Mini Channel Evaporators using R134a in the Design for Vaccine Transport Boxes

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Abstract
Portable applications of the refrigeration system have become a major trend recently. Such applications would include the portable medicine storage kits. These kits are useful for the proper storage of certain temperature-sensitive medicines and vaccines that require low temperatures if they are to be stored and transported to far-flung remote areas. This trend can only be achieved through the miniaturization of the refrigeration system. The main objective of this study is to design, fabricate, and evaluate the performance characteristics of the mini-channel copper block evaporator. Three 10.6 cm x 6.0 cm copper block evaporator with channel hydraulic diameters of 3.0 mm, 2.5 mm, and 2.0 mm were designed, fabricated, tested, and evaluated. All of the units were connected in a vapor compression refrigeration cycle, and utilized refrigerant R134a as its cooling medium. Forced draft air was also introduced to the evaporators through a wind tunnel or ducting system, to establish heat transfer from the ambient air to the refrigerant R134a. Thirty (30) trials in a thirty (30) seconds interval were conducted per mini channel evaporator. The flow rate of the refrigerant R134a was set to pre-determined values. The data showed that the 3.0 mm copper block evaporator produced the lowest temperature, as well as the lowest pressure drop, since it has the largest channel cross sectional area resulting to a lower thermal conductivity of the copper block evaporator and an increase of the residency time of the refrigerant flowing through the mini channel copper block evaporator.

Keywords: Heat exchanger, Heat transfer coefficient, Vaccine storage kit, Mini channel evaporator, Tetraflouroethane refrigerant, Wind tunnel.

1. Introduction

Mini channel evaporators are nowadays widely used and studied over a number of various applications. Such applications would include the thermally modeled Mobile Air Conditioning (MAC) and Automotive Air Conditioning (AAC) systems, and medicines and vaccines storage practices[1]. One such advantage of the mini channel evaporator is the definite reduction of the size of the equipment. Due to this reason, mini channel evaporators are often applied to certain electronic applications, such as laptop coolers since its increasing demand for a higher or better performance requires a cooler temperature, and to portable medical storage kits since certain temperature sensitive medicines and vaccines need to be stored in a lower temperatures ranging from 2 ^{o}C to 8 ^{o}C [2]. Both demands can be produced from a miniaturized design of an evaporator. The mini channel evaporator is considered to be very essential for both applications since it reduces or minimizes the amount of adopted material during its manufacturing process

In response to the demand of developing miniaturized evaporators, a mini channel evaporator is designed. This mini channel evaporator is similar to a typical shell-and-tube heat exchanger. The copper block will serve as the tube while the surroundings will serve as the shell. There are headers at both ends of the copper block where the refrigerant is allowed to be stored before entering and leaving the copper block. The rest of the system follows the principle of the basic refrigeration compression system and its corresponding refrigeration equipment[4]. Therefore, the only major modification that will be done in this study is the design of the mini channel evaporator.

The global alert regarding the greenhouse effect has influenced an increasing interest on the latest HVAC/R technologies that have low environmental impact and utilizes environment friendly refrigerants. As a result, a great number of chlorinated refrigerants are phased out. Thus, choosing of refrigerant is to be considered one of the most important parameter in the study. In this case, the authors choose to utilize R134a or tetraflouroethane as the refrigerant of the system[5].

This paper focuses on enhancing the efficiency of the mini channel evaporator present in devices, such as portable medical storage kits, through fabricating three mini channel evaporators with different internal diameters, but maintaining the same external heat transfer surface area, and to minimize the possibility of capillary effect[6]. Thus, it is necessary for the authors to be vigilant of the flow rate of the refrigerant in the system, since the flow rate is considered to be an important parameter in determining the rate of heat transfer of the mini channel evaporator, the overall heat transfer coefficient, pressure drops, the temperature at the inlet and outlet of the evaporator, and the temperature of the air before and after the evaporator. If the efficiency of the mini channel evaporator increases, then it is apparent that the cooling capacity, as well as its ability to conserve energy also increases[7].

There are a number of communities situated at remote areas that seek medical attention from urban cities. Such medical attention would include transporting medicines and vaccines which would adhere to their various medical needs. However, almost all of the temperature sensitive vaccines require storage at temperatures that are much lower than the ambient temperature. Thus, it is a necessity to store such vaccines in refrigerated portable storage kits that utilizes a mini channel evaporator.

Mini channel evaporators are heat exchangers having hydraulic diameter from 200 µm to 3.0 mm[4]. There was already a design of a mini channel evaporator done by the previous mechanical engineering students of Xavier University. However, their design possesses certain problems that can be readily modified to achieve a higher efficiency of the evaporator and as a result, will yield higher heat transfer rate between the system and the surroundings[8]. Therefore, there is a need for a modification of the existing design of the mini channel evaporator.

1.1. General objective

The main objective of this study is to design and fabricate the three mini channel evaporators of different internal diameters but the same external heat transfer surface area and evaluate its performance characteristics and efficiency.

1.2. Specific objectives

The specific objectives of this study are the following statements:

1. To design three mini channel evaporators of different internal diameters in which the heat transfer surface area of the copper block is to be increased.
2. To install capillary tubes which have smaller internal diameters than the evaporators to minimize the possibility of capillary effect in the evaporators.
3. To correlate the performance characteristics of the three evaporators (heat transfer rate, overall heat

transfer coefficient, pressure drop, mass flow rate, and temperature).
4. To evaluate the performance characteristic of the mini channel evaporators.
5. To evaluate the Energy Efficiency Ratio (EER) of the systems.

1.3. Significance of the study

Recently, mini channel evaporators are being studied for a variety of applications. Due to the fact that this type of evaporator uses lesser material, saves energy, and most importantly, it minimizes the space occupied to provide bigger room for more applications[9]. The success of this study will mean an improvement of the previous designs and the possibility of the designed evaporator to be used for portable medical storage kits in remote areas.

1.4. Scope and limitations

The study will only be concentrated on the enhancement of the efficiency of the heat exchanger or the mini channel evaporator alone. The design of the portable medicine kit is not included in the study.

The data that will be recorded in this study are limited to pressure drop, mass flow rate and the temperature entering and leaving the evaporator side. The amount of heat transfer rate and overall heat transfer coefficient of the evaporator will be obtained by calculation. These data are limited only with R134a as the refrigerant[10]. The modifications in the evaporators and the capillary tubes that have to be done are limited with the equipment available and the technical capabilities of manpower found in the mechanical engineering laboratory.

2. Methodology and Materials

The rampant increase in the demand of portable designs of refrigerating equipment and devices has lead the researchers in developing or constructing a mini-channel evaporator which may have a better efficiency compared to the previous fabricated designs, which can then be utilized for various applications. The research strategy adopted was to simultaneously fabricate three mini-channel evaporators with unique internal diameters but identical external heat transfer surface areas, and observe the behaviors of the significant parameters of the refrigerant being utilized[11]. The main data gathering techniques used as reference in this research were from applied engineering textbooks (HVACR textbooks), group discussions, and the results attained from actual experiments.

2.1. Flow diagram of the study

This study is divided into seven sections and is provided with a flow chart which will provide a glimpse of the methodology as a whole. In the first section, this study reviewed the previous study done by the previous groups of from the Department of Mechanical Engineering of Xavier University. The section enables the present authors to plan and perform appropriate actions in order to improve the overall efficiency of the previous studies. The section also includes the selection of the necessary references, namely thermodynamics and HVAC/R textbooks and consultations of the faculty members of the Mechanical Engineering Department, as well as the necessary data or information gatherings, which will be useful for the duration of the study[7].

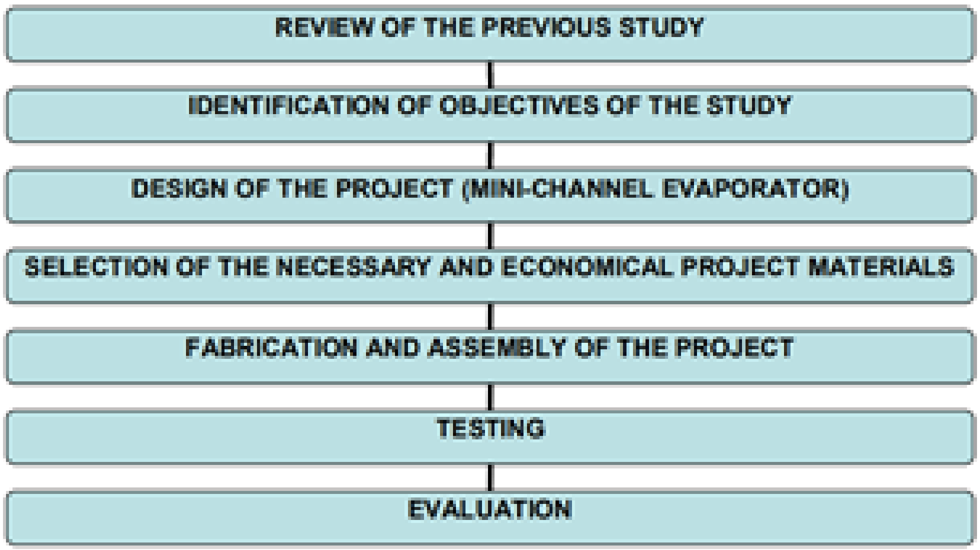

Figure 1. Flow diagram of the study

The next section focuses on the identification of the objectives of the current study. The formulated objectives shall focus on the actions to be done in order to be able to increase the efficiency attained by the previous study. The third section is all about the design of the actual mini channel evaporator. The details of the design of the project will be explained further in the later part of the study. The fourth section focuses on the selection of the necessary and economical materials to be used in the fabrication of the mini channel evaporator. However, the selection of the cost of the materials should not compensate for its effectiveness in aiding the mini channel evaporator in attaining an increase in efficiency. The fifth section discusses the fabrication as well as the assembly of the entire study. The sixth section is the testing of the assembled and fabricated experimental rig. This would be the output or the prototype of the study. Finally, the last section requires the evaluation of the entire study. This section would determine whether or not the general objective of attaining an increase in efficiency is achieved.

2.2. Materials and fabrication of mini channel

The designs of the mini channel evaporators are similar to a typical shell and tube heat exchanger. There are headers at both ends of the evaporator. The only major difference is that the shell in these mini channel evaporators will be the surroundings instead of cylindrical enclosures. The mini channel evaporator is made up of a copper block which has a length of 106.0 mm, a width of 60.0 mm and a height of 12.5 mm.

Figure 2. The fabricated mini channel evaporator

The headers of the evaporators will have a dimension of 106.0 mm by 15.0mm by 12.5 mm. The inner portion of the headers will be grooved to attain a depth of 10.0 mm and in such a way that the refrigerant will pass the drilled holes of the copper blocks four times before leaving the mini channel evaporator. One of the headers will be drilled at both ends. These holes are used to connect tubes from and to the mini channel evaporator. The solid portion of the mini channel evaporator is where most of the heat exchange occurs. It has a dimension of 106.0 mm by 30.0 mm by 12.5 mm. The solid portion of the copper block is drilled along its width and height. There are ninety-nine (99) drilled holes parallel to the copper block's height and each having a diameter of 2.0 mm and a length of 12.5 mm. The air to be conditioned will pass through these drilled holes. Also, there are twelve (12) drilled holes parallel to the copper blocks' width each having a length of 30.0 mm and will have diameters of 2.0 mm, 2.5 mm and 3.0 mm for each mini channel evaporator. These holes will then be the conduit of the refrigerant R134a flowing through the mini channel evaporators. The headers and the solid portion of the evaporators will be connected using oxy-acetylene welding. A soap leak test will be performed after the fabrication of the designed mini channel evaporator to ensure a good quality of the assembly.

2.3. Fabrication of the experimental rig

The mini air-conditioning system or the fabricated experimental rig will be made by utilizing the refrigeration system of a typical commercial water dispenser unit. It is done by installing a bypass near the inlet of the original evaporator connected to the tube after the outlet of the said evaporator. In the bypass, a gate valve shall be provided for the connection of the mini channel evaporators under study.

The mini channel evaporators shall be installed at the bypass section one at a time for testing and data gathering. The bypass section is equipped with flow regulating valves placed before and after the mini channel evaporator. These valves will be used to control the flow of the refrigerant R134a. Also, the inlet and the outlet of the mini channel evaporators will be installed with a pressure transducer connected to a data logger. These pressure transducers will be used to record the pressure drop in the mini channel evaporators. Moreover, a flowmeter will be installed at the bypass section, before the inlet of the mini channel evaporator and it will be used to measure the amount of refrigerant that will enter into the mini channel evaporator.

For the sake of having accurate temperature measurements, the mini channel evaporators that will be tested and evaluated will be enclosed in a wind tunnel as shown in Figure 3.

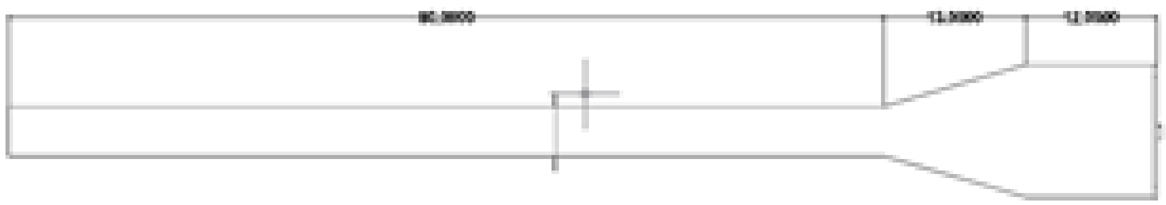

Figure 3. The fabricated wind tunnel

The wind tunnels are equipped with a fan on one of its openings and will be insulated to minimize heat gain from the surroundings. After the fabrication of the mini air-conditioning system, the experimental rig, a soap leak test will be performed to make certain that the system is properly installed. The system will be vacuumed before charging the refrigerant R134a.

2.4. Data gathering

Before the measurements of the data were taken, the system was allowed to run until it became stable. The mini channel evaporators were tested individually. The flow regulating valves were adjusted so that the desired range of refrigerant flow rate will be attained. The pressure drop was obtained by calculating the difference in the pressures indicated by the pressure transducers which were installed at the inlet and outlet of the mini channel evaporators[12]. The amount of refrigerant that flowed in the entire system for each evaporator was recorded by the flowmeter. The temperature of the air entering the evaporators was the ambient temperature and the air leaving the evaporators was measured at the open end of the wind tunnel using a temperature sensor connected to the data logger. Thirty (30) trials were conducted for every mini channel evaporator. Each trial consists of thirty (30) measurements taken every thirty (30) seconds interval for every parameter being considered, in order to clearly observe the behavior of the system.

2.5.Mathematical relationship

Heat transfer rate values were obtained by utilizing the energy balance inside the wind tunnel.

Heat removed from supply air = Heat absorb by the refrigerant,

$$Q_{air} = Q_{ref} \quad (1)$$

where:

Q_{air} = $m_{air}\, cp_{air}\, (\Delta t)$

m_{air} = mass of air entering the wind tunnel

= $\rho_{air}\, A_w\, V_{air}$

ρ_{air} = density of the air

A_w =cross sectional area of the wind tunnel

cp_{air} = specific heat of air

V_{air} = air velocity inside the wind tunnel

Δt = temperature difference of entering and leaving air

Q_{ref} = $U\, A_s\, C_p\, (\Delta T_{lncf})$

U = overall heat transfer coefficient

A_s = total surface area of the mini channel evaporator

ΔT_{lncf} = log mean temperature difference for cross flow

= $[\Delta T_1 - \Delta T_2] / [F \ln(\Delta T_1 / \Delta T_2)]$

ΔT_1 = $T_{air, in} - T_{evap,out}$

ΔT_2 = $T_{air, out} - T_{evap,in}$

F = correction factor

Using the equation above, the overall heat transfer coefficients were computed; and therefore, the heat transfer rate can also be calculated using basic heat transfer equations. Computations were done as follows:

$$U = Q_{ref} / [A_s\, \Delta T_{lncf}] \quad (2)$$

$$Q_{ref} = U\, A_s\, [T_{air} - T_{evap}] \quad (3)$$

T_{air} = leaving temperature of air

T_{evap} = average temperature of the evaporator

The mass flow rates of the refrigerant were computed as shown below.

$$m_{ref} = \rho_{ref}\, Q_v \quad (4)$$

where,

ρ_{ref} = density of the refrigerant

Q_v = volume flow rate of the refrigerant

The EER can be computed by dividing the refrigerating effect in BTU/hr by the power input in Watts as shown below.

EER = Refrigerating effect (BTU/hr) / Power input (Watts) (5)

3. Experimental

The data needed in the analysis of the performance characteristics of the mini channel evaporator include the values of the pressure drop of refrigerant R134a, the air temperature differences in the wind tunnel and the volume flow rate of the refrigerant R134a[13]. These data are measured simultaneously from the fabricated experimental rig as shown in Figure 4.

The volume flow rate of refrigerant R134a is also measured using the flowmeter attached to a data logger together with the temperature sensor of the air temperature difference in the wind tunnel.

Figure 4. The experimental rig

4. Results and Discussion

The prototype system was tested and evaluated to determine the performance characteristics of the designed mini channel evaporators.

4.1. Specific Objective 1: To design three mini channel evaporators of different internal diameters in which the heat transfer surface area of the copper block is to be increased.

Figure 5. The fabricated mini channel evaporator

Three (3) mini channel evaporators having an internal diameter of 2.0 mm, 2.5 mm, and 3.0 mm were fabricated as shown in Figure 5. The outside heat transfer surface area of the evaporators is all equal to 0.0181316 m^2.

One significant improvement in the design of these mini channel evaporators is that there are perforated holes parallel to the evaporators' thickness. These holes will not only enable the air to pass through the mini channel evaporator but also, increased the heat transfer surface area of the evaporator which is equal to the area of the cylindrical holes.

4.2.Specific Objective 2: To install capillary tubes which have smaller internal diameters than the evaporators to minimize the possibility of capillary effect inside the mini channel evaporators.

The installed capillary tube in the experimental rig has a diameter of 1.0 mm which is smaller than the internal diameters of the mini channel evaporators. Also, the design of the mini channel evaporator itself in which it contains headers where the refrigerant R134a is allowed to be stored before entering the main part of the mini channel evaporator, which most of the heat transfer between the refrigerant and the air occurs, can also minimize the possibility of capillary effect alone.

4.3. Specific Objective 3: To correlate the performance characteristics of the three mini channel evaporators.

The experimental data and calculated results obtained during the experiment are tabulated and presented in graphs as shown in Figure 6.

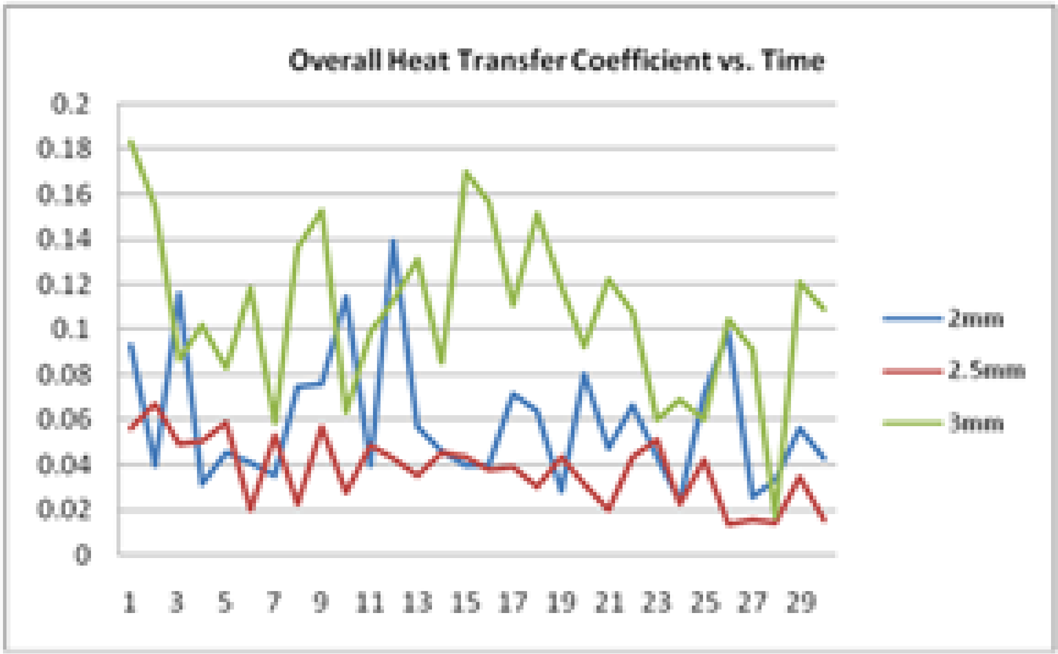

Figure 6. Overall heat transfer coefficients of mini channels

The controlled variables in that experiment are the volume flow rate and the pressure at the low-pressure side of the system; in which these variables are set to a specified range of values before data gathering has started. The mini channel evaporator temperature difference and heat transfer rate correlation in the mini channel evaporators showed a weaker correlation. The evaporator temperature difference and overall heat transfer coefficient correlation in the 2.5 mm evaporator showed a better correlation while the other two showed a weaker correlation. The air temperature differences and the overall heat transfer coefficient correlation for the 2.0 mm mini channel evaporator showed a weaker correlation while the other two (2) mini channel evaporators showed a better correlation. The air temperature difference and heat transfer rate correlation for the 3.0 mm mini channel evaporator showed a better correlation while the other two (2) mini channel evaporators showed a weaker correlation.

The overall heat transfer coefficient and heat transfer rate of the three (3) mini channel evaporators are fluctuating and unstable due to the pulsating action of the reciprocating compressor. But even if the data and results are irregular, the 3.0 mm mini channel evaporator has the highest overall heat transfer coefficient and heat transfer rate. It only means that the 3.0 mm evaporator is the most efficient among the three (3) mini channel evaporators as shown in Figure 6.

4.4. Specific Objective 4: To evaluate the performance characteristic of the mini channel evaporators.

The evaporator temperature differences are almost constant with respect to time for all the three (3) mini channel evaporators as shown in Figure 7. The air temperature difference showed little distinction among the three (3) mini channel evaporators. The 3.0 mm mini channel evaporator has the highest air temperature difference among the three evaporators as shown in Figure 7.

For the air temperature difference and evaporator temperature difference correlation, the 2.0 mm and 2.5 mm mini channel evaporators showed good correlation while the 3.0 mm mini channel evaporator shows a weaker correlation.

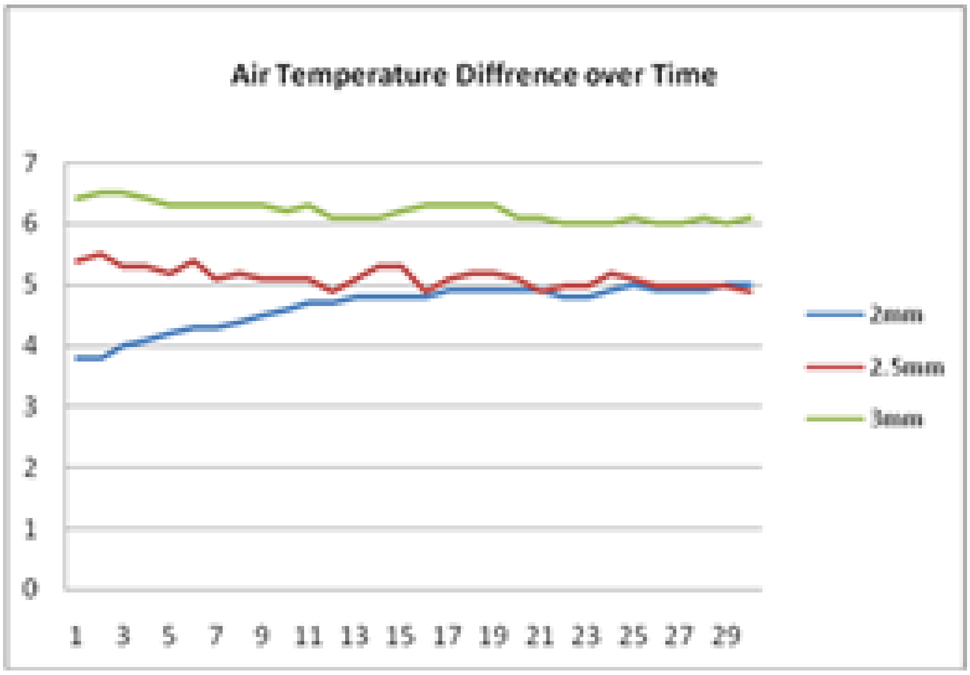

Figure 7. Wind tunnel air temperature differences for the three mini channel evaporators

4.5. Specific Objective 5: To evaluate the Energy Efficiency Ratio (EER) of the systems.

The obtained EER of the three (3) mini channel evaporators have low values as compared to the typical values of EER which ranges from 8 to 10. Also in theory, EER should always be greater than 1.

Table 1. Energy Efficiency Ratio (EER)

Diameter, mm	Power Input,W	Ref.Effect,BTU/hr	EER	COP
2.0	70.0	70.33086798	1.004727	0.294456
2.5	70.0	36.15364568	0.516481	0.151366
3.0	70.0	93.70619732	1.33866	0.392322

However, the 2.5 mm mini channel evaporator has an EER of less than one as shown in Table 1. It is not surprising since the compressor used in the experiment was for a typical commercial size water dispenser and the mini channel evaporator cannot carry all the load of the system due to its miniature capacity. Because of that, two (2) mini channel evaporators are used simultaneously; a mini channel evaporator and the original evaporator. The original evaporator absorbs the heat that cannot be carried out by the mini channel evaporator to attain a vapor state of refrigerant before entering the compressor. However, the energy that was absorbed by refrigerant R134a at the mini channel evaporator was only a small fraction compared to the energy absorbed by the refrigerant at the original evaporator.

Therefore, the value of the EER are only fractions of the total value of the EER of the systems, excluding the fractions due to heat absorption of the original evaporator. But among the three mini channel evaporators, the 3.0 mm mini channel evaporator has the highest value of EER equivalent to 1.339 as compared to an EER of 1.005 for the 2.0 mm mini channel evaporator and 0.516 for the 2.5 mm mini channel evaporator.

5. Conclusion and Future works

5.1. Conclusion

From the data gathered during the study, the 3.0 mm mini channel evaporator has the highest air temperature difference among the three (3) mini channel evaporators tested and evaluated having an average value of 6.20 K. Also, it showed the highest overall heat transfer coefficient attaining an average value of 108 W/m^2-K and the highest heat transfer rate obtaining an average of 27.50 Watts. Since the same compressor was used during the study of the three (3) mini channel evaporators, it follows that the 3.0 mm mini channel evaporator has the highest value of EER having an average value of 1.34.

5.2. Future works

1. Leakages in fittings are commonly encountered during the study. It can be eliminated by bending the copper tubes instead of using elbows and flare knots. It can also be eliminated by joining the copper tubes using oxy-acetylene welding.
2. During study, as much as possible, make sure that the same cooling load was introduced to the system. Avoid touching the original evaporator because the authors have observed that an increased in cooling load in the original evaporator will cause a slight increase of pressure at the low pressure side of the system.
3. Use fan that can deliver higher flow rate of air than the five (5) DC volts fan used in this study. It was observed that after a prolong time of the data gathering, the mini channel evaporators are completely covered with ice and the holes, where the air was supposed to flow, were blocked. Therefore, using a fan that can help cope up the heat transfer requirements of the mini channel evaporators is highly recommended.

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Compliance with ethical standards

Disclosure of conflict of interest. No conflict of interest to be disclosed.

References

1. Stoker W and Jones J. (1982). Refrigeration and Airconditioning, Second edition. New York, McGraw Hill, 182.
2. Kimberlin D., Brady M., Jackson M., Long S. (2018). Active and Passive Immunization, American Academy of Pediatrics, Thirty-First edition, Itasca IL, Red Book. 20.
3. Dollera E, Co JK, Dotdot KJ, Gamotin JL and Mobida DJ. (2020). Mini channel evaporator as MAC device for laptop cooling system, International Journal of Recent Technology and Engineering, 8(5), 2993-2998.
4. Kandlikar S. (2002). Fundamental issues related to flow boiling in mini-channels and microchannels. Experimental Thermal and Fluid Science.26(1), 389-407.
5. ASHRAE. (1985). Handbook of Refrigeration, SI Version, Atlanta, GA, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 85-256.
6. Pabilona L,Villanueva E, and Dollera E. (2015). An experimental and simulation study of heat transfer coefficient of the mini channel condenser for refrigeration system, Australian Journal for Basic & Applied Sciences, 9(37), 6-14. Special Issue.
7. Dollera E, Villanueva E, Pabilona L, Dotdot KJ, Dollera Jr. G. (2019). Temperature distribution in mini channel heat exchanger for the development of a portable vaccinecarrier, International Journal of Recent Technology and Engineering, 8(4). 222-226.
8. Sonntag R, Borgnakke C and Van Wylen G. (2013). Fundamentals of Thermodynamics, Sixth edition, New York, John Wiley & Sons, Inc.,133-170.
9. Dollera E, Dablo CF, Dollera,Jr G, Nasara H, Maquiso KB. (2019). Choke point in mini expansion device for the development of portable vaccine kit, International Journal of Engineering and Advanced Technology, 9(2), 3387-3393.
10. Cabading P, Cabading PK, Dollera E, Lusterio D and Rosete J. (2020). Solar powered window type air conditioner using inverter technology, International Journal of Scientific and Technology Research, 9(2), 2107-2112.
11. Rajput R. (1999). Refrigeration and Air-conditioning, Third edition. New Delhi, S.K. Kataria & Sons, Inc., 98-115.
12. Moran J, Shapiro H, Boettner D, Bailey M. (2011). Fundamentals of Engineering Thermodynamics, Seventh edition, New York, John Wiley & Sons Inc., 163-74.
13. Rin Y, Jae H, Yongchan K. (2006). Evaporative heat transfer and pressure drop of R410A in micro-channels. International Journal of Refrigeration. 29(1), 92-100.