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COMPARATIVE STUDY OF PRESSURE DROP ON A MICRO EXPANSION DEVICE FOR THE DEVELOPMENT OF A MINI VACCINE CARRIER

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1.Introduction

Cooling systems have been a huge contributor in the living of people in the modern era. It is used differently in many fields such as for comfort, health, preservation, manufacture, and etc. As it is used in different fields, it also varies from functionality, design, and size. From large vapor compression systems, to small scale vapor compression systems. One field use of refrigeration is on medical purposes, serves as storage for medicines specially vaccines.

In relation to the commercial refrigeration unit system for medical purposes, various dimensions and volumes are designed to meet the requirement of a certain heat load or a space which the equipment will be installed or carried upon. On the aspect of small scale refrigeration system, it could be really helpful to the cold-chain of vaccines. The development of technology able to create compact devices to an extent to reach its smallest possible size, and still serves its purpose and functions at it is expected to. If one size of the parts of a vapor compression system is scaled to a smaller dimension, it associates that the other parts will be adjusted. This comes to a change in the whole vapor compression refrigeration unit, so as to follow the proper capacity, working parameters, and standard working conditions. To superbly apply such enhancement of a system, a thorough understand of its major components should be done.

In this study, the behavior of the expansion device specifically the capillary tube is studied to gain a conclusion on its functionality. This study involves a basic vapor compression refrigeration system, which consists the main parts namely: Compressor, Condenser, Capillary Tube, and Evaporator. The helpful development of the study composed of different sizes of capillary tube to evaluate the effect of pressure drop, affiliates to the advancement of mini vapor compression systems. One example is for a mini vaccine carrier.

1.1 Statement of the Problem

Compactness of a system is a major characteristic in the progression of technology in the modern times. This is also applied to the refrigeration systems. In contribution to the development of mini refrigeration systems, the researchers decide to focus and understand a single major part of the vapor compression cycle, the capillary tube. This expansion device separates the high side from the low side pressure of the system. In order to take advantage of its function for working in a mini vapor compression cycle, a thorough understanding through experiments is required, answering how its small change in dimension affects the system.

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1.2 General Objectives

i. To design and fabricate a portable vaccine carrier kit with variable small diameter capillary tubes.

1.3 Specific Objectives

i. To assemble five (5) small diameter capillary tubes – 0.20mm, 0.25mm, 0.30mm, 0.35mm, and 0.40mm.
ii. To measure the pressure drop made by the different small diameter capillary tubes.

1.4 Significance of the Study

The highlight of the study is the behavioral property of the pressure drop on small diameter capillary tubes. This study aimed to design a mini expansion device with capillary tubes of different cross-sectional area, attach to a mini vapor compression refrigeration system and measure the corresponding pressure drops. As to understand thoroughly the significant pressure drop on the system, a small scale actual model is fabricated, and researchers gather the data of the pressure drop occurring in the fabricated capillary tubes with the proposed dimensions. The results may be used as a basis for designing the expansion devices for mini vapor compression refrigeration systems for vaccine carrier kit.

1.5 Scope and Limitations

The scope of the study only covers the measurement of the pressure drop of the assembled mini expansion devices of the vaccine carrier kit using R134a as a refrigerant. The study is also limited with the available tools and instruments in the Mechanical Engineering Laboratory of the Xavier-Ateneo College of Engineering.

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1.6 Theoretical Framework

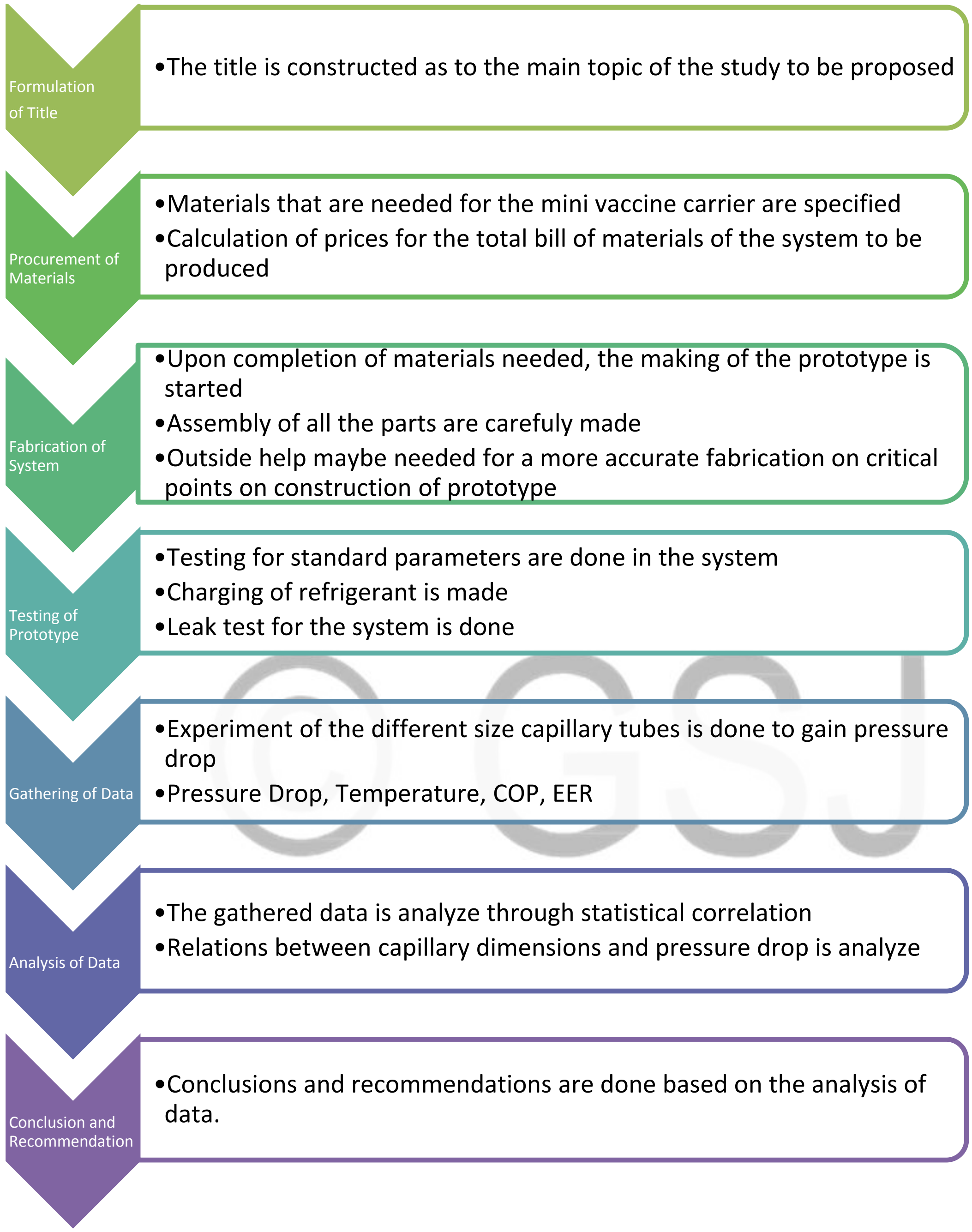

Fig. 1.1 Theoretical Framework

1.7 Review of Related Literatures

In the study of Vacek, V. and Vins V. titled “A Study of the Flow through Capillary Tube Tuned up for the Cooling Circuit with Fluoroinert Refrigerants”, have stated that the first small pressure drop occurs at the inlet of the capillary as the sub-cooled liquid coolant enters the capillary. In the calculations Vacek and Vins made, it included the energy equation and entropy equation. The capillary flow was also defined by the following parameters, temperature and pressure at the capillary inlet, refrigerant mass flow rate, discharge diameter, and thermophysical properties of a considered refrigerant. However, in the experiment of Vacek, the following simplifications were assumed in the model. Capillary flow is solved as one dimensional steady state problem, two equilibrium capillary flow regions are considered, the inner, outer diameter and wall roughness are not varying along capillary tube length. Gravity is not put into consideration while capillary is solved for the horizontal position. On the final results of the experiment done, Vacek concluded that the agreement between the experimental and simulation results, mostly for the adiabatic capillary tube with separated two-phase flow indicates that the model can be used to predict complex flow behavior in capillary tubes. Which it can also help to select appropriate dimension of capillaries in refrigeration cycles in special applications.

In another study entitled “A Flow Model for Spiral Capillary Tube and its Sizing”, by Singh R. K., it presents a model that has been developed design and study the performance of a spiral capillary tube used in small capacity vapor compression refrigeration systems. The model takes into account single phase region and two phase regions separately. The model is based on the fundamental equations of conservation of mass, energy, and momentum. Homogeneous model is used to model the two-phase flow through the capillary tube. The model also uses well established correlations for friction factor. The effect of sudden contraction at the capillary entrance is also considered in the model. The model includes the effect of various parameters like condenser and evaporator pressures, refrigerant flow rate, degree of sub cooling, tube diameter, internal roughness of the tube and pitch of the spiral on the length of the capillary tube. Also, a software is used in order to simulate the model. The software gives the required length of the capillary tube for given input parameters. It also gives the variation of temperature, velocity, friction factor, pressure, specific volume and quality of the refrigerant along the length of the capillary tube.

2.Methodology

The mini vapor compression refrigeration cycle consists of four major components, namely, the compressor, condenser, expansion valve, and evaporator. These components are used in the fabricated unit and will be the measuring platform in conducting the experiment on the pressure drop data, and the source of the values of COP (Coefficient of Performance) and EER (Energy Efficiency Ratio). The first stages of the study were on the design of the vaccine carrier kit. This includes the size of the storage, dimensions of the case, and calculation of heat load of the vaccine. The needed materials were prepared, including the fabrication of the experimental capillary tubes with the guitar strings inserted on it.

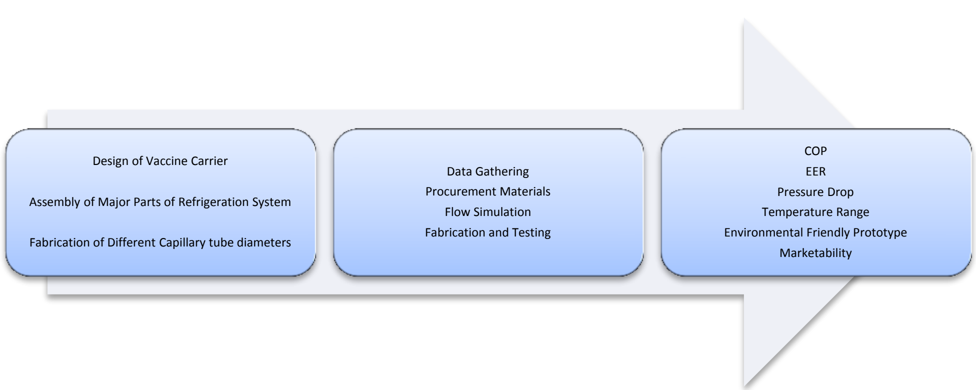

Figure 2.1 Plan Layout of Study

2.1 Equipment and Materials Used

The equipment and materials that are present in the study are the R-134a Hermetic type compressor, 3/16 " Condenser copper tubes, copper filter dryer, 1/8hp Capillary tubes, 1/4" evaporator copper tubes, gate valves, thermostat, and pressure gauges.

The R-134a Hermetic type compressor used in the study, Figure 2.2, is a recycled from a water dispenser. The compressor was tested if it is still functional and available to use for a fabricated compression refrigeration system. The making of the whole system was carefully done since the disadvantage of a hermetic compressor is that it cannot be repaired. If the compressor fails due to mishandling or faulty acts on materials, it should be replaced for a new compressor. However, the advantage of a hermetic compressor is that it is one-piece welded steel casing which cannot be opened, so situations of gas leaks are impossible to happen.

Figure 2.2 R-134a Hermetic Compressor

Figure 2.3 Copper filter drier

The condenser copper tubes with 3/16 " size is mounted and connected on the original condenser of the water dispenser. The length and size are followed to the original assembly of the compressor where it is used because these dimensions are the most suitable design for the specific compressor. The researchers fabricated the same dimensions for the condenser with a new material but with a different wiring plot. The same idea is done in determining the dimensions of the designed evaporator. The evaporator copper tubes of 1/4 " size and length were based on the original dimensions of the parts of the compressor assembly.

The filter drier used, Figure 2.3, is also made of copper and is suitable for the refrigerant R-134a. It has three orifices which the other one is used for recharging the refrigerant.

The capillary tubes, Figure 2.4, in the system uses the 1/8hp capillary tubes. This category determines that the capillary tubes are for 1/8 horsepower compressors, which is the standard value of the available hermetic compressor with a length of one meter. There are two passes of the capillary tubes, one is the main pass and the second one is the experimental capillary pass. In this section, the assembled capillary tubes were attached to the pressure gauges to in order to measure the pressure drops. The capillary tube diameters include the 0.20mm, 0.25mm, 0.30mm, 0.35mm, and 0.40mm.

Figure 2.4 Capillary tubes section

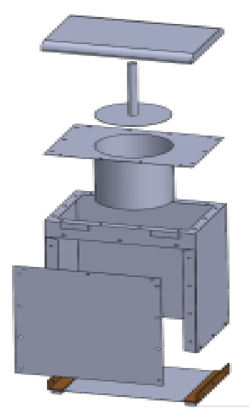

Figure 2.5 Vaccine casing CAD design

The gate valves that are present in the mini refrigeration system are connected at the end extension branch for the connection of the experimental capillary tubes. This gate valves holds the bypass of the refrigerant passing at the main capillary tube and the experimental capillary tubes. There are a total of three gate valves in the system, one attached to the inlet of the main capillary, and the other two is located on the inlet and outlet of the experimental capillary tubes with different diameters.

The pressure gauges that are attached to the system are consist of six items. Two pressure gauges that are high side (red) and four pressure gauges that are low side (blue). One high side gauge and low side gauge is attached at the main refrigeration system. The other four gauges are attached to the experimental capillary tubes. The extra one high side gauge is attached at the inlet of the capillary, after the filter drier, two extra low side gauges in between the sections of the capillary and one extra low side gauge at the outlet of the capillary. This provides four pressure readings in a one-meter length of capillary tube.

The thermostat in the system is attached to the compressor. The purpose of the thermostat is to control the operating temperature by regulating the flow of the refrigerant in the compressor.

Figure 2.6 Thermostat used in the system

Figure 2.7 Casing design of vaccine carrier

Figure 2.7 shows the casing of the mini vapor compression system and is made of galvanized steel grade 00. The sheets are joined with rivets on the edges. The whole casing has a dimension of 12 " × 8 " × 15 " inches. The inside compartment is about 6 " inches diameter and 4.3 " inches in height as shown in Figure 2.5.

2.2 Research Design

The study was centered in obtaining the characteristics of pressure drop of capillary tubes with different inside diameter. The research project started formulating the research title and then producing the chapters 1, 2 and 3 of the study. These chapters are important since it consist the introduction of the project, the problems and objectives are identified, and the limitations of the project are set. Related articles, journals, and thesis are provided for supporting enough ideas and knowledge in the proposed study. The procedures and the designs that are needed and important are then formulated for the whole project study. This is to prepare for the experiments and data gathering.

In Figure 2.8, the vapor compression system is a modified design compared to a regular cycle. An extra connection for the capillary tubes with gate valves are added to the main system.

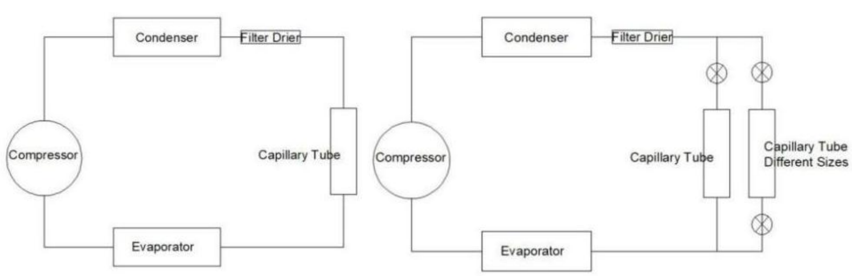

Figure 2.8 Main system (left) and Modified vapor compression system (right)

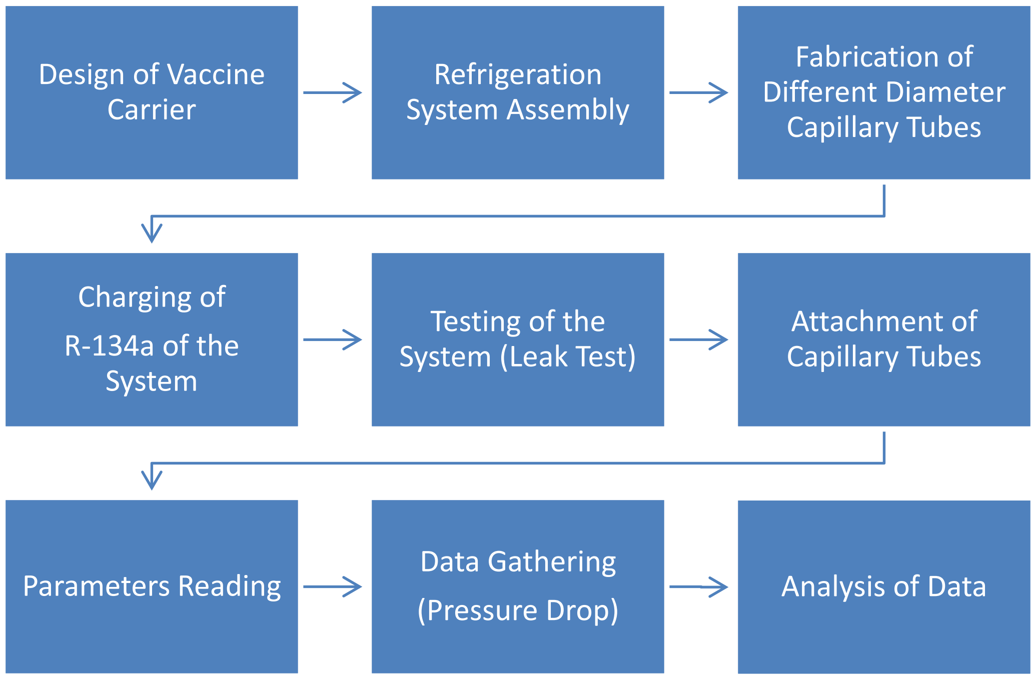

Figure 2.9 Research Design

In the design of the vaccine carrier, there are also sample calculations have been done such as the heat load available on the vaccine, dimension of the whole system, and the capacity number of vaccine. Figure 2.5 shows a computer aided drafting is used in the design of the casing. A specific sample size of a vaccine bottle, is used as a model for the dimension of the vaccine compartment. The casing was joined using rivets.

In the fabrication of the different diameter capillary tubes, the use of proper size guitar strings is inserted to adjust the size of the cross-sectional area of the tube. A fabricated copper "T's" are used to connect the capillary tube to the line of the pressure gauge. After the connection is arranged, soldering process using oxygen acetylene welding and silver rod is done.

2.3 Fabrication Process

The first step in fabrication of the prototype is the casing, Figure 2.9. The casing was designed in a rectangular prism, the same as a vaccine carrier used in health centers. The dimensions are considered to fit a hermetic compressor from a water dispenser and to fit other components needed as a measuring device for gathering data on capillary tubes. Such as, pressure gauges and custom connections. The casing of the system uses galvanize steel plate and rivets to fix the different parts.

2.3.1 Refrigeration Components

The first part to be attached to the system is the compressor. This is the heart of the system and need to be placed first due to its size and weight. After the compressor, the condenser is designed to its line in the system, the same way is done to the evaporator. Two pressure gauges is attached, one on the high side pressure and another in the low side pressure. The use of oxy-acetylene gas and silver rod works to connect the copper tubes for the refrigeration system. Three gate valves are attached to the system, the sole purpose of the first one is to be able to condemn the main capillary tube, and the two other is to condemn the experimental capillary tube. After the assembly, the system is charged with R134a and uses soap in the key parts for leakage detection. After a successful leak test, the system is good to be part of the experimentation of small diameter capillary tubes.

2.3.2 String Insertion and Assembly of Capillary Tubes

The first step in fabrication of the capillary tubes is dividing the whole length of the capillary into 335 mm per section. The use of knife and long nose plier is used in cutting the capillary. A careful work is needed on this part, so the orifice of the capillary will come out. Next, is insertion of the strings with different sizes. Proper number of strings is considered to achieve the desired diameter of capillary tubes. After the insertion of strings is the fabrication of “T” connections. The use of drill bit tool is done in making a hole on one side of the copper tube, and inserting the other copper tube in upright direction, forming a “T”. It is then soldered using oxygen-acetylene gas and silver rod. Copper tubes with ¼ size are also needed in the fabrication since it is attached to the ¼ flare nut. A total of five flare nuts and one compression nut is attached to a single small diameter capillary tube.

2.4.Heat Load of the System

It is important to calculate the heat load since it the value that is needed for the system to be cooled. It is the reference on how much heat to be removed. The heat load calculation of the system includes the surroundings, material conductivity, and vaccine load.

2.4.1Theoretical Vapor Compression System

In designing the vapor compression system, calculations are made using the appropriate design formula. This includes the analysis of basic vapor compression cycle T-S diagram and P-H diagram. Property conditions are set as to the designed refrigeration system. The condenser temperature should be higher than the ambient temperature and the evaporator temperature is the temperature required in order to remove heat from the confined space, or in the vaccine compartment. The refrigerant to be used is R-134a with the chemical name tetrafluoroethane, as it is the best option as of today. It has insignificant ozone depletion potential and availability in the market.

2.4.2 Data Collection Procedure

The data will be gathered for 6 hours with 75 minutes for each different diameter size, up to 15 trials. Pressure transducers, flow sensors and temperature sensors are used in this experiment. The data will then be gathered in conformation with the researchers testing procedures;

1. Before starting the whole system, make sure that the globe valve to the main capillary tube is open.
2. Make sure that all the pressure transducers for the experimental capillary tubes are tightened so there will be no leaking of refrigerant.
3. After all other conditions are checked, start up the system and let it run for 10 minutes before starting checking data. This is to create a stable pressure inside the system.
4. After 10 minutes mark, start to take reading the pressure transducers, starting from the high side pressure gauge to the low side pressure gauge. These pressure readings will be annotated as P1, P2, P3, and P4 respectively.
5. The data will be gathered every 5 minutes interval, up to 15 trials, the system will be running for about 75 minutes for each capillary tube. This procedure will be repeated with the other sizes of capillary tubes.
6. Measure the surface temperature using temperature sensors for every 335 mm section of the capillary tube, including the temperature of the compartment. Repeat this procedure with the other sizes of capillary tubes.
7. After 15 trials of testing with the capillary tubes, turn off the system and wait to stabilize by observing the main pressure gauges.
8. After all the system is stabilize, detached the experimental capillary tube and replace with another different size. Leaks happen at this part so charging it with refrigerant is needed.
9. Repeat the whole procedure for the next sets of capillary tubes.

3.Results and Discussion

In this chapter, the calculations and experiment results are presented. The theoretical values and actual values are analyzed and discussed. This chapter also includes answers of the objectives of the study.

General Objective: To improve data analysis of using different capillary tubes diameters for a mini vapor compression refrigeration system.

In improving the data analysis for the study, the volume flow rate is measured, and every different diameter properties are determined. Figure 3.1 and Figure 3.2 shows the average flow rate and pressure drop for 0.20mm small diameter capillary tube .

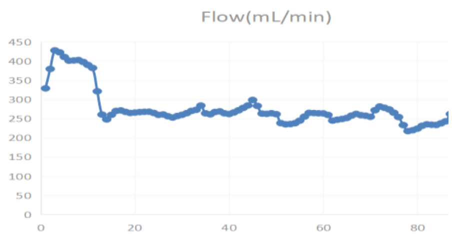

Figure 3.1 0.20 mm Flowrate

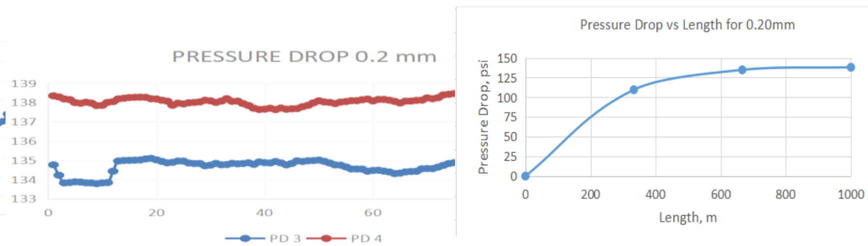

Figure 3.2 0.20 mm Pressure Drop

Figure 3.1 shows the flow rate of around 280 mL/min on average and Figure 3.2 shows the pressure drop of around 138.02 psi. and the secondary segment pressure drop is 134.68psi.

For the 0.25 Ø mm small diameter capillary tube.

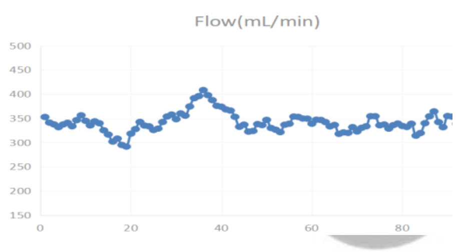

Figure 3.3 0.25 mm Flowrate

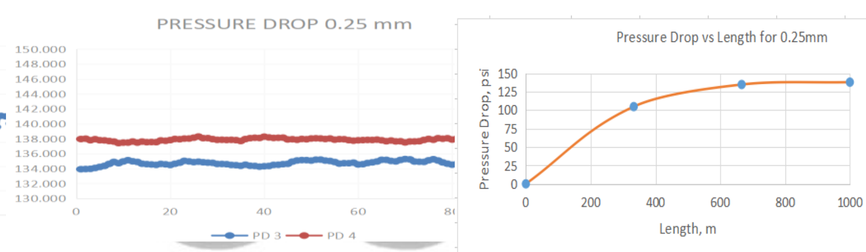

Figure 3.4 0.25 mm Pressure Drop

Figure 3.3 shows the flow rate for 0.25mm small diameter tube of around 320 mL/min while Figure 3.4 shows the average pressure drop of 137.88 psi. with a secondary segment pressure drop of 134.70psi.

For the 0.3 Ø mm small diameter capillary tube.

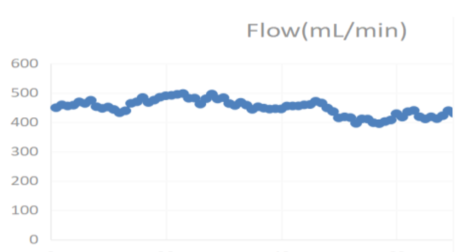

Figure 3.5 0.30 mm Flowrate

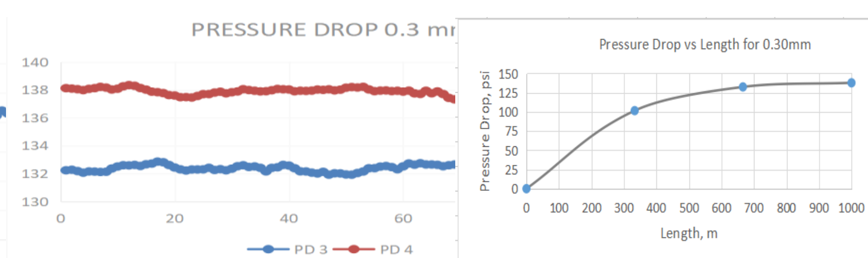

Figure 3.6 0.30 mm Pressure Drop

Figure 3.5 shows the flow rate for 0.30mm small diameter capillary tube at an average of 450 mL/min while Figure 3.6 shows the average pressure drop of 137.82 psi. with a secondary segment pressure drop of 132.47psi.

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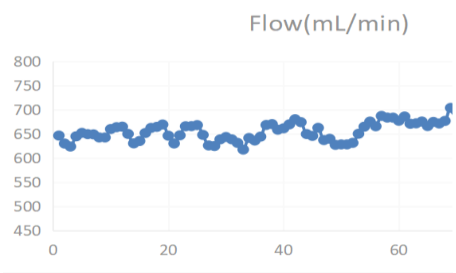
For the 0.35mm small diameter capillary tube.



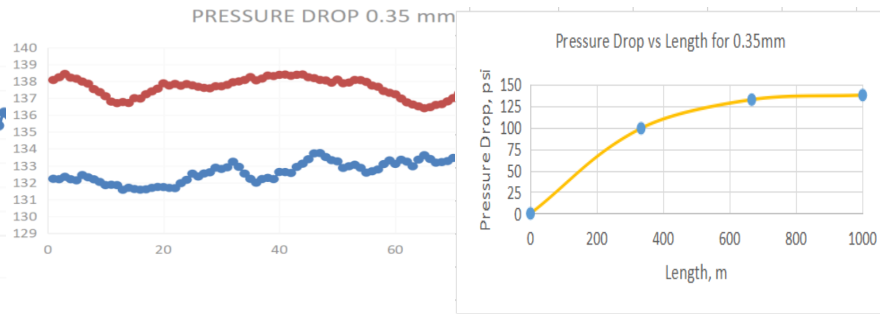
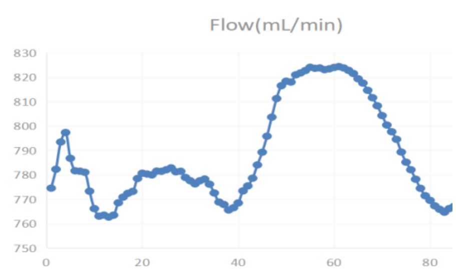


Figure 3.7 0.35 mm Flowrate

Figure 3.8 0.35 mm Pressure Drop

Figure 3.7 shows the flow rate for 0.35mm small diameter capillary tube at an average of 650 mL/min while Figure 3.8 shows the average pressure drop of 137.66 psi. with a secondary segment pressure drop of 132.44psi.

And finally, for 0.40mm small diameter capillary tube.



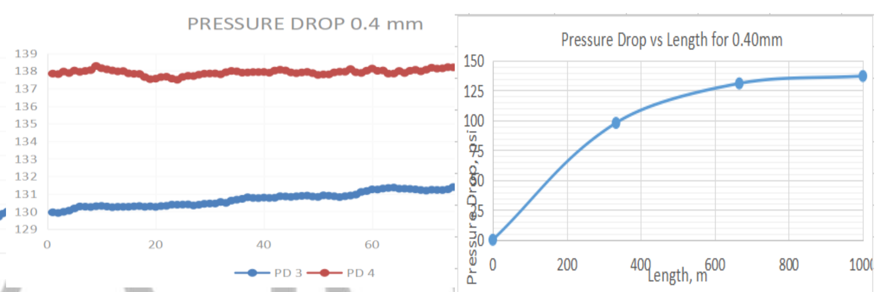


Figure 3.9 0.40 mm Flowrate

Figure 3.10 0.40 mm Pressure Drop

Figure 3.9 shows the flow rate for 0.40mm small diameter capillary tube at an average of 788 mL/min while Figure 3.10 shows the average pressure drop of 137.92 psi. with a secondary segment pressure drop of 130.95psi.

Specific Objective 1: To assemble five (5) small diameter capillary tubes–0.20mm,0.25mm,0.30mm,0.35mm,and 0.40mm.

The fabrication of the capillary tubes with different diameters was a challenging part. The guitar string insertion includes careful activity because if the string is bent accidentally, the crease will no longer be healed. Another string should be replaced if such action occurs. This happened a lot in the insertion of two strings and up. Insertion of a single string is an easy task since the string will only slide inside the capillary tube, and thus no problem at all.

Another challenging part in the fabrication of the capillary tubes is the “T” connection in the system. The “T” connection is fabricated and not been bought. This is due to not being available in the market. There are available “T” connections but the size is large for the component. The hand drill equipment is used in creating a hole on the copper tube. There are mistakes that have been made in fabrication of “T” connections. Such as blocking the path way inside, and the way is not upright. However, beside the challenges, the problems were solved and successfully made the capillary tubes.

Specific Objective 2: To measure the pressure drop made by the different small diameter capillary tubes.

The small diameter capillary tubes have different pressure drops as displayed in Figure 3.11. The capillary tube with a hydraulic diameter of 0.40 mm has the lowest pressure drop and the capillary tube with hydraulic diameter of 0.20mm has the highest pressure drop.

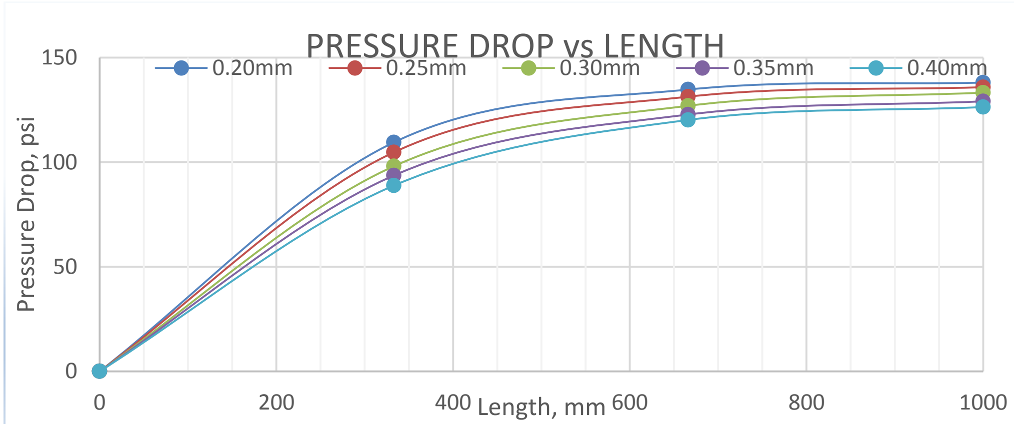


Figure 3.11 Comparison of Small Diameter Tube Pressure Drops

4.Conclusion and Recommendation

In this chapter, the conclusion for the results and analysis of data are stated. The recommendations for further researchers if this study is to continue are also elaborated in this chapter.

4.1 Conclusion

For the expansion devices in mini refrigeration system, the drop of temperature in the evaporator is directly proportional to the pressure drop of the expansion device. The data showed that the 0.20mm small diameter capillary tube has the greatest pressure drop of around 138.02 psi. It can be concluded that the 0.20mm small diameter capillary tube has the lowest evaporator temperature to be used for the vaccine carrier kit.

5.2 Recommendations

The researchers encourage those who will conduct the same research to develop the system to a more portable set-up. The use of compact compressor is highly suggested since it has a great effect on the size of the vaccine carrier kit. If the study is to be compacted and solely made as a vaccine carrier, the use of battery cell is a much-desired idea for the system. If the vapor compression system is continued for the experiment of the capillary tubes, a proper fabricated “T” connection is suggested. It is better to have a machine fabricated “T” or commercially available “T” is a more accurate solution on the constraints that can happen during the manual fabrication of the “T”.

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