Walk-In Freezer Thermodynamic Study

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ABSTRACT

The goal of the Walk-In Freezer Thermodynamic study was to create a real time stand-alone diagnostics device with the capabilities to predict and identify failures within a refrigeration cycle. The failure of walk-in freezer systems can be costly. The contents within the freezers as well as the parts themselves are insured by insurance companies. A diagnostics device was made to relay this information on a continuous stream, sending warning signals of freezer failures instantaneously.

The refrigeration cycle is one that is dependent on 4 key components in which refrigerant R404a passes through, a compressor, expansion valve, condenser and evaporator. These components work in tandem to extract heat from one closed environment and expel it to another.
This device was designed using Linux open source operating system running on an Arduino Mega 2056. This device collects data from multiple transducer powered by independent power supplies ranging between 5 – 30 VDC. The transducers provide output voltages correlating to temperature, pressure, and current measurements across a R404a refrigeration cycle of a walk-in freezer useful for refrigeration analysis. The transducers placed at key locations between and on specific components of the cycle will provide real-time data and diagnostics of the walk-in freezer's refrigeration cycle conditions. Using Laboratory Virtual Instrument Engineering Workbench (LabVIEW) interfaced with Arduino, the data logged can be broadcast and archived for past and present analysis. The Coefficient of performance COP$_R$ of a running freezer was 1.77.

INTRODUCTION

Limited quantified research and data exists on the commons causes of the refrigeration cycle failure. These causes include the following:

1. Gathered dirt on Condenser coils
   i. Inhibits heat transfer process
2. Frosted evaporator coils
   i. Inhibits heat transfer process
3. Refrigerant leakage
   i. Reduces mass flow rate resulting in a reduction of heat transfer rate

The nature of the vapour compression cycle necessitates inter-component dependencies on one another. The inefficiencies of one component have impacts on the entire cycle as well as efficiency and performance of another. In order to accurately diagnose the time and location of a failure, comparative data between a fully functional cycle and one that has induced inefficiencies are recorded.

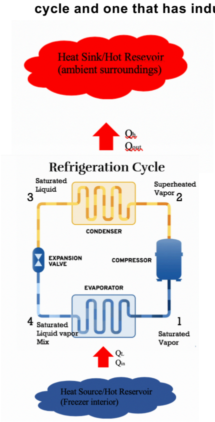


Figure 1 (Left) : Vapor is condensed to liquid in the condenser, thus giving off heat at a high temperature to the surrounding environment. Finally, the high pressure, high temperature liquid leaving the condenser is cooled and reduced in pressure by passing it through an expansion valve.

Figures 2 (Right) : Partially installed Walk-in Freezer and all components of cycle.

MATERIAL AND METHODS

- **Walk-In Freezer installed in Trinity College CT Shock Tube Lab.**

Selection Of Data Acquisition Devices

- Determine methods to identify inefficiencies
- Predicted thermodynamic system performance from spec sheet information
- Identifying effective transducer installation locations
- Selecting devices based based on compatibilities with:
  - Modelled system performance
  - Manufacturer Specifications
  - Analog to digital Data Acquisition Software

Data Collection Protocol

- Transducers wired and connected to Arduino Mega 2560
- Analog output voltage (V) to Digital Input of Arduino Mega 2560
- Arduino measures voltage (V) drop across the transducer from 0 to 5VDC
- 0 to 5 VDC output voltage (V) corresponds to transducer monitor range e.g. 0 to 500 PSIG of pressure transducer.
- LabVIEW software interfaced with Arduino records and publishes data to spreadsheet.

TSCA current sensor:

- 4 – 20 mA Output
- 4.5 - 30 VDC Input
- 2 wire leads

Figure 3: TSCA open loop current sensor.

915 Titan series flow meter
- 0 – 5V output
- 0.12 to 1.5 L/min
- 4.5 – 30 VDC input
- 40 Bar pressure rating

Figure 4: 900 series Flow meter

Px-309 Pressure Transducer

High Pressure = 0 - 500 G
Low Pressure = 0 – 150 G
10 – 30 VDC input
0 – 5V output
3 wire flying leads

Figure 5: Px-319500G pressure transducer

T-Type thermocouple

- *TC-T-NPT-U-72*
- Sub – zero temperatures
- Temp range = -200 to 350°C
- NPT 14-inch fittings
- Flush fitting
- 72-inch wire leads

Figure 6: thermocouple probe.

Arduino Mega 2560

- 16 Analogue input pins
- Compatible with LabVIEW
- Python Programming language
- 54 Digital output pins
- 5 VDC operating voltage
- 7-12 VDC input power

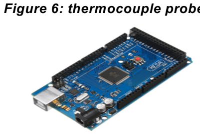


Figure 7: Arduino Mega board

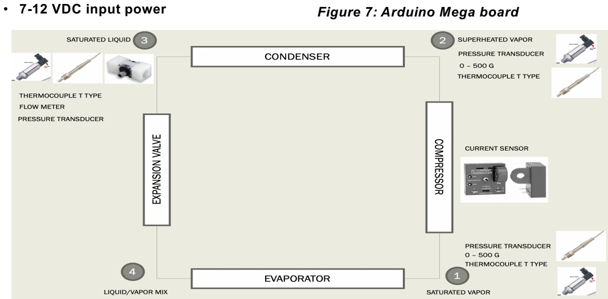


Figure 8: Virtual representation of transducer locations.

RESULTS

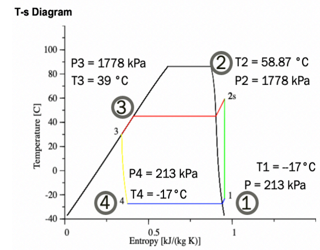
- 3 pressures (kPa) reading measured
- Measurements provided high and low pressures to be:
  P_h = 1770 kPa
  P_L = 210 kPa

- Several assumptions made to determine freezer performance
  i. No pressure drop across heat exchanger components
  ii. Isentropic compression
  iii. No Change in enthalpy (J/Kg) through expansion valve

The following equtions sumarise the performance of the system:

$$\mu = V \cdot \rho = 1209.8\frac{kg}{m^3} \cdot 4.62 \cdot 10^{-6}\frac{m^3}{s} = 5.59 \cdot 10^{-3} kg/s$$

$$COP_R = \frac{Q_L}{W_c} = \frac{518.75\ w}{292.48\ w} = 1.7736$$



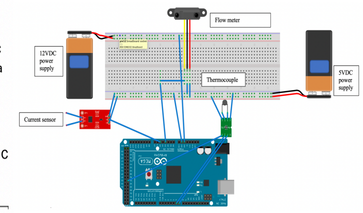


Figure 9 (left) : Measured temperatures (°C) and pressures (kPa) of walk in freezer operating under fully functional conditions.

Figure 10 (right) : Breadboard circuit wiring of transducers to Arduino Mega 2560.

CONCLUSIONS

There were several assumptions made in the analysis of the freezer which therefore creates a significant amount of uncertainty in the analysis and conclusion of the cycle. The Coefficient of performance of the modeled system and the measure system are fairly equivalent at approximately $COP_R = 1.7$. The modeled freezer operates at an about 500 kPa higher than that of the measured freezer along the high-pressure region and approximately 50 kPa higher of the low-pressure region. It is most likely expected the freezer will not run at as high a pressure as that of the specs provided. The Freezer will continue to be worked on throughout the summer and more accurate results produced.

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