TFES Lab (ME EN 4650)
Vapor-Compression Refrigeration Cycle

Textbook Reference: Sections 3.5, 11.3 – 11.5 from Cengel and Boles, 5$^{\text{th}}$ ed., McGraw-Hill

Objectives

(i) measure temperatures and pressures in a refrigeration system designed on the vapor-compression cycle,

(ii) determine the coefficient of performance COP_R using the First Law of Thermodynamics as a function of refrigerant flow rate,

(iii) determine the amount of heat rejected from the refrigerant as a function of refrigerant flow rate, and

(iv) calculate the isentropic compressor efficiency as a function of refrigerant flow rate.

Background

Most household and commercial refrigerators operate based on the vapor-compression refrigeration cycle. A drawing of this type of refrigerator is shown in Figure 1, along with a schematic identifying the main mechanical components: compressor, condenser, expansion valve or throttling device, and evaporator. The main idea behind a refrigerator is to cool the air inside an enclosed space to a low temperature (typically around 3°C in the refrigerated

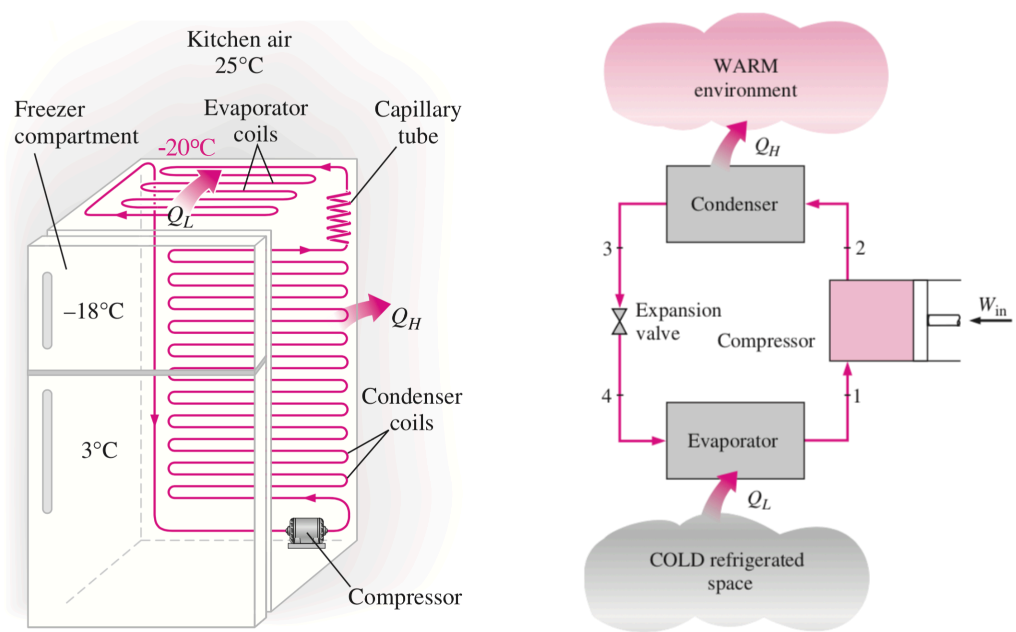

Figure 1. (left) Drawing of a typical household refrigerator showing the main mechanical components. (right) Schematic of an ideal vapor-compression refrigeration cycle.

section and around -18°C in the freezer section). In contrast, ambient air temperature is usually 23–25°C. Note however, in the immediate vicinity of the refrigerator, the surrounding air temperature is warmer than ambient, due to the heat rejected as part of the thermodynamic cycle.

The vapor-compression refrigeration cycle operates as a closed system, with a refrigerant as the working fluid. Hydrofluorocarbons are commonly used as refrigerants today, especially R-134a. These substances have special properties, namely a saturation pressure of 1 atm or higher at -20°C. As the refrigerant flows around the system, it changes phase through two sets of fin-and-tube heat exchangers i.e., vapor-to-liquid in the condenser, and liquid-to-vapor in the evaporator. This allows the heat transfer processes between the air and refrigerant to occur at atmospheric pressure, which is important because it would be very inconvenient if your refrigerated space was at a higher or lower pressure relative to atmospheric conditions (that would make opening/closing the refrigerator door difficult).

The path of the refrigerant through the cycle is described in Table 1. The corresponding temperature-entropy (T-s) and pressure-enthalpy (P-h) diagrams for the *ideal* scenario are shown in Figure 2, with the four state points labeled. In the *ideal* scenario, path lines are assumed to be infinitesimal. In other words, the physical effect of the tubing used to carry the refrigerant around the enclosure is ignored.

At state 1, the refrigerant is in vapor form at low temperature and pressure. The vapor enters the compressor which does work on the refrigerant to raise its pressure, while also increasing its temperature above ambient. At state 2, high pressure, high temperature refrigerant vapor exits the compressor. At this point, the temperature of the vapor needs to be reduced in order to achieve cooling. Therefore, the refrigerant vapor is routed through a condenser unit that serves as a heat exchanger, rejecting heat from the high temperature refrigerant vapor to the surrounding air (see Appendix I). The heat rejected to the surroundings is denoted by Q_H. Typical refrigerator condensers operate on the principle of natural convection (no fans are used). During this heat exchange process, the refrigerant crosses its saturated liquid-vapor line, so that heat rejected serves to change its phase from vapor to liquid. At state 3, high pressure, med temperature liquid exits the condenser. Cooling inside the refrigerated space is achieved with a throttling device (also called an expansion valve) that restricts the flow of the liquid refrigerant. This is achieved using either a gate-type valve or a coiled section of smaller diameter tubing (called capillary tubing). As high pressure liquid refrigerant is forced through the restriction, its velocity increases to conserve mass. This simultaneously decreases the pressure (due to Bernoulli's equation); and, hence the temperature of the

Table 1. Path of the refrigerant through the cycle, and its corresponding temperature and pressure.

State	Fluid Type	Location in Cycle	Temperature	Pressure
1	vapor	evaporator outlet, compressor inlet	low	low
2	vapor	compressor outlet, condenser inlet	high	high
3	liquid	condenser outlet, expansion valve inlet	med	high
4	liquid	expansion valve outlet, evaporator inlet	low	low

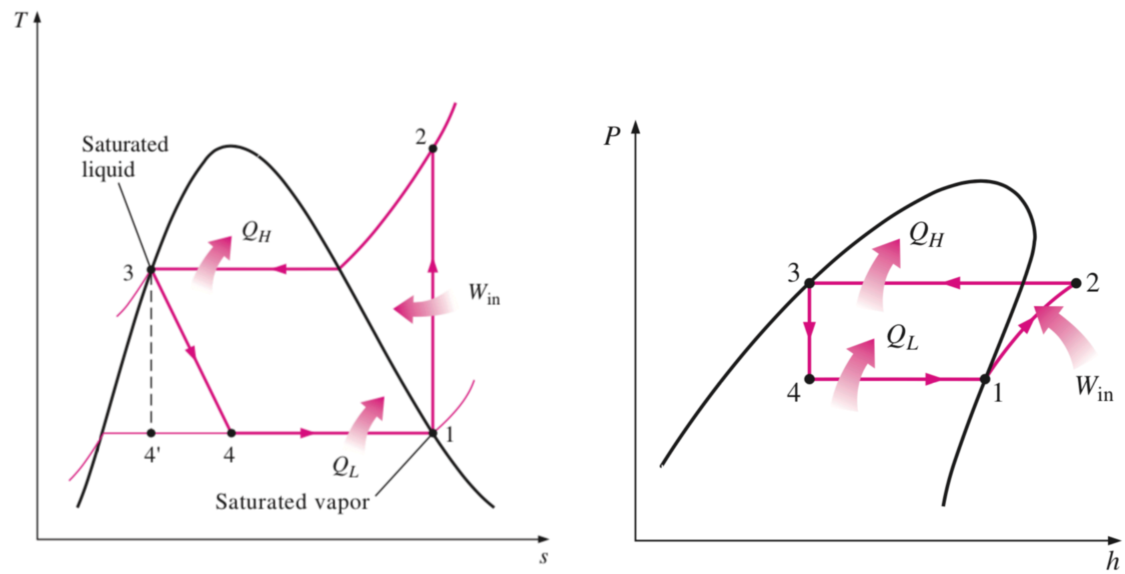

Figure 2. Example (left) T-s diagram and (right) P-h diagram of an ideal vapor-compression refrigeration cycle.

liquid refrigerant decreases as well to a value of about -20°C. At state 4, the very cold liquid refrigerant is routed through another heat exchanger (called an evaporator). Because the liquid refrigerant is now at a temperature lower than the desired temperature of the freezer, it will absorb heat from the air inside the freezer/refrigerator enclosure (i.e., heat "flows" down the temperature gradient). The heat removed from the cold space is denoted by Q_L. During this process, the liquid refrigerant crosses its saturated liquid-vapor line again, such that the absorbed heat serves to change its phase back to a vapor. This is important, because the compressor unit will only function if the working fluid is in vapor form.

Experimental Setup

A Scott air conditioning and refrigeration system, Model 9086, is used to evaluate the operational characteristics of a typical air conditioning and refrigeration system. A photograph of the experimental setup is shown in Figure 3. The system operates on a closed vapor compression cycle with Refrigerant HFC-134a as the working fluid. The experimental apparatus is comparable to the most common commercial refrigeration and air conditioning systems and can be operated with reverse flow to demonstrate heat pump operation. The refrigerant flow rate may be varied by manually adjusting the needle valve V4, located between the condenser and expansion valve.

The temperature and pressure of the refrigerant at five state points in the system, as listed in Table 2, will be measured experimentally. Note that two measurement stations for temperature and pressure (locations 1 and 5) are located between the evaporator and compressor at slightly different positions. Location 5 represents the evaporator outlet and location 1 represents the compressor inlet. Table 3 lists the quantities that will be measured in the lab, along with their native units.

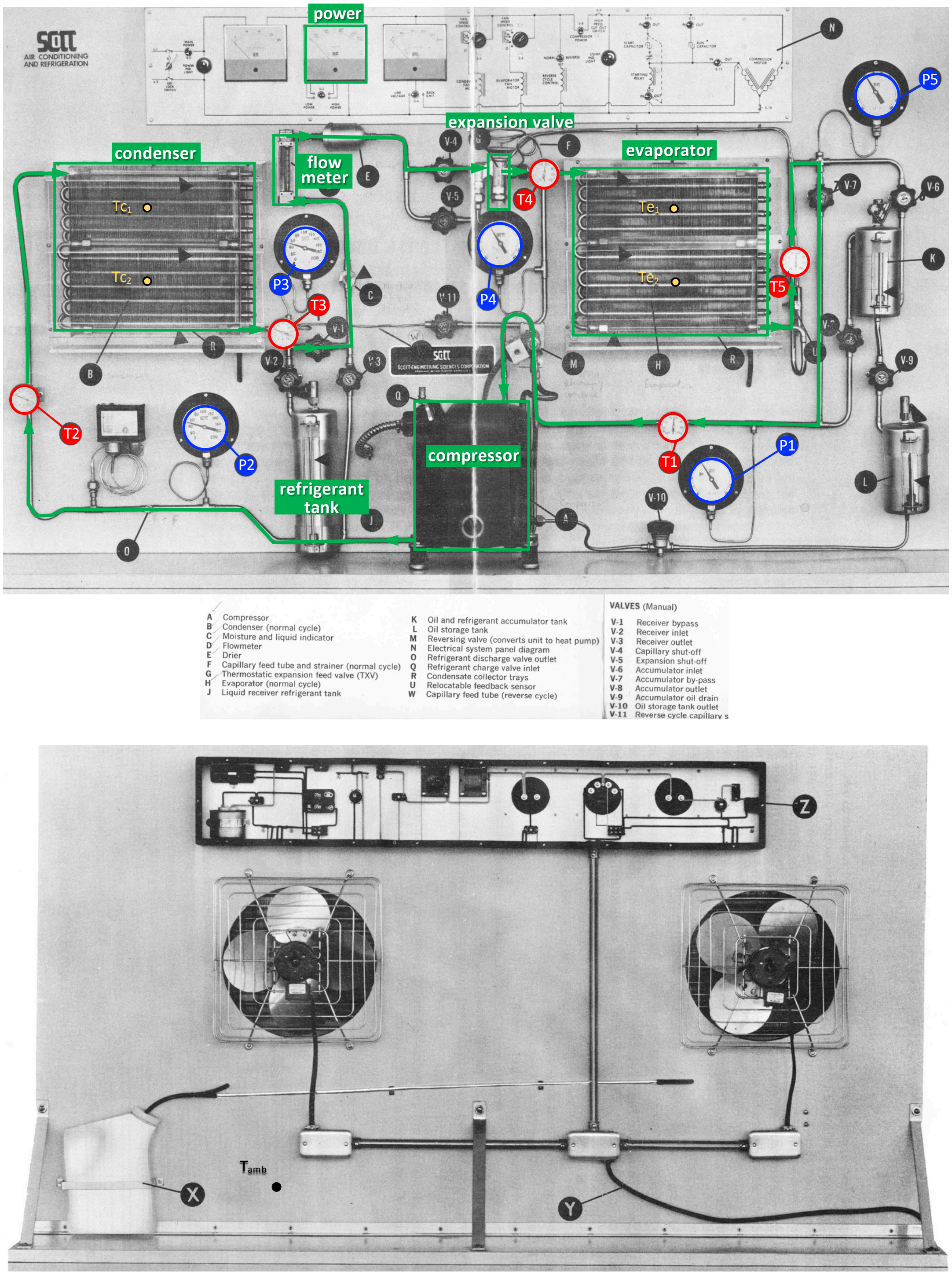

Figure 3. Photograph of the experimental setup showing the locations of the components and state point measurements. The path of the refrigerant is highlighted in green, along with the main components. Pressure measurement locations are indicated in blue; and, temperature measurement locations are indicated in red.

Table 2. List of measured state points in the experiment.

	Pressure	Temperature
compressor inlet	P_1	T_1
compressor outlet (condenser inlet)	P_2	T_2
condenser outlet (expansion valve inlet)	P_3	T_3
expansion valve outlet (evaporator inlet)	P_4	T_4
evaporator outlet	P_5	T_5

Table 3. List of measurements acquired in the experiment with their native units.

Quantity	Symbol	Units	Instrument
Refrigerant temperature	T	°F	dial gauge
Refrigerant pressure	P	psig	dial gauge
Air temperature	T_e, T_c	°C	thermocouple
Refrigerant volume flow rate	$\dot{V}$	gpm	rotameter
Electrical power	$\dot{W}_{\text{total}}$	W	analog meter

Laboratory Procedure

Refrigerant flow rate is the primary control variable for this experiment. Four different flow rates will be investigated. In each case, the dependent variables will be measured and recorded once the system has reached steady state. Note that the system uses DuPont HFC-134a refrigerant, which is a more ozone-layer friendly substance than the older R-12 Freon.

1. Identify the following components on the experimental apparatus (note the native units for each measurement instrument):
   a. main power switch S2
   b. compressor
   c. compressor power switch S8
   d. condenser
   e. expansion valve
   f. evaporator
   g. refrigerant volumetric flow meter
   h. fan for condenser (backside)
   i. fan for evaporator (backside)
   j. analog meter to measure power $\dot{W}$ supplied to the system (top panel, frontside)
   k. thermocouples to measure air temperatures at condenser and evaporator, T_{e_1}, T_{e_2}, T_{c_1}, T_{c_2}
   l. digital thermometer instrument box with switch to measure air temperatures
   m. analog thermometers to measure refrigerant temperature at T_1, T_2, T_3, T_4, T_5
   n. analog pressure gauges to measure refrigerant pressure at P_1, P_2, P_3, P_4, P_5

2. Make sure power cords (e.g., for the thermocouple meter) are clear of obstructions and that student packs and/or accessories will not cause interference with controls, cords, valves, or switches.
3. Verify that the system has been filled with refrigerant (will be done by the teaching staff). Verify that T_2 is below (and remains below) 190°F. If T_2 ever exceeds 190°F, immediately decrease the flow rate in the system by adjusting valvel V4.
4. Verify that main power switch S2 is on.
5. Verify that the digital thermocouple meter is powered on.
6. Measure atmospheric pressure P_{atm} (mm Hg) using the barometer located in the laboratory. Measure room air temperature T_{amb} (°C) using the thermocouple located near the inlet of the evaporator and condenser fans (on the backside of the experimental apparatus). It is read using position 5 on the thermocouple meter.
7. Turn on the evaporator and condenser fans to high if not already on, using the switches labeled Fan Speed Control S5 and S6.
8. Measure the electrical power required for the fans, $\dot{W}_f$ (W).
9. Turn on the compressor using switch S8.
10. Measure the electrical power required for the combined fans and compressor, $\dot{W}_{\text{total}}$ (W).
11. Set the volumetric flow rate to 0.2 gpm (maximum) using valve V4 (which requires only a very small amount of valve rotation). Note that the <u>rotameter is read relative to the center of the spherical float</u>.
12. Allow the system to stabilize for approximately 3 minutes while closely monitoring T_2. Should T_2 exceed 190°F, decrease the refrigerant flow rate using valve V4.
13. Once the system has reached steady state, record the following measurements on your data sheet: T_{e_1}, T_{e_2}, T_{c_1}, T_{c_2}, P_1, T_1, P_2, T_2, P_3, T_3, P_4, T_4, P_5, T_5, $\dot{V}$.
14. Repeat steps 11–13 for volumetric flow rates of 0.15, 0.1, and $<$0.1 gpm. Note, the flow rate is changed by slowly closing valve V4. The valve is highly sensitive.
15. Turn off the compressor with switch S8.
16. Turn off the condenser and evaporator fans with switches S5 and S6, respectively.
17. Drain the refrigerant from the system back into the reservoir. Note, this will be performed by one of the teaching staff.
18. Turn off the main power using switch S2.

Data Analysis

Several different quantities are of interest in the analysis of refrigeration cycles. These include enthalpies at all state locations in the cycle, compressor work delivered to the refrigerant, heat loss from the compressor, and the coefficient of performance for the refrigerator, COP_R. Perform the following data reduction process for each data set corresponding to the different refrigerant volumetric flow rates.

1. Convert all measurements to their proper SI units. This includes converting $T_1, \ldots, T_5$ (from °F to K), $P_1, \ldots, P_5$ (from psig to kPa absolute), and $\dot{V}$ (from gpm to m^3/s). Note, the data from the pressure gauges must be converted to absolute pressure by adding the barometric pressure.
2. Compute the average air temperature at the condenser and evaporator outlets

$$\overline{T_c} = \tfrac{1}{2}(T_{c_1} + T_{c_2}) \qquad \text{and} \qquad \overline{T_e} = \tfrac{1}{2}(T_{e_1} + T_{e_2}). \tag{1}$$

3. Determine the enthalpy for all 5 states of the refrigerant based on the absolute pressure P (in kPa) and temperature T (in K) measured at each state. To do this, you can use one of two methods: (i) bilinear interpolation of the provided R134a Property Tables, as described in Appendix II, or (ii) CoolProp library in Matlab or Python to evaluate the refrigerant properties, as described in Appendix III. Note that state 4 is expected to be a liquid-vapor mixture. This means that T and P are not independent at state 4; so, some other property must be used to define state 4, such as the quality (i.e., the percentage of liquid verus vapor in the mixture). For purposes of this lab, we will assume that the expansion process in the expansion valve is adiabatic, which yields $h_3 = h_4$. This is a pretty good assumption because the expansion process occurs rapidly through the valve.
4. Determine the refrigerant density at each state ρ (in kg/m^3) from the measured T and P values, along with the provided R134a Property Tables (use bilinear interpolation) or using CoolProp.
5. Determine the mass flow rate of the refrigerant $\dot{m}$ (in kg/s) using the relationship

$$\dot{m} = \rho_3 \, \dot{V}. \tag{2}$$

Note, we use the density at state 3 because the rotameter sensor used to measure volume flow rate is located inline between the condenser outlet and the expansion valve inlet defining state 3.

6. The electrical power supplied to the compressor motor $\dot{W}_c$ can be determined as the difference between the power supplied to the compressor plus fans and that supplied to the fans alone

$$\dot{W}_c = \dot{W}_{\text{total}} - \dot{W}_f. \tag{3}$$

7. The power supplied to the refrigerant by the compressor $\dot{W}_{\text{in}}$ is less than the electrical power delivered to the compressor $\dot{W}_c$ because of mechanical losses and losses in translating compressor rotor power to refrigerant power. Introducing mechanical efficiency η_M and hydraulic efficiency η_H allows one to account for both types of losses in the compressor.

$$\dot{W}_{\text{in}} = \eta_M \, \eta_H \, \dot{W}_c. \tag{4}$$

Note, for the vapor-compression refrigeration system examined in the laboratory, the product of mechanical and hydraulic efficiencies is $\eta_M \, \eta_H$=78%.

8. Determine the specific work to the refrigerant, w_{in} (in kJ/kg), using the relationship

$$w_{\text{in}} = \frac{\dot{W}_{\text{in}}}{\dot{m}}. \tag{5}$$

9. Determine the heat per unit mass rejected from the refrigerant in the condenser, q_H, by writing the appropriate energy balance. Note, there is no work done on or by the condenser. Therefore,

$$q_H = -(h_3 - h_2). \tag{6}$$

Similarly, by writing the energy balance for the evaporator, we find that the heat per unit mass transferred to the refrigerant in the evaporator q_L is

$$q_L = h_1 - h_4. \tag{7}$$

10. If the compressor were adiabatic, the specific enthalpy value at the compressor exit would be $h_1 + w_{\text{in}}$. However, we know that the compressor transfers some heat to its surroundings. We can determine this heat loss, q_{loss}, by writing the energy balance (per unit mass) for the refrigerant, assuming steady-state conditions,

$$q_H = q_L + w_{\text{in}} - q_{\text{loss}}. \tag{8}$$

Substituting in (6) and (7), and assuming an adiabatic expansion process through the expansion valve (i.e., $h_3 = h_4$) yields an equation for the heat loss to the surroundings

$$q_{\text{loss}} = w_{\text{in}} + h_1 - h_2. \tag{9}$$

11. Determine COP_R from the enthalpy change across the evaporator and the specific work applied to the refrigerant. By definition,

$$\text{COP}_\text{R} = \frac{q_L}{w_{\text{in}}}. \tag{10}$$

The coefficient of performance represents the units of thermal energy removed from the refrigerated space for each unit of electric energy consumed by the system. Typical values of COP_R for household refrigerators are in the range of 2–4.

12. Determine the enthalpy at the compressor exit for an <u>ideal</u> vapor-compression refrigeration cycle, h_{2_s}. Recall that in the ideal cycle, the compression process is assumed to be isentropic, i.e. $s_1 = s_2$. Therefore, we can follow these steps:
    (i) Calculate s_1 from the Property Tables or CoolProp using the measured T_1 and P_1.
    (ii) Calculate s_2 by assuming $s_2 = s_1$.
    (iii) Calculate h_{2_s} from the Property Tables using s_2 and the measured T_2.

13. Finally, we can calculate the isentropic efficiency of the compressor, η_c, which is defined as the isentropic work divided by the actual work required to compress the vapor from state 1 to state 2,

$$\eta_c = \frac{w_s}{w_{\text{in}}} \cdot 100\% = \frac{h_{2_s} - h_1}{h_2 - h_1 + q_{\text{loss}}} \cdot 100\%, \tag{11}$$

where we have used substituted the energy balance relation in (9) for w_{in}.

Required Figures

Captions

A meaningful and comprehensive caption must accompany all figures. For the three figures, the caption is placed *below* the figure and includes the label Figure 1x., where x denotes the letter a–e according to the plot order listed below.

Plots

1a. On a single figure, plot the ambient air temperature (T_{amb}), refrigerant temperature at the condenser outlet & expansion valve inlet (T_3), refrigerant temperature at the expansion valve outlet & evaporator inlet (T_4), air temperature exiting the condenser ($\overline{T_e}$), and air temperature exiting the evaporator ($\overline{T_c}$) as functions of refrigerant mass flow rate, $\dot{m}$. Plot temperatures on the y-axis in units of °C, and mass flow rate on the x-axis in units of kg/s. Plot the refrigerant temperatures using *open* markers, the ambient air temperature as a black dashed line, and the other air temperatures using *solid* markers. Use the following marker/line styles for each data set: ○ T_3; □ T_4; ● $\overline{T_c}$; ■ $\overline{T_e}$; - - T_{amb}. Be sure to include a legend. Do NOT connect the data points with lines.

1b. On a single figure, plot the specific energy terms (q_L, q_H, q_{loss} and w_{in}) as a function of refrigerant mass flow rate, $\dot{m}$. Plot the specific energy terms on the y-axis in units of kJ/kg, and refrigerant mass flow rate on the x-axis in units of kg/s. Use the following marker/line styles for each data set: ○ q_L; □ q_H; × q_{loss}; ◇ w_{in}. Be sure to include a legend. Do NOT connect the data points with lines.

1c. Plot the coefficient of performance of the refrigerator COP_R (on the y-axis) as a function of refrigerant mass flow rate $\dot{m}$ (on the x-axis in units of kg/s). Use a marker for your data. Do NOT connect the data points with a line.

1d. On a single figure, plot both the isentropic efficiency of the compressor η_c and the total electrical power supplied $\dot{W}_{\text{total}}$ (in units of W) versus refrigerant mass flow rate $\dot{m}$ (in units of kg/s). To do this, create two different y-axes: one on the left side (for η_c) and another on the right side (for $\dot{W}_{\text{total}}$). Plot $\dot{m}$ on the x-axis. Use different marker styles for η_c and $\dot{W}_{\text{total}}$. Do NOT connect the data points with a line. Be sure to include a legend. [See the "Help Notes" on CANVAS for creating this type of plot.]

1e. For the highest refrigerant mass flow rate, plot the **actual** cycle processes on a P-h diagram for R134a. To do this, open the provided Matlab figure of the P-h diagram for R134a (see Appendix IV). Draw points on the P-h diagram that represent the five state points of the actual processes, as determined from your analysis. Be careful to notice that the units on the provided P-h diagram is MPa for pressure and kJ/kg for specific enthalpy. Label each of your state points on the diagram. Finally, draw lines connecting the state points representing the process paths. Use a red color for your points and process path lines. Note, the enthalpy **reference state** for the P-h diagram provided is such that h=200 kJ/kg and s=1.0 kJ/kg·K for saturated liquid at T=0°C. Therefore it is important that you use this same reference state when evaluating the enthalpy for each state point.

Short-Answer Questions

2a. List and explain the observed differences in the P-h diagrams between an ideal cycle (as depicted in Figure 2) and that obtained from your actual measurements. [4–6 sentences]

2b. Based on your results and your engineering judgment, at what flow rate should the refrigerator be run. Justify your answer. [3–4 sentences]

2c. Perform a brief literature search of vapor-compression refrigeration systems to determine how one can improve the coefficient of performance of an actual system. Describe at least one means of increasing COP_R and explain how it works in terms of equation (10). Include one or more references from your literature search. [3–6 sentences]

APPENDIX I: Condenser and Evaporator Units

Figure 4 illustrates the types of fin-and-tube heat exchangers used in the condenser and evaporator units of most household refrigerators. Fins are needed to increase the heat transfer surface area. Condensers are located on the outside of the refrigerator, either along the entire backside or as a compact unit underneath the refrigerator. The units on the back of the refrigerator operate by natural convection and do not use fans. Evaporators are usually located inside the freezer/refrigerator, typically along the back panel of the freezer section.

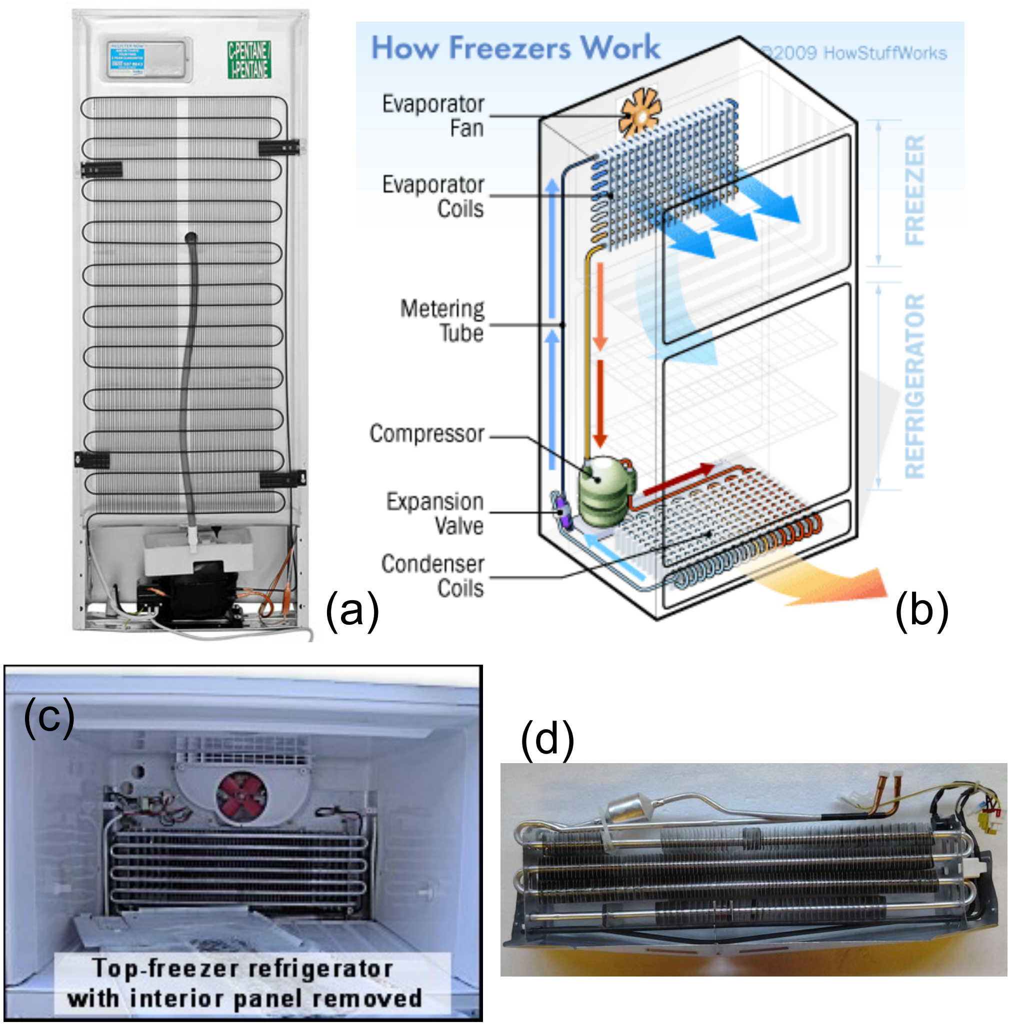

Figure 4. (a) Photograph of a condenser located along the backside of a refrigerator. (b) Illustration of a condenser located at the bottom of a refrigerator. (c) Photograph of an evaporator inside the freezer section of a refrigerator. (d) Phtorgraph of an evaporator unit from a household refrigerator.

APPENDIX II: Bilinear Interpolation of P-h Diagram

In utilizing a P-h diagram to obtain the thermodynamic properties of a substance, one typically needs to perform bilinear interpolation. For example, consider the case where we want to determine the enthalpy (h), given the temperature (T) and pressure (P) defining a particular state. Let f denote the functional dependence of h on T and P, i.e., $h = f(T, P)$. We assume that we only know f at discrete values of T and P, as would be the case for thermodynamic property tables. Therefore, in order to determine f at any general (T, P), we need to locate the four grid points that bracket (T, P), denoted as point R in Figure 5, and apply bilinear interpolation using the steps below.

1. Obtain f at the four grid points surrounding R by looking up the corresponding values in the property tables: $f_{11} = f(T_1, P_1)$, $f_{12} = f(T_1, P_2)$, $f_{21} = f(T_2, P_1)$, $f_{22} = f(T_2, P_2)$.
2. Perform linear interpolation in the T-direction by holding P constant to determine the value of f at points R_1 and R_2:
$$\text{value at point } \mathsf{R}_1: \; f(T, P_1) = \frac{T_2 - T}{T_2 - T_1} f_{11} + \frac{T - T_1}{T_2 - T_1} f_{21} \tag{12}$$
$$\text{value at point } \mathsf{R}_2: \; f(T, P_2) = \frac{T_2 - T}{T_2 - T_1} f_{12} + \frac{T - T_1}{T_2 - T_1} f_{22} \tag{13}$$
3. Perform linear interpolation in the P-direction by holding T constant to determine the value of f at point R:
$$f(T, P) = \frac{P_2 - P}{P_2 - P_1} f(T, P_1) + \frac{P - P_1}{P_2 - P_1} f(T, P_2). \tag{14}$$

We can write these steps compactly in vector-matrix form as

$$f(T, P) = \frac{1}{(T_2 - T_1)(P_2 - P_1)} \begin{bmatrix} (T_2 - T) & (T - T_1) \end{bmatrix} \begin{bmatrix} f(T_1, P_1) & f(T_1, P_2) \\ f(T_2, P_1) & f(T_2, P_2) \end{bmatrix} \begin{bmatrix} (P_2 - P) \\ (P - P_1) \end{bmatrix}. \tag{15}$$

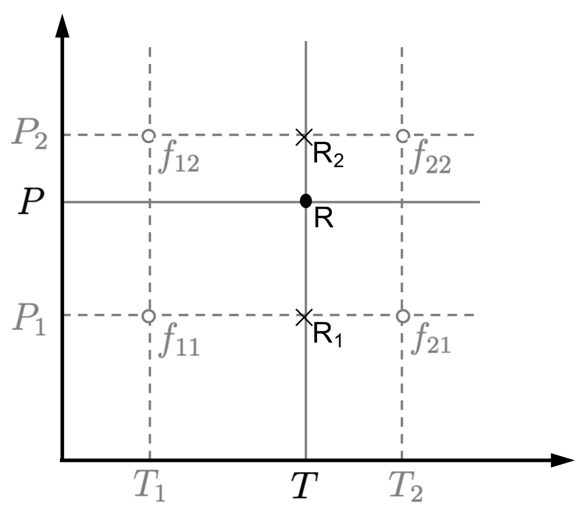

Figure 5. Grid used to apply bilinear interpolation.

APPENDIX III: Using CoolProp to Evaluate Fluid Properties

CoolProp is an open-source database of fluid and humid air properties (www.coolprop.org), formulated based on the most accurate state equations available in the literature. The CoolProp package has already been installed on the CADE LAB machines. It can be accessed via Python, and imported into Matlab. To do this, type the following line into the Matlab Command Window upon startup of the program:

```
>> pyversion C:\Anaconda3\python.exe
```

This command tells Matlab where to find the CoolProp library. Note, you only need to type this command ONCE per Matlab installation. If you quit Matlab and restart it, you do not need to type in this command again. Then, at the top of your Matlab script for the Refrigeration Lab analysis, include the following line in order to import the CoolProp library into Matlab:

```
% load the CoolProp package into Matlab
import py.CoolProp.CoolProp.PropsSI
```

Since enthalpy is a relative property (only changes in enthalpy represent the important physical characteristic of a system), we need to set the reference state. We will utilize a standard reference state where h=200 kJ/kg and s=1.0 kJ/kg·K for saturated liquid at T=0°C. To do this, add the following line to your Matlab script:

```
% set reference state to match that in provided P-h diagram
py.CoolProp.CoolProp.set_reference_state('R134a','IIR')
```

You can now calculate fluid properties using the PropsSI function. For example, to calculate the enthalpy (in J/kg) at state 1, you would type the following:

```
H1=PropsSI('H','T',T1,'P',P1,'R134a');
```

where the input/output arguments are:

output: value of desired property (`H1` contains the enthalpy in J/kg)

input 1: desired property of interest (`'H'` indicates enthalpy)

input 2: first known state variable (`'T'` indicates temperature)

input 3: value of first state variable (`T1` contains the temperature in K)

input 4: second known state variable (`'P'` indicates pressure)

input 5: value of state variable (`P1` contains the pressure in Pa)

input 6: substance of interest (`'R134a'` indicates R134a refrigerant)

To calculate the mass density of the refrigerant (in kg/m^3) at state 1, you would type:

```
r1=PropsSI('D','T',T1,'P',P1,'R134a');
```

Note, PropsSI is NOT capable of handling arrays. Therefore, you will need to call this function once for each state point of interest (i.e., 15 times to analyze all of the measured data). It is recommended that you place the function call inside a FOR-LOOP and loop over all of the measured data.

APPENDIX IV: P-h Diagram for R134a (in SI units)

Figure 6 is the P-h diagram for R134a based on a reference state of $h = 200$ kJ/kg, $s = 1.0$ kJ/kg·K for saturated liquid at $T = 0°C$. The black line is the saturated liquid-vapor line for R134a. The blue lines represent lines of constant temperature. And, the green lines represent lines of constant specific entropy.

The figure is available for download from CANVAS as a Matlab FIG file called `Ph_Diagram_R134a.fig`.

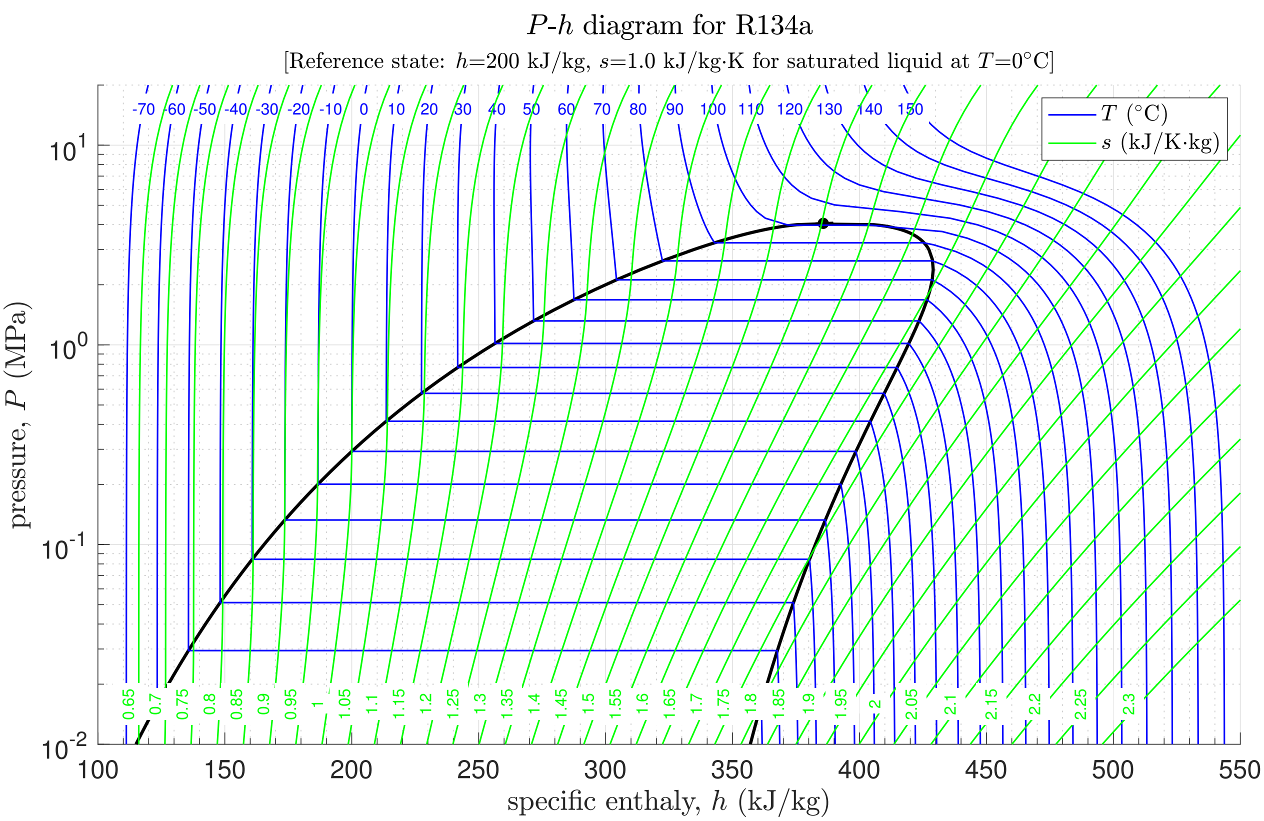

Figure 6. Pressure-enthalpy diagram for R134a based on data provided by CoolProp.