Vapor-Compression Refrigeration

Prepared by Courtney Smith & Sarah Brown

Executive Summary

Data was collected for an actual vapor-compression refrigeration cycle utilizing the Thermostatic Expansion Valve (TXV), operating with Refrigerant 134a and under the conditions of low condenser fan speed and high evaporator fan speed. Analysis was performed in order to compare an actual refrigeration cycle to that of an idealized cycle. Data was collected by means of 14 thermocouples spread throughout the cycle which was condensed into 5 state points; 4 gage pressures were also recorded. Through calculations and the implementations of formulas (shown below), the thermodynamic efficiency was: 75.5% , and coefficient of performance was: 2.80.

Detailed Outcomes

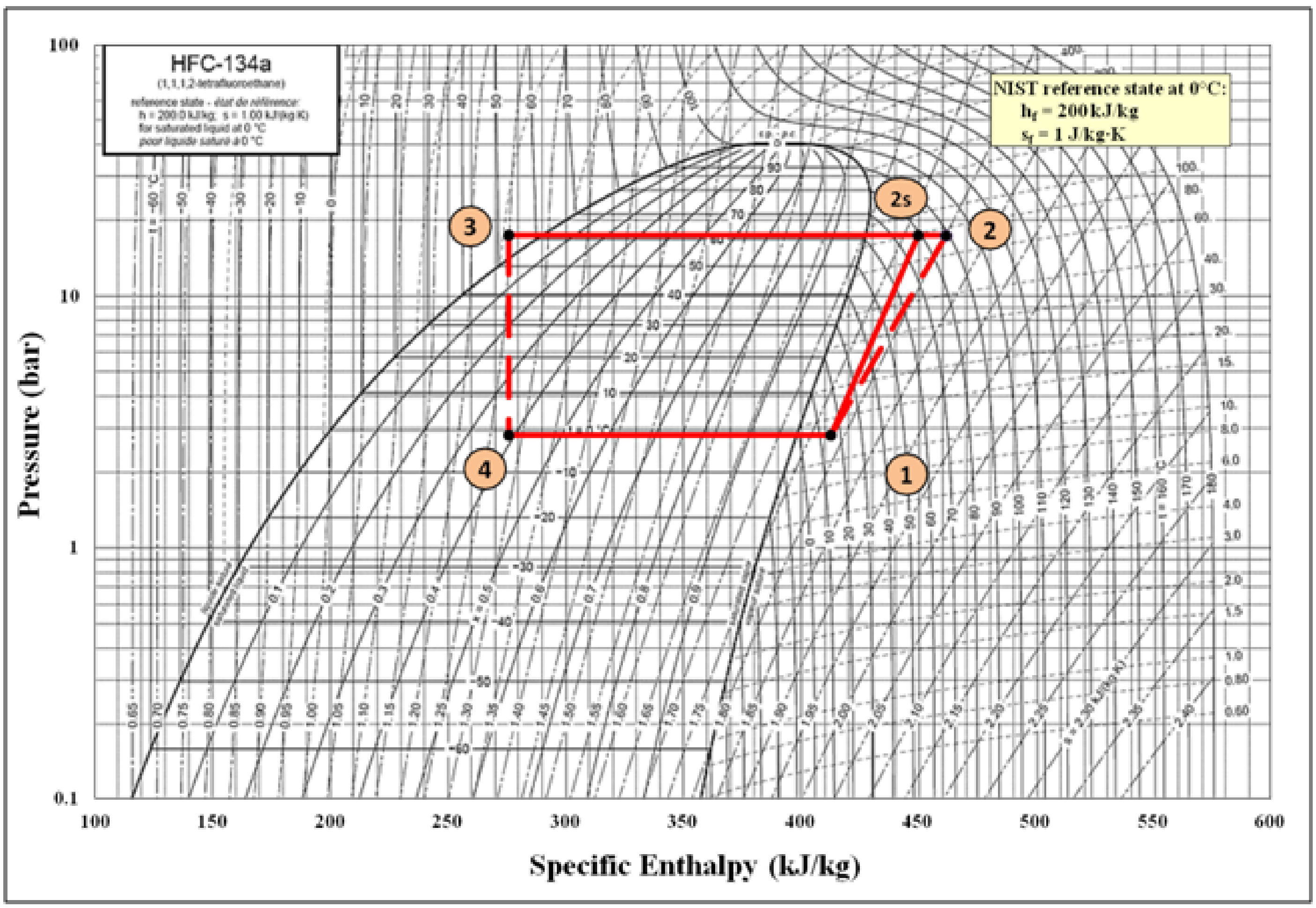
- To simplify the data, both the low pressures and both the high pressures were averaged together. This allowed the phase change from 2-3 and 4-1 to have the same pressure. The temperatures between each of the simplified phases were then averaged together to get an approximate temperature at each phase. A few temperatures were omitted from the averaging because of discrepancies. Discrepancies may have occurred due to the compressor shutting off multiple times during data collection.
- The evaporator inlet pressure for phase 4 was assumed to be the same as the pressure for phase 3 as temperature and pressure are not independent in the Saturated Liquid Region. The temperature at state point 4 was averaged the same way as all the other state points. These assumptions were tested by graphing the data on the P-h diagram and state point 3 was located in the 2 phase region.
- Because both the condenser and evaporator are exchanging heat with the room an assumption must be made in order to determine the temperatures used for the hot and cold reservoirs when calculating the Carnot coefficient of performance. The room temperature (77°F) cannot be used for both T_H and T_C in the equation because this would result in 0. So the hot reservoir temperature is calculated by adding the change in temperature across the condenser to the room temperature, and the cold reservoir temperature is calculated by subtracting the change in temperature across the evaporator from the room temperature. The resulting Carnot coefficient of performance is 8.98. *Note, all temperatures must be absolute temperatures, we converted from degrees fahrenheit to Rankine.*
- The actual cycle's coefficient of performance was calculated to be 2.80 in comparison to a value of 8.98 for the Carnot coefficient of performance. Our cycle's coefficient of performance was about 3.2 times lower than the idealized value. This makes sense that our cycle's performance is lower than the Carnot COP because the Carnot calculation is the maximum value for an idealized cycle. We do not have an idealized cycle; we were observing an actual refrigeration cycle.

Results

Measured Refrigeration Temperatures and Pressures (See Supporting Documentation for Diagram of marked locations)														
Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Trial 1 (Temp °F)	65	208	128	72	130	50	52	58	193	134	140	135	93	62
Trial 2 (Temp °F)	66	210	128	73	130	50	51	59	192	133	141	136	91	61
Average (Temp °F)	66	209	128	73	130	50	52	59	193	134	141	136	92	62

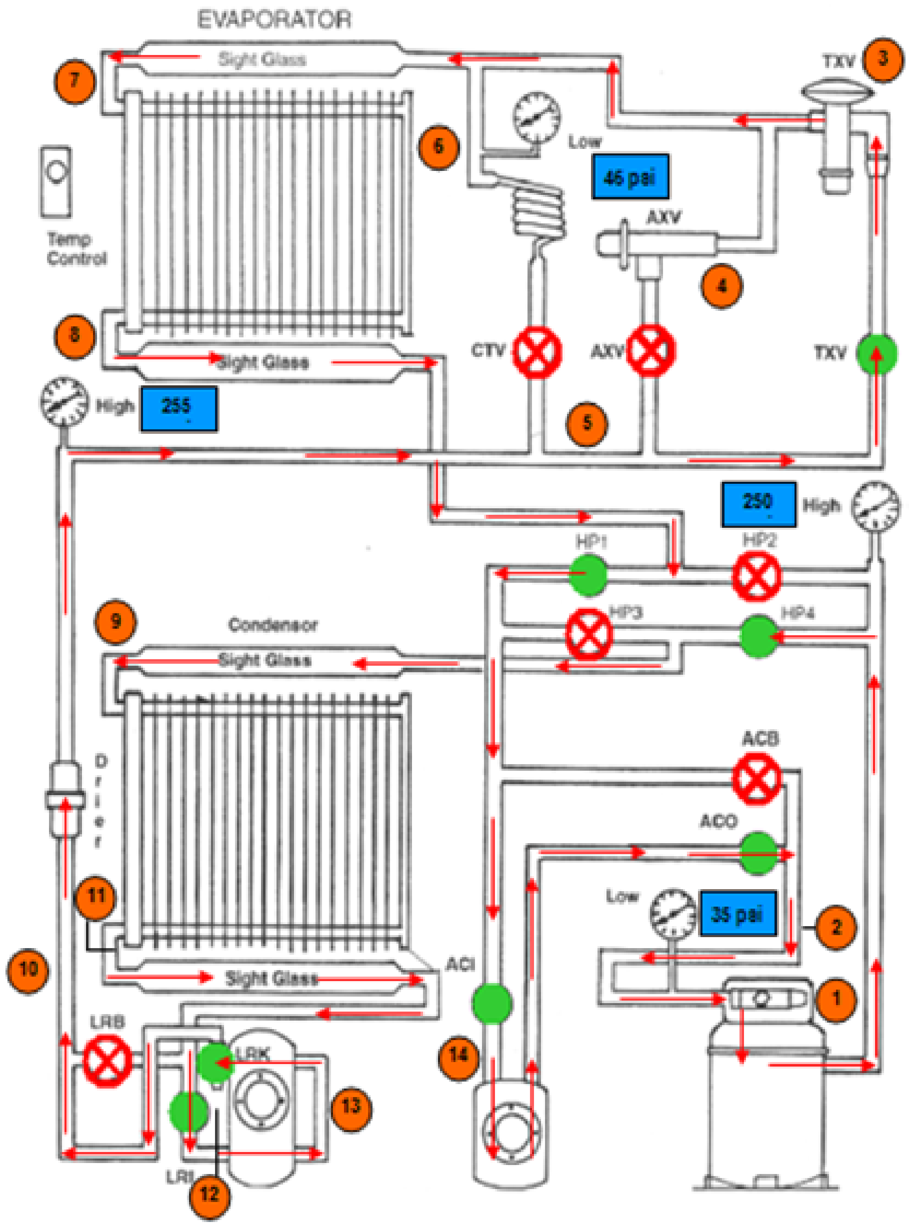
Location	Pressure (psi)
High Pressure Gage #1	250
Low Pressure Gage #1	46
High Pressure Gage #2	255
Low Pressure Gage #2	35

Temp. Location	State	Temp. (°F)	Pressure (psi)	Pressure (bar)	*Enthalpy (kJ/kg)	*Entropy (J/g*K)	Phase
2**,8,14	1	61	35	2.4	414.11	1.7973	vapor
1**, 9	2	193	250	17.2	277.57	1.2546	liquid
3,5,10,11,12,13	3	127	255	17.6	275.79	1.249	liquid
4**, 6,7	4	51	46	3.2	410.82	1.764	vapor
	1	61		2.8	413.23	1.7825	
	2	193		17.4	461.91	1.8019	
	2s			17.4	450		
	3	127		17.4	275.8	1.2491	
	4	51		2.8	408.32***	1.7653	
* NIST							
**Omitted from Calculations							
***enthalpy for phase 4 changed to 276 for diagram							



Supporting Documentation

The following diagram shows the physical location of all thermocouples and pressure gages. The red arrows illustrates the flow of refrigerant through the cycle.



- All of our data comes from **unit B** of the Brodhead-Garrret Model 9001A trainer refrigeration system utilizing the **thermostatic expansion valve**. The condenser fan was set to **low**, and the evaporator fan was set to **high**.
- The Room conditions where data was collected were as follows:
  - Relative Humidity: 27%
  - Room Temperature: 77ºF
  - Barometer Reading: 1026 mbar

- Coefficient of performance was calculated using the following formula:

$$COP = \frac{Qin/m}{Wc/m} = \frac{h1-h4}{h2-h1}$$

*Enthalpies are in **KJ/kg** which results in a **unitless** coefficient of performance*

- Carnot coefficient of performance was calculated using the following formula:

$$COPmax = \frac{Q/m}{Wc/m - Wt/m} = \frac{Tc}{Th-Tc}$$

T_H=Room Temperature + change in Temperature over condenser

= 77°F + (193°F-141°F)⟵(Temp #9-Temp #11) = 129°F ⇒588.67 R

T_C=Room Temperature - change in Temperature over evaporator

= 77°F - (59°F-52°F)⟵(Temp #8-Temp #7) = 7°F ⇒466.67 R

*Temperatures are in **Rankine** which results in a **unitless** carnot coefficient of performance*

- Thermodynamic efficiency (compressor efficiency) was calculated using the following formula:

$$\eta c = \frac{(Wc/m)s}{Wc/m} = \frac{h2s-h1}{h2-h1}$$

*Enthalpies are in **KJ/kg** which results in a **unitless** value for thermodynamic efficiency*

- The errors from this lab result from a few qualitative and quantitative sources as follows:
  - All temperatures from the thermocouples are rounded to the nearest degree. They are accurate to ±1°F
  - The thermocouples have a natural error associated with them due to their connection to the pipes in the system and how accurate they can be.
  - All pressures are rounded to the nearest whole number because the gauges are only accurate to the nearest whole integer. They are accurate to ±2 psi.
  - The compressor would shut off and on multiple times throughout data collection resulting in some fluctuation of accurate pressure and therefore temperature readings.
  - To minimize error we had two trials for data collection which could give us an average reading for each thermocouple.