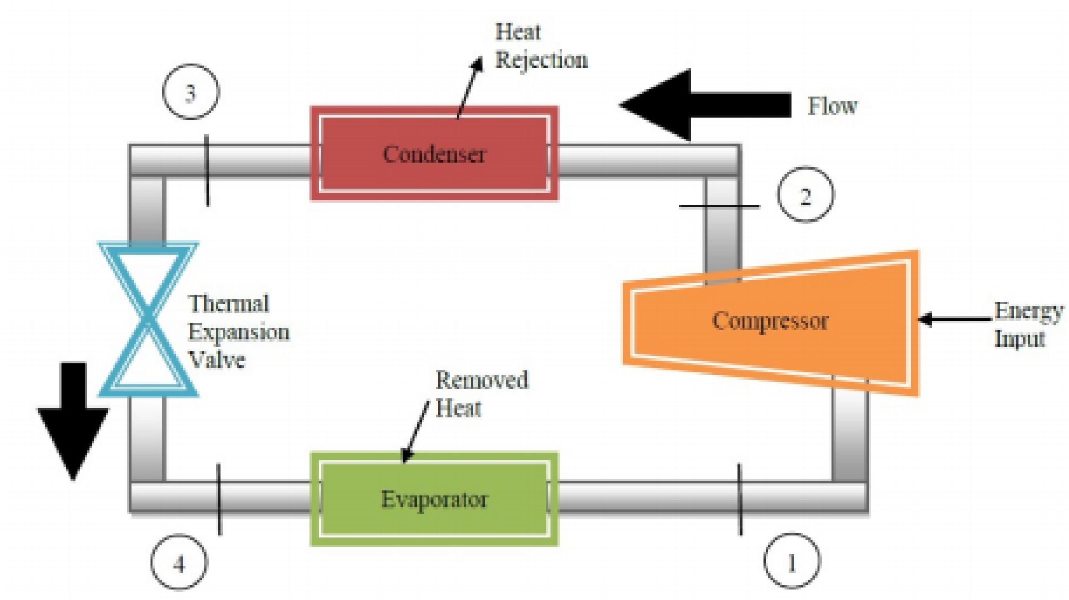


Figure 1: Vapour compression refrigeration cycle.

ASSUMPTIONS

Here are our assumptions:

- This is an open system because there's a total exchange
- It operates under steady-state and steady-flow processes
- Kinetic and Potential energies across each device is negligible
- Compressor and expansion devices are adiabatic
- Evaporator and condenser are considered constant pressure devices
- The isentropic efficiency of the turbine was selected to be 75%.

For our project, we choose to operate with Difluoromethane (R-407C). This refrigerant is made from a mixture of hydrofluorocarbons to the likes of difluoromethane, pentafluoroethane, and 1,1,1,2-tetrafluoromethane. Some other factors are that R-407C has zero ozone depletion potential making it less harmful to our environment and it works in medium temperature refrigeration systems. The freezing point of Difluoromethane is -160°C which means it's less

than our T-Low (min), -25°C. It has a critical temperature (86.0) that is higher than the atmospheric temperature of the earth and has a boiling point of -43.6°C.
We decided to use the efficiency Al-Arfaj and Abu-Mulaweh had in their project. We are convinced that if the value for their efficiency was wrong they would not be able to publish their paper. They used an efficiency of 75% to ensure that the system will operate over their entire range and also the safety factor of 1.3 was used which emulates our project.

P-H DIAGRAM

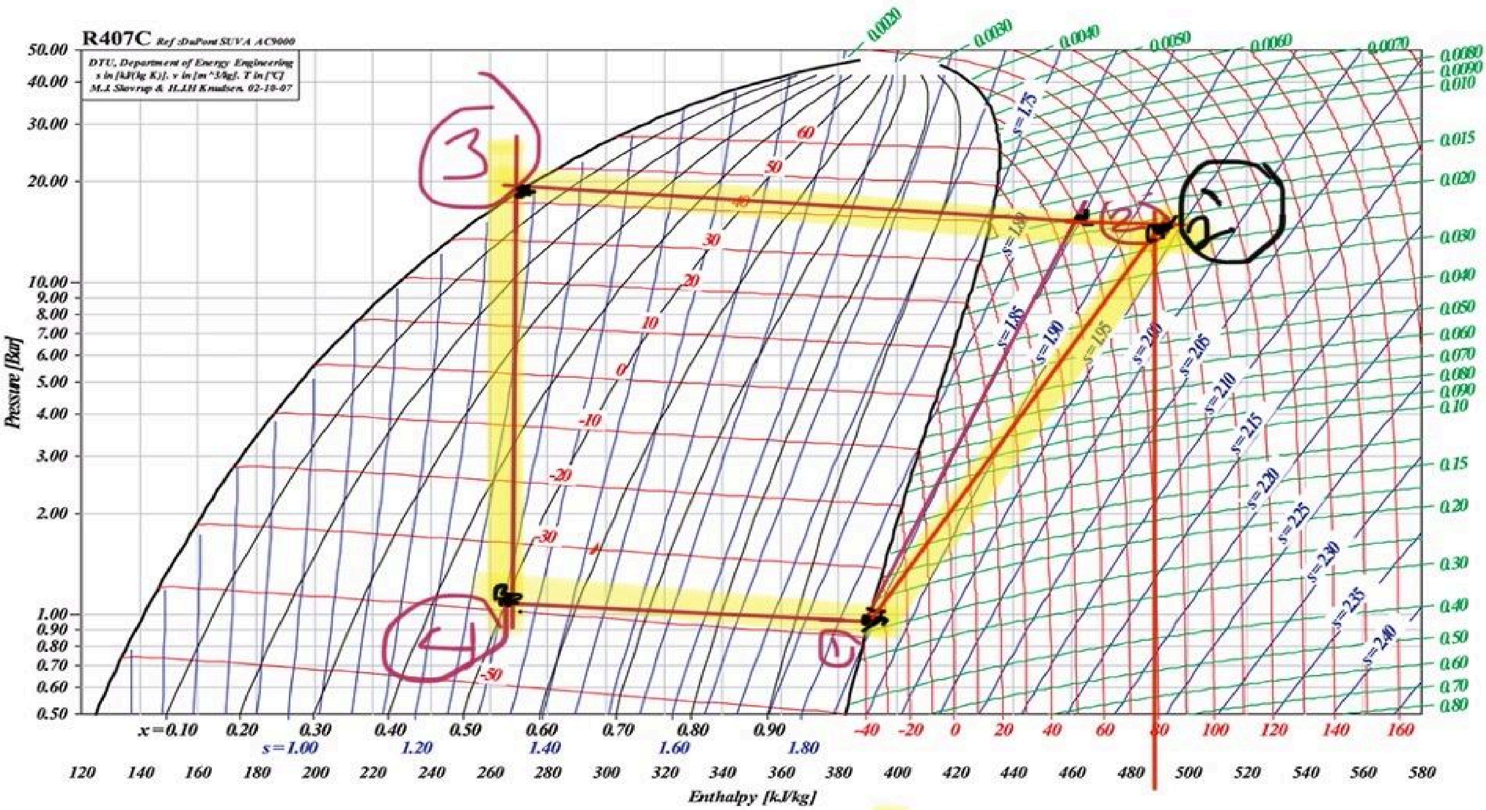


TABLE 1: Thermodynamic properties at the relevant states.

State	T (°C)	P (kPa)	H (kJ/kg)	S (kJ/kg.K)	x
1	-40	1.48	385	1.85	1
2s	40	20.12	457	1.85	N/A
2a	80	20.12	481	1.92	N/A
3	40	20.12	262	0	0
4	-40	1.48	262	1.23	0.30872

Using the P-H diagram we can fill out Table 1, but we have to calculate our h_{2a} and plot it on the diagram to get the temperature, pressure, and entropy for 2a. To calculate this we used the formula:

$$h_{2a} = \frac{(h_{2s} - h_1)}{.75} + h_1$$

$$h_{2a} = \frac{(457 - 385)}{.75} + 385 = 481\ kJ/kg$$

TABLE 2: Initial design values.

Q_{in} (W)	26
Q_{out} (W)	46.29
W_{comp} (W)	20.29
ṁ (kg/s)	.21138
COP	1.281

To fill out Table 2, we used the following formulas:

From the problem statement we were given that our thermal load is 20kW and a factor of safety of 1.3. If we multiply 20 by 1.3 we get a cooling load of 26kW.

We know the formula for an open system is:

$$\Delta H + E_k + E_p = Q + W$$

For our refrigeration system the kinetic and potential energies across each device is negligible so our formula now is:

$$\Delta H = Q + W$$

We now apply this formula over each component.

Evaporator: $\Delta H = Q + W_s$ (there's no work done here, so $W_s = 0$)

So we use this formula: $\Delta H = Q$

$$\dot{m} = \frac{Q_{in}}{(h_1 - h_4)}$$

$$\dot{m} = \frac{26}{(385-262)}$$

$$\dot{m} = .21138\ kg/s$$

Compressor: $\Delta H = Q + W_s$ (this is adiabatic, so Q = 0)

So we use this formula: $\Delta H = W_s$

$$\dot{m}\,(h_{2a} - h_1) = W_s$$

$$.21138\ (481 - 385) = 20.29$$

Condenser: $\Delta H = Q + W_s$

So we use this formula: $\Delta H = Q$

$$\dot{m}\,(h_{2a} - h_1) = Q_{out}$$

$$.21138\ (481 - 262) = 46.29$$

COP: Coefficient of Performance

$$COP = \frac{Q_{in}}{W}$$

$$COP = \frac{26}{20.29} = 1.281$$

We decided to use 75% for our efficiency, but having all this data let's prove the isentropic efficiency of the compressor. The formula is:

$$\eta = \frac{h_{2s} - h_1}{h_{2a} - h_1}$$

$$= \frac{457-385}{481-385}$$

$$\eta = .75$$

CONCLUSION

This project was given to test our understanding of the concepts and principles of what we've covered so far in Thermodynamics I. It was meant to be easy but proved quite difficult. This is what we were able to accomplish as a group with our collective knowledge of thermodynamics, so far. Thank you for the experience and all your help. The paper by Al-Arfaj and Abu-Mulaweh was of big help. Honorable mentions go to Chemical Engineering Thermodynamics, 8th edition book, the ever faithful google.com and youtube academy.

This concludes the assignment.

Respectfully submitted,

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