University of Guelph, School of Engineering

ENGG*3260 Thermodynamics

Lab 2: Refrigeration and Heat Pump Cycle Analysis

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1. Introduction

Lab 2 introduces the vapor-compression refrigeration cycle. This cycle eliminates most of the impracticalities associated with a reversed Carnot cycle by vaporizing the refrigerant completely before it is compressed. This is applied by replacing the turbine with a throttling device, in this case an expansion valve was used. The ideal vapor-compression refrigerant cycle is shown in figure 1. This cycle is most widely used cycle for refrigerators, AC systems, and heat pumps.

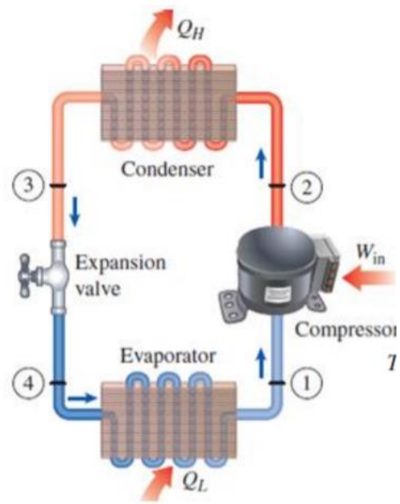


Figure 1: The Ideal Vapor- Compression refrigerant cycle

Stages of the Vapor Compression refrigeration cycle

- 1-2 Isentropic compression in a compressor.
- 2-3 Constant-pressure heat rejection in a condenser.
- 3-4 Throttling in an expansion device.
- 4-1 Constant-pressure heat absorption in an evaporator.

One of the most important properties reffered to when comparing such system is the COP, Coefficient of performance. This property shows the ratio between the heat transfer at each heat sink compared to the work by the compressor into the system. A more efficient system has a higher COP value

2. Objective

The main objective of lab 2 is to measure and analyze the performance of a vapor compression cycle working in both the refrigeration and heat pump modes. To analyze the system accurately and successfully, the COP in the refrigeration and heat pump modes should be calculated by applying the energy balance equation learned in class.

3. Methodology

The system lab 2 consists of 4 main components. A condenser, evaporator, compressor and an expansion valve. Attached to this system is a high pressure and a low pressure valve, and temperature readout devices that helped in obtaining accurate results. The energy meter was plugged in and the main switch was turned on 1 hour prior to the experiment. The in and out water hoses to both water tank was then connected with tap water supply to close the water circuit. The tap water valve was opened slowly to allow a continuous water flow into the tanks. The compressor was then plugged in as the electrical stand switch was turned on until the steady state temperature was achieved. Through this system, the condenser's pressure and temperature, cooling water temperature inlet and outlet ,and the cooling water flow rate was obtained. For the evaporator, the pressure and temperature, heating water temperature inlet and outlet ,and the heating water flow values where collected using the temperature readout and pressure valve described above. Figure 2 described the system used in Lab 2:

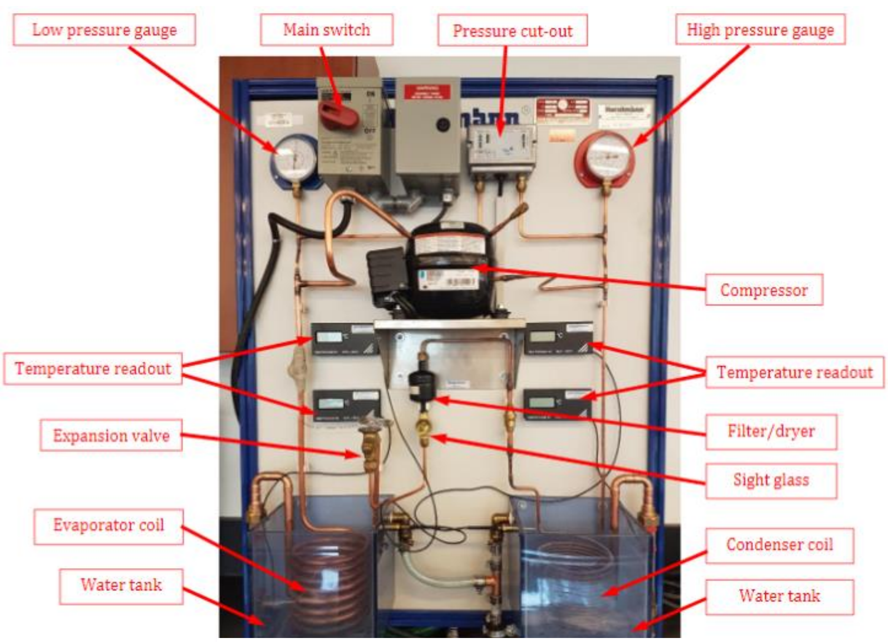


Figure 2: Apparatus used in lab 2

4. Results

4.1. Experimental Values

	Evaporator	Condenser
Temperature	0.67 °C	32.62 °C
Pressure	300 KPa	755 KPa
Water flow	0.035 kg/s	0.042 kg/s
Inlet water temperature	11.5 °C	11.5 °C
Outlet water temperature	8.9 °C	15.6 °C

Electrical Power Consumption of compressor = 150W

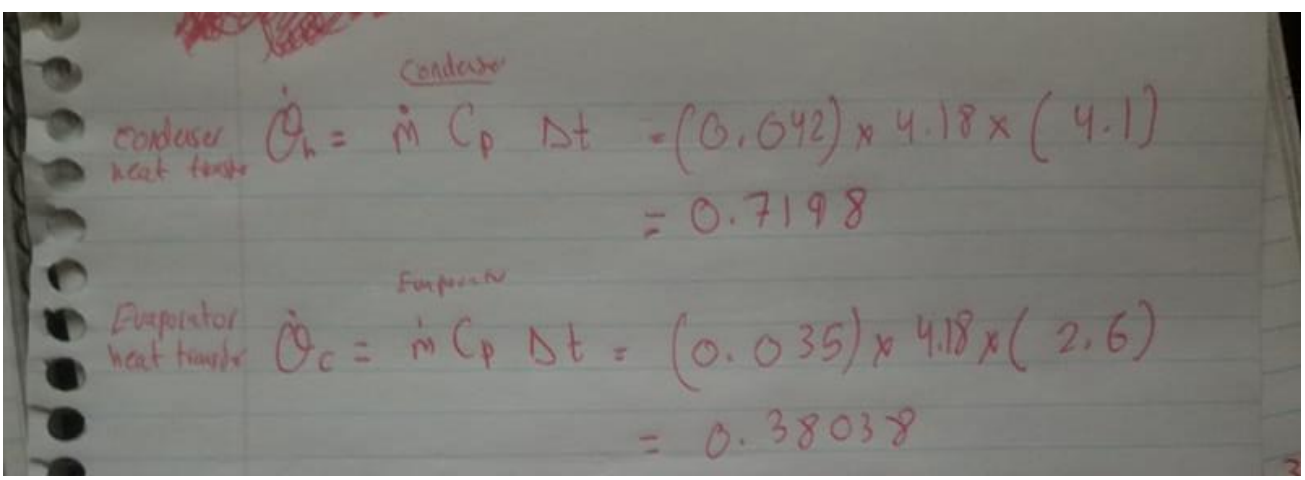
Stage	Pressure (KPA)	Temperature (°C)	Enthalpy (KJ/kg)
1	300 KPa	0.67 °C	250.85 KJ/kg
2	755 KPa	32.62 °C	270 KJ/kg
3	755 KPa	29.3 °C	92.6 KJ/kg
4	300 KPa	0.67 °C	92.6 KJ/kg

(Check appendix for detailed calculations)

Calculation	Result
Condenser Heat transfer	0.7198 kW
Evaporator Heat Transfer	0.38038 kW
Refrigeration COP	4.799
Heat Pump COP	2.54
Maximum COP (Refrigeration, Heat Pump)	29.92, 30.92
Refrigerant Mass flow	0.0041 Kg/sec
Isentropic Work Of Compressor	20.85 J
Compressor Work	39.3 J
Isentropic Efficiency Of Compressor	54.5%

(Check Sample calculation (Section 4.2) for detailed calculations)

4.2. Sample Calculations



Refrigeration COP $\quad COP_H = \dfrac{\dot{Q}_H}{0.150} = \dfrac{0.71988}{0.150} = 4.799$

Heat pump COP $\quad COP_L = \dfrac{\dot{Q}_L}{0.150} = \dfrac{0.38038}{0.150} = 2.54$

Mass flow $\quad \dot{m}_g = \dfrac{\dot{Q}_H}{h_2 - h_3} = \dfrac{0.7198}{270 - 92.6} = 0.0041\ kg/s$

① $\rightarrow 0.67$ ② $\rightarrow 29.3$

$$\eta_c = \frac{\text{Isentropic Work}}{\text{compressor work}} = \frac{20.85}{C_p(T_2 - T_1)}$$

$1.23\ (31.95)$

$$\frac{20.85}{39.3} = 54\%$$

isentropic work $= (h_2 - h_1) = 280.85 - 260 = 20.85$

Work $= C_p(T_2 - T_1) = 1.23(31.95) = 39.3$

$COP\ R,rev = T(\mathrm{L})/T(H) - T(L) = 11.2+273/((20.7+273)-(11.2+273)) = 29.92$

$COPHP,rev = T(\mathrm{H})/T(H) - T(L) = 20.7+273/((20.7+273)-(11.2+273)) = 30.92$

4.3. Experimental Graph representation

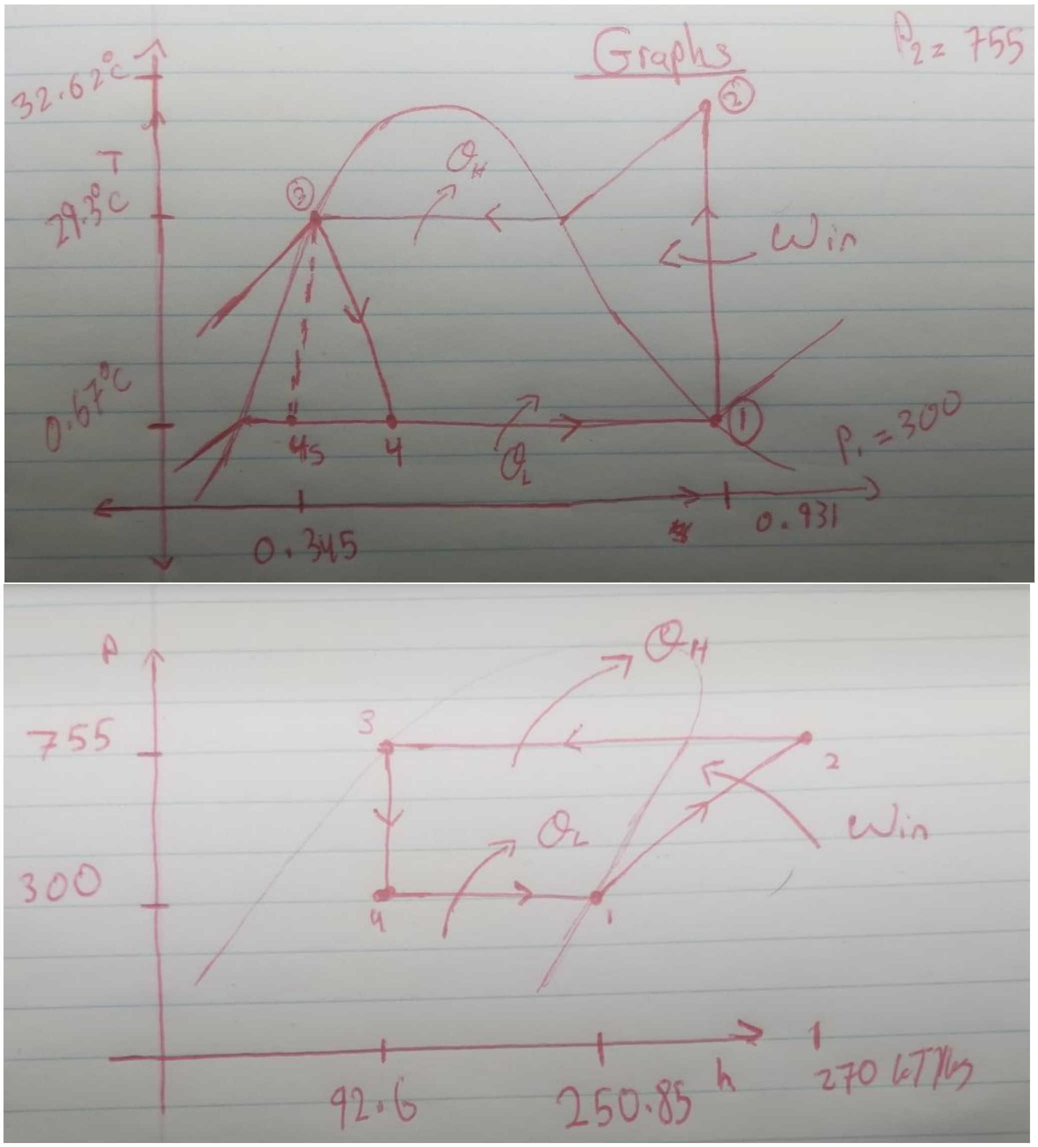


Figure 1: Experimental Results Plot

The plot in Figure 1 shows the calculated Temperature Vs Entropy diagram and the Pressure vs Enthalpy diagram of the vapor-compression refrigeration cycle.

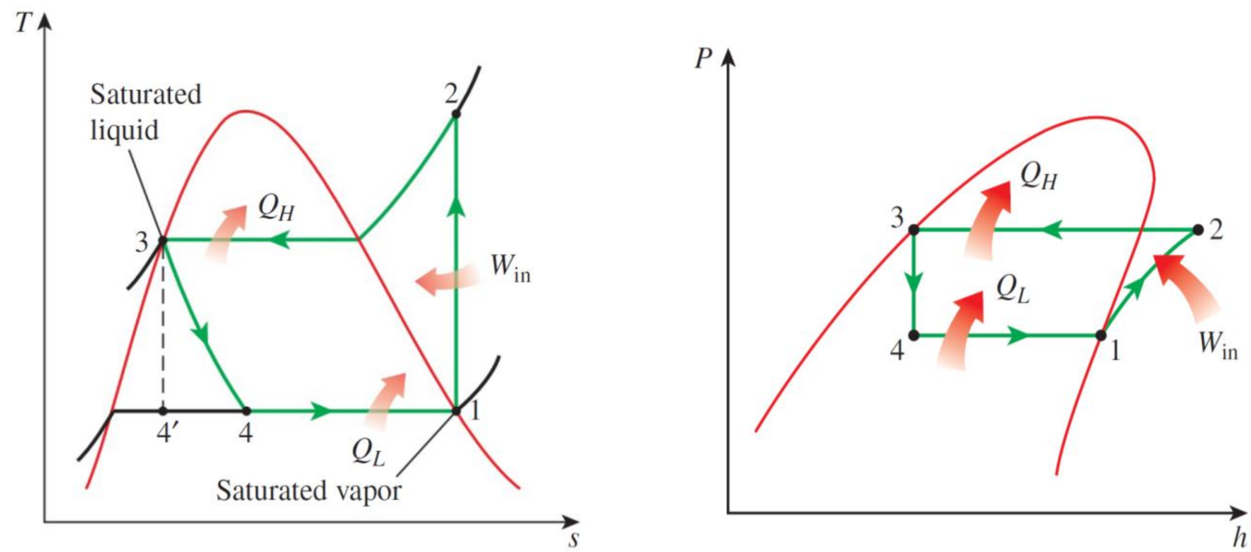


Figure 5: ideal P-H and T-S diagrams for system

The plots in figure 5 represents the ideal Temperature Vs Entropy diagram and the Pressure vs Enthalpy diagram of the vapor-compression refrigeration cycle.

5. Observation And Analysis

In this system, the temperature change of Refrigerant-134a was monitored as it flows through the system. In its hot and gaseous state, Refrigerant-134a enters the compressor at state 1 as saturated vapor, which gets compressed isentropically to the condenser pressure. During this isentropic process the temperature of the refrigerant increases above the surrounding temperature. At stage 2, the refrigerant enters the condenser as super-heated vapor and leaves as saturated liquid to stage 3 due to heat rejection to the surrounding. The temperature of the refrigerant at this stage is still above the temperature of the surrounding. By passing the saturated liquid refrigerant from stage 3 through an expansion valve the refrigerant is throttled to the evaporator’s pressure. The temperature of the refrigerant drops below the temperature of the refrigerant space during the process.

In stage 4 the refrigerant enters the evaporator as a low quality saturated mixture and is later completely evaporated by absorbing heat from the refrigerate space. The refrigerant leaves the evaporator as saturated vapor and reenters the compressor completing the cycle. The efficiency of the system can be determined by calculating the COP value using the difference in temperature for high/low pressures in the system.

By analyzing the results from section 4, the COP of the evaporator is low compared to the condenser. This is due to the greater energy loss at the condenser than the energy lost at the evaporator. As the first law of thermodynamics states, the heat output should equal to the work done in the system plus the heat put into the system. This can be seen since the work done by the compressor plus the heat added by the evaporator equal to a close amount of the heat outputted by the condenser.

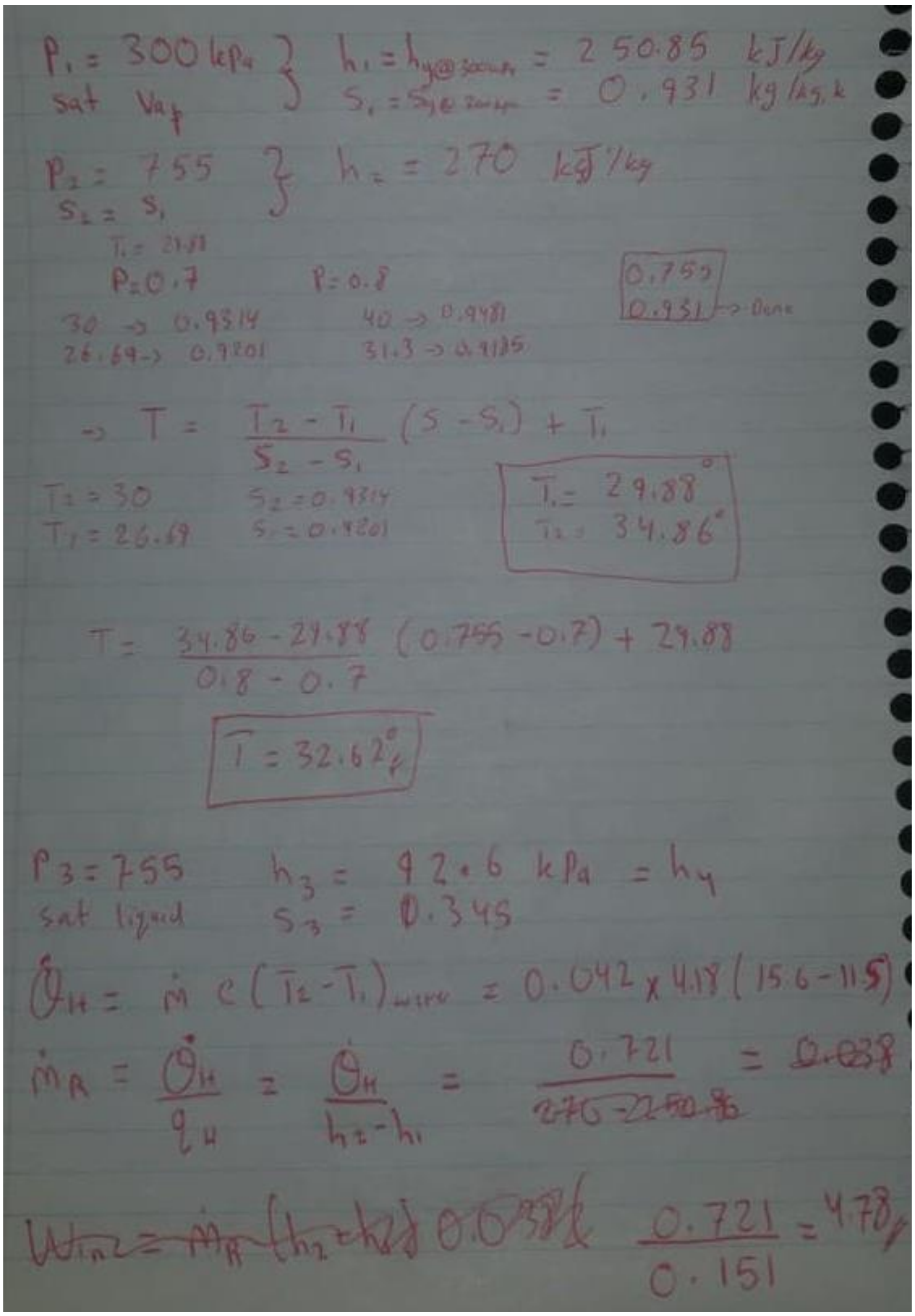
6. Conclusion

Through lab 2, The theory behind how a heat pump functions was explained. From this lab we learn that heat dissipated is always greater than the heat absorbed due to work by the compressor on the system. This proves why the COP of the condenser is higher than that of an evaporator. This experiment shows how to use basic properties such as temperature and pressure to calculate the COP of the system. Calculating the COP helps in analyzing what parts of the system are most efficient. Efficiency of part is a very important in industrial production as high efficiency minimizes the costs of production and help companies excel in their sectors.

7. References

Cengel, Yunas A. and Boles, Michael A. Thermodynamics: An Engineering Approach, *8th Edition.* New York: McGraw-Hill Education, 2015.

8. Appendix


$P_1 = 300$ kPa, sat Vap } $h_1 = h_{g@300kPa} = 250.85$ kJ/kg; $S_1 = S_{g@300kPa} = 0.931$ kg/kg.k

$P_2 = 755$, $S_2 = S_1$ } $h_2 = 270$ kJ/kg

$T_1 = 21.83$

$P = 0.7$ | $P = 0.8$ | $\boxed{0.755 \quad 0.931} \rightarrow$ Done

$30 \rightarrow 0.9314$ | $40 \rightarrow 0.9481$

$26.69 \rightarrow 0.9201$ | $31.3 \rightarrow 0.9135$

$$\rightarrow T = \frac{T_2 - T_1}{S_2 - S_1}(S - S_1) + T_1$$

$T_2 = 30$, $T_1 = 26.69$, $S_2 = 0.9314$, $S_1 = 0.9201$

$\boxed{T_1 = 29.88^\circ \quad T_2 = 34.86^\circ}$

$$T = \frac{34.86 - 29.88}{0.8 - 0.7}(0.755 - 0.7) + 29.88$$

$$\boxed{T = 32.62^\circ C}$$

$P_3 = 755$, sat liquid; $h_3 = 92.6$ kPa $= h_4$; $S_3 = 0.345$

$\dot{Q}_H = \dot{m}\, c\, (T_2 - T_1)_{water} = 0.042 \times 4.18\,(15.6 - 11.5)$

$$\dot{m}_R = \frac{\dot{Q}_H}{q_H} = \frac{\dot{Q}_H}{h_2 - h_1} = \frac{0.721}{\cancel{270 - 250.85}} = 0.038$$

$\cancel{W_{in2} = \dot{m}_R (h_2 - h_1)}\ 0.038$; $\dfrac{0.721}{0.151} = 4.78$