Vaccine Transport Kit Using Mini DC Rotary Compression Refrigeration System

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Abstract

Refrigeration compressors powered by direct current electrical energy have been banished to mobile refrigeration systems, where batteries are the source of power. Mobile refrigeration and portable cooling have been re-energized creating new opportunities for innovative appliances that do not rely on grid power. These portable refrigeration systems may be applied to medicinal transport kits which have capabilities to cool vaccines. Vaccines are susceptible to heat and light. In this case, they require low storage temperature that would range between 2°C to 8°C. The primary aim of this study is to make use of a mini rotary compressor that will be used for a medical transport kit which can cool vaccines in transit to remote and mountainous off grid areas. The compressor is fitted into a vapor compression refrigeration system using tetraflouroethane as refrigerant. The system used a dc rotary compressor with 56.0 mm in diameter, 78.0 mm in height, and weighs 600.0 grams. The rotary compressor has a rolling piston design with a displacement of 1.40 milliliters and is powered by a high-torque brushless 24V DC motor. The design is very small, lightweight, and relatively high in cooling effect. The rotary compressor is powered by a battery and controlled with a potentiometer to vary the angular velocity. It was observed that the optimal cooling effect for vaccine kit operating the system is with the 3,000 rpm and with the capillary tube hydraulic diameter of 0.91 mm. For efficient performance, this design is adaptable to variable speed operation up to 6,000 rpm.

Keywords: Coefficient of performance, Rotary compressor, Portable cooling, Vaccine kit, Vaccine preservation.

Introduction

Immunization is a highly effective way of protecting individuals and communities from infectious disease. However, to remain potent, vaccines must be stored within the temperature range (ASHRAE, 2009) recommended by most vaccine manufacturers between 2 ˚C to 8 ºC (Kimberlin et al. 2018). Failure to store vaccines correctly, can reduce vaccine effectiveness and cause destruction of vaccines. Having the vaccines transported to off grid locations may increase the risk of the reduction of its potency. This reduction of potency of the vaccines in transit can be prevented by a medical transport kit using a mini dc rotary compressor refrigeration system (Dollera et al. 2019). A mini rotary compressor is used for the preservation system with limited space and for minimum weights. This makes the whole system portable which makes the transportation of the vaccines more convenient and simpler. The design of the compressor was intended to be very small, lightweight and relatively high in its cooling effect. Given its modest size and weight, the cooling effect maybe amazingly high for preservation and transportation of vaccines and other temperature-sensitive medicines.

A compressor is a mechanical device that increases the pressure of a gas by reducing its volume. Compressors can come in a wide variety of different types and sizes. While there are many types of compressors, they all perform the same function, which is to increase the pressure and reduce the volume of a given medium (Cengel et al. 2008).

Vaccines are fragile. They must be maintained at the temperatures recommended by vaccine manufacturers (2°C to 8°C) and protected from light at every link in the cold chain (Kimberlin et al. 2018). Most live virus vaccines tolerate freezing temperatures but deteriorate rapidly after they are removed from cold storage. Inactivated vaccines can be damaged by exposure to temperature fluctuations such as extreme heat or water freezing temperatures (Sonntag et al. 2013). Potency can be adversely affected if vaccines are left out too long or exposed to multiple temperature excursions and out-of-range temperatures that can have a cumulative negative effect.

A striking but seldom used parameter is that of cooling power density, both volumetric and by weight. The inference to be drawn from this comparison is that a large space and weight savings can be achieved using the mini compressor. Such factors have historically been used in mobile refrigeration systems only. A small vapor compression system can have large performance and efficiency advantages over thermoelectric coolers than have been used in some small appliance products (Stoker et al. 1982).

The main objective of this study is to provide a medicine transport kit using a mini rotary refrigeration system for maintaining the potency of vaccines. It includes the design and fabrication of a vaccine transport kit, to measure and determine the temperature differences in the vaccine compartment with respect to various angular speeds, and to evaluate the effectiveness of the use of a mini compressor by determining the COP of the system (Dittus et al. 1930).

This study will be a significant endeavor in having a probable solution to vaccine impotency problems. This study will also be beneficial to people who are planning to innovate this existing study. By understanding the needs of the people, we come up with the idea of aiding one of the most common problems with regards to medicinal transport.

Moreover, this study will provide recommendations on how to evaluate the performance of the refrigeration system that will be used to cool the vaccines. This will also serve as a future reference for researchers on mini compressors for further analysis and improvement. And most importantly, this study will educate the readers that medicine cooling may be aided by a portable refrigeration system which can be hand carried or backpacked. Making a medicine transport kit having a mini rotary compressor be fitted in a refrigeration system for vaccine cooling is the scope of this study. The refrigerant to be used is tetraflouroethane refrigerant (Faires et al. 2013). This study is limited to the cooling of the medicines only between 2˚C to 8˚C (Kimberlin et al. 2018). The selection of the compressor was based on the comparison of the performances of other mini compressors conducted by past researchers. The operation of the system was conducted on a thirty (30) minute duration only for every capillary tube in various rpm.

Methodology

In the refrigeration system, the compressor is the center of the refrigeration cycle. It works as a pump to control the circulation of the tetraflouroethane refrigerant, and in the process, it adds pressure to the tetraflouroethane refrigerant necessary to induce its circulation within the vapor compression refrigeration system (Kandlikar, 2002). With the increase in tetraflouroethane refrigerant pressure, its temperature is also increased higher than the ambient temperature, thereby making it possible to release the absorbed heat to the surroundings.The compressor also draws vapor away from the evaporator to maintain a lower pressure and lower temperature before sending it to the condenser. In this study, this system had been improved in such a way that the normal size of the system is reduced (Moran et al. 2011).

With the availability of a mini dc rotary compressor, it can potentially be used in a miniature vapor compression refrigeration system intended for portable cooling applications. The dc rotary mini compressor is quiet and has low energy consumption. It operates in conditions where vehicle batteries, on-grid, or solar power are available as the direct current power supply.

The dc rotary mini compressor provides compact design of the cooling system combined with precision angular speed control, and its unique flexibility. It fulfills a growing need for miniature thermal management systems not only as a vaccine transport kit but for other miniature cooling application. With its unusual weight and size, it can be applied in mobile or portable systems using either battery or even connected directly to the vehicle power. And due to its low energy consumption, it is very suitable for small stationary applications (Stoker et al. 1982).

Research design flow

The research design of this study is displayed below. Basic information and data for the preservation of vaccines are gathered and used for the optimum design of the cooling system.

Information Gathering
↓
Evaluation
↓
Selection of Compressor
↓
System Design
↓
Fabrication and Assembly
↓
Project Testing
↓
Data Gathering
↓
Calculations
↓
Evaluation of Results
Figure 1. Research design flow

This information was used to analyze and decide the right size and dimension of the fabricated experimental rig. The dc rotary compressor is the key element in the design of the different parts of the system. All the parts of this miniature cooling system must conform with the rated capacity of the dc rotary mini compressor for the system. A series of tests will be conducted, and data will be gathered to determine the performance of the mini compressor and to evaluate its performance with the whole refrigeration system.

Table 1. Comparison of refrigerant compressors

	Engel rotary compressor*	Hitachi reciprocating compressor*	Aspen rotary compressor
Dimensions			
Height (mm)	166	195	78
Length/diameter (mm)	Φ 85	204	Φ 56
Width (mm)	-	13 mm	-
Displacement (cc)	2.3	2.0	1.4
Weight (kg)	2.8	4.3	0.6
Performance with refrigerant R134a			
Pressure ratio	2.1 – 3.2	1.9 – 3.0	2.0 – 3.5
Speed (rpm)	2000	2000	3000 – 6000
Volumetric efficiency (%)	57.0 – 79.3	58.1 – 73.0	73.2 – 90.5
Overall isentropic efficiency (%)	40.6 – 59.5	43.2 – 56.5	44.1 – 70.3
Cooling capacity (W)	130.1 – 256.4[†]	152.2 – 208.8[†]	160.2 – 489.6[§]
System COP	3.0 – 5.7	2.6 – 3.7	2.1 – 7.4

Selection of rotary vane compressor

Table 1 shows the different model of dc rotary mini compressors available from the suppliers in Japan. For this study, the authors chose an Aspen rotary compressor weighing 600.0 grams, a diameter of 56.0 mm and a height of 78.0 mm.

Specification of the rotary vane compressor

Table 2 shows the characteristics of the Aspen rotary compressor. The minimum angular speed is 2,000 rpm, and the maximum angular speed is 6,500 rpm. This is a brushless dc compressor with a compressor displacement of 1.40 cubic centimeters.

Materials and Equipment Used

The materials used in the fabrication of the vaccine transport kit are available in the local market. The materials used in the fabrication are the following items but not limited to the copper tube for condenser and evaporator, capillary tubes with three different hydraulic diameters, copper tubes, evaporator coil (6.30 mm), galvanized iron sheet, tie wrap, flare nuts, screws, enamel paints and insulations (Dollera et al. 2019). The dc rotary compressor is not available in the local hardware and the nearest available supplier of the dc rotary compressor is in Japan. Through online marketing, a 24-dc rotary compressor was purchased and delivered at the doorstep in three-week time.

Table 2. Specification of the rotary compressor

Refrigerant	R-134a
Lubrication oil	Nu Calgon RL68H Polyol ester oil
Compressor type	Rotary (rolling piston)
Compressor displacement	1.4 cc
Compressor speed	Variable
Speed range	2,000 rpm to 6,500 rpm
Motor	Brushless DC
Voltage	24 V DC
Maximum current	12 Amps, continuous
Evaporator temperature range	-18 ^{o}C to 24 ^{o}C
Condenser temperature range	27 ^{o}C to 71 ^{o}C
Maximum discharge temperature	130 ^{o}C
Maximum compression ratio	8:1

The experimental rig was constructed using the facilities in the mechanical engineering laboratory. Some of the tools and equipment used in the fabrication of the experimental rig are the following items but not limited to thermocouple, bender, pliers, long nose, file, flaring tools, screwdriver, scissors, and bar cutter (Dollera et al. 2019). Most of the system parts were purchased from the hardware while some equipment and tools were rented from VP Ordiz refrigeration shop such as the oxyacetylene welding set, hand drill, air compressor, exhaust fans and the vacuum pump. A power supply of 24-DC 20-A is used to supply power to the dc rotary compressor. Data logger is also used to gather and record the pressure, temperature, volume flow rate of tetraflouraethane refrigerant and the varying angular speed of the dc rotary compressor mounted in the experimental rig.

Experimental rig

The conceptualization and design of the experimental rig were done from scratch paper and eventually improved according to the standards of the Department of Health. The calculation of the dimension of the vaccine kit and the documentation of the final version of the design was made possible through the introduction of the AutoCAD software on the design as shown in Figure 2.

The dimension of the brine container is 102.0 mm x 76.0 mm and then attached to a compartment which will tend to hold the vaccines to be cooled and stored at the same time. The tubing which connects the evaporator, and the capillary tubes were enclosed by rubber insulation to prevent heat absorption before reaching the vaccine compartment in the evaporator. The condenser coil is wrapped by a galvanized iron sheet fitted just the same size as the coil. A fan is installed parallel to the coil to increase the condensing capability of the condenser. The other side of the coil was sealed loose with a Styrofoam insulation to let the air from the surrounding enter the holes from the galvanized iron sheet (Rajput, 1999).

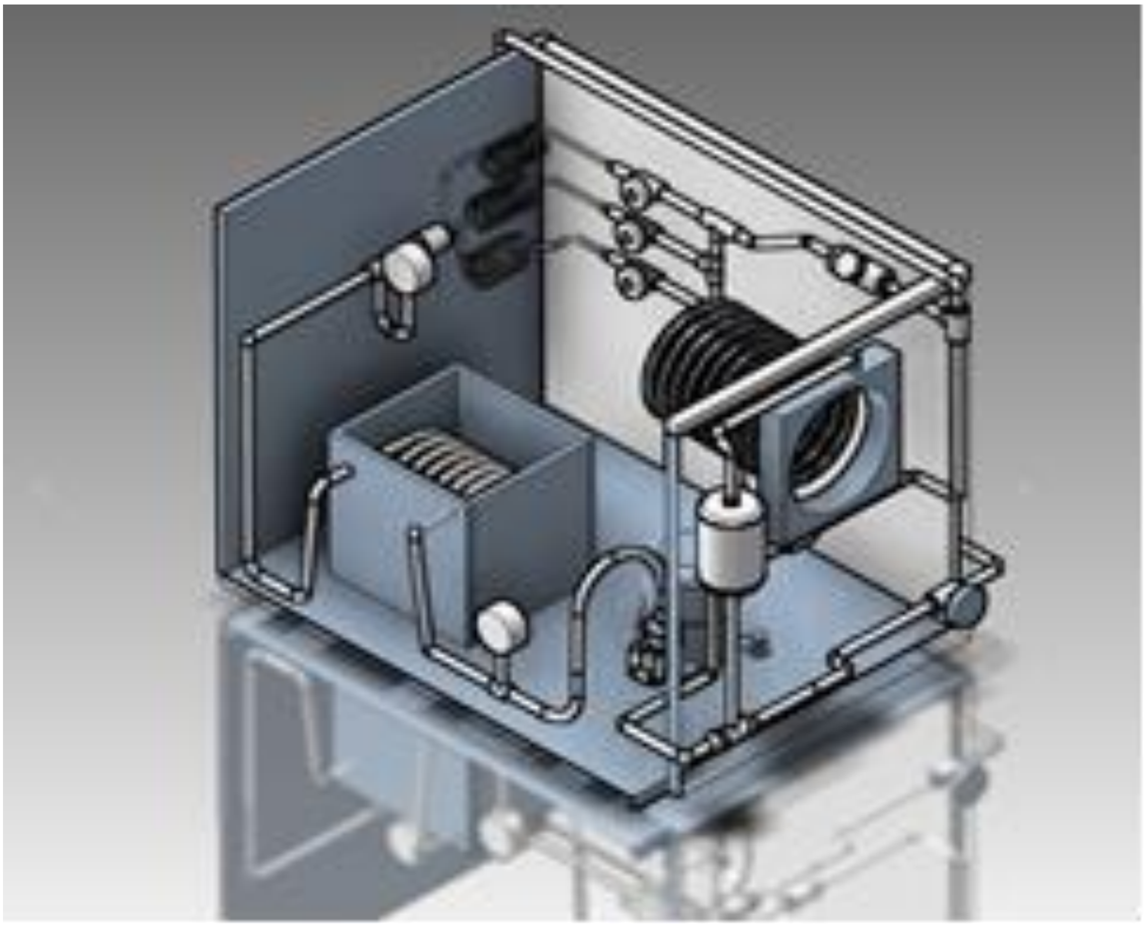

Figure 2. Set-up of the experimental rig

The temperature of the dc rotary compressor normally reaches 100 ºC when the maximum speed is reached at 6,500 rpm. To reduce the temperature of the rotary compressor, a fan is mounted and attached parallel to the dc rotary compressor.

Before the dc rotary compressor was tested, a circuit board was connected to the dc rotary compressor and eventually, to the power supply. The circuit board is wired to a 20K potentiometer to vary the VDC power supply to be delivered to the dc rotary compressor. For a corresponding VDC power supply, there is an equivalent angular velocity of the dc rotary compressor in revolution per minute or in rpm. The power supply is good for experiment purposes only. But for the portability's sake, batteries will be used to supply power and drive the vaccine transport kit.

Data Gathering

The standard vapor compression refrigeration system consists of used by household and industrial refrigeration system consists of four (4) major components, namely, the compressor, the condenser, the expansion device and the evaporator as the cooling compartment. In this study, the size of the standard vapor compression refrigeration system must be reduced in such a way that portability becomes the dominant factor of the design (Rin et al. 2006).

The compressor is the heart of the system, where tetraflouroethane refrigerant is pumped and circulated throughout the system. The condenser is a heat exchanger of the system where the heat absorbed in the evaporator is rejected to a heat sink or to the environment. The evaporator is also a heat exchanger used to absorb the heat from the surroundings and reject this heat in the condenser. In this study, the evaporator is used as the cooling compartment of the vaccine vials or other forms of temperature sensible medicines. The expansion device is a component used to create pressure drops in the system. This component is used to lower the pressure level in the condenser to the pressure level of the evaporator (Dollera et al. 2020).

In this study, capillary tubes are used as the expansion device of the vaccine carrier kit. The author chose this type of expansion device because of its simplicity in design and lightweight. There are three different capillary tubes used in this study. The first capillary tube has a hydraulic diameter of 0.79 mm, the second capillary tube has a hydraulic diameter of 0.91 mm and the third capillary tube has a hydraulic diameter of 1.25 mm. These capillary tubes are chosen because these are the standard sizes of copper tubes used as capillary in standard vapor compression refrigeration system. Tests were tediously performed in the data gathering needed for this study to achieve the different specific objectives in this endeavor. Data logger records all the data needed for this study.

The following data were collected after the series of tests having an interval of thirty (30) seconds: temperature of tetraflouroethane refrigerant in the condenser, temperature of tetraflouroethane refrigerant in the evaporator, mass flow rate, suction and discharge pressure of tetraflouroethane refrigerant as it passes through the vaccine compartment.

The coefficient of performance of the system is calculated from the data obtained from the vaccine transport kit. The coefficient of performance is the ratio of the refrigerating effect and the work of compression of the dc rotary compressor. The refrigerating effect is the total quantity of heat that each pound of refrigerant absorbs from the refrigerated space that produces useful cooling (Holman, 2010).

Data gathering on the capillary tube No.1

The first capillary tube used in this study is a capillary tube with a hydraulic diameter of 0.79mm.

Table 3. Measured data on capillary tube No.1 at 2000 RPM

TRIAL	Tcond, °C	Tevap, °C	Psuc, psi	Pdis,psi	COP	ΔT, °C
1	28.3	-8.2	12.0	125.0	7.255	1.0
2	28.6	-7.3	13.0	130.0	7.405	1.0
3	28.8	-8.2	13.0	132.5	7.161	0.0
4	29.0	-8.0	13.0	135.0	7.166	0.0
5	29.0	-7.5	14.0	137.0	7.275	1.0
6	29.2	-7.2	15.0	140.0	7.306	1.0
7	29.3	-7.4	14.0	140.0	7.241	-1.0
8	29.4	-7.9	15.0	140.0	7.111	-1.0
9	29.3	-8.3	13.0	140.0	7.044	0.0
10	29.4	-8.7	12.0	140.0	6.941	-1.0
11	29.4	-8.9	12.0	140.0	6.599	0.0
12	29.5	-9.4	11.0	140.0	6.780	-1.0
13	29.3	-10.2	11.0	137.5	6.623	0.0
14	30.8	-10.0	10.0	135.0	6.450	-1.0
15	31.2	-10.4	10.0	135.0	6.315	0.0

16	31.2	-10.6	10.0	135.0	6.281	0.0
17	31.4	-11.2	10.0	135.0	6.149	0.0
18	30.9	-11.7	10.0	132.5	6.137	0.0
19	31.2	-12.0	10.0	131.0	6.045	0.0
20	31.9	-12.0	10.0	131.0	5.949	0.0
21	32.0	-12.2	9.0	131.0	5.904	-1.0
22	31.7	-12.0	9.0	130.0	5.976	0.0
23	31.3	-12.2	9.0	130.0	5.999	0.0
24	31.2	-13.0	8.0	130.0	5.836	-1.0
25	30.9	-13.2	8.0	130.0	5.805	0.0
26	30.9	-12.8	8.0	130.0	5.958	0.0
27	30.8	-13.1	8.0	130.0	5.924	0.0
28	30.8	-13.4	8.0	130.0	5.877	0.0

This capillary tube was tested at 2,000 rpm, 3,000 rpm, 4,000 rpm, 5,000 rpm and 6,000 rpm of the dc rotary compressor. All the parameters were gathered and recorded in the data logger. These parameters were gathered on a thirty (30) seconds interval. Stabilization of the performance is observed in line with time. The condenser temperature increases with time. The condenser's temperature is inversely proportional to that of the evaporator's temperature. As observed, both the suction and discharge pressures increase and then decrease with time. The change in temperature drops abruptly in merely one minute which makes the system effective at some point of operation (ASHRAE, 2009).

Data gathering on the capillary tube No.2

The second capillary tube with a 0.91 mm in hydraulic diameter was tested at 2,000 rpm, 3,000 rpm, 4,000 rpm, 5,000 rpm and 6,000 rpm of the dc rotary compressor. All the parameters were gathered by the data logger and stored in the laptop computer.

Table 4. Measured data on capillary tube No.2 at 2000 RPM

TRIAL	Tcond, °C	Tevap, °C	Psuc, psi	Pdis,psi	COP	ΔT, °C
1	28.1	5.4	30.0	120.0	12.271	-8.6
2	28.2	3.7	27.0	119.0	11.205	-1.7
3	28.4	3.4	26.0	120.0	11.062	-0.3
4	28.7	3.0	27.0	124.0	10.745	-0.4
5	28.9	2.3	26.0	125.0	10.355	-0.7
6	28.5	2.1	26.0	127.5	10.426	-0.1
7	28.5	1.9	26.0	130.0	10.341	-0.2
8	28.5	2.0	26.0	130.0	10.583	0.1
9	28.5	1.7	25.0	130.0	10.256	-0.3
10	28.6	1.4	25.0	130.0	10.094	-0.1
11	28.6	1.8	24.0	130.0	10.259	0.4
12	28.5	2.0	25.0	127.5	10.383	0.2

13	28.5	1.9	24.0	127.5	10.340	-0.1
14	28.7	1.8	25.0	127.5	10.221	-0.1
15	28.6	1.3	25.0	127.5	10.053	-0.5
16	28.6	1.7	25.0	125.0	10.237	0.4
17	28.6	1.7	24.0	125.0	10.217	0.0
18	28.6	1.7	24.0	126.0	10.217	0.0
19	28.8	1.5	24.0	125.0	10.080	-0.2
20	28.8	1.6	24.0	125.0	10.101	0.1
21	28.8	1.5	24.0	125.0	10.060	-0.1
22	28.7	1.6	24.0	125.0	10.138	0.1
23	28.8	1.2	24.0	125.0	9.940	-0.4
24	28.8	1.5	24.0	125.0	10.080	0.3
25	28.8	1.4	24.0	125.0	10.020	-0.1
26	28.9	1.2	24.0	125.0	9.904	-0.2
27	29.0	1.0	24.0	125.0	9.792	-0.2
28	29.0	1.1	24.0	125.0	9.830	0.1

Data gathering on the capillary tube No.3.

The third capillary tube with a 1.25 mm inner and hydraulic diameter was tested at 2,000 rpm up to its maximum rpm capacity of the dc rotary compressor of 6,000 rpm. All the parameters were gathered and recorded using a data logger. Calculations were made for the coefficient of performances. Data recording was made on a specific time interval of thirty (30) seconds for the temperatures and pressures readings

Result and Discussion

Tests were made to gather the necessary technical data from the experimental rig to achieve the specific objectives in this study.

Specific objective No.1: To design and fabricate a vaccine transport kit.

The Department of Health and the vaccine manufacturers required storage temperature for vaccines for as low as 2 ^{o}C to as high as 8 ^{o}C. With the fabricated vaccine compartment, the required preservation temperature is well achieved using the three different capillary tubes as shown in Figure.2.

Figure 3. Fabricated medicine transport kit

Specific objective No.2: To measure and determine the temperature difference in the vaccine compartment with respect to various angular speeds.

To determine the maximum temperature difference in vapor compression refrigeration system is to determine the coefficient of performance. The coefficient of performance is the ratio of the refrigerating effect to the work of compression of the dc rotary compressor. Evaporator's temperature difference drops abruptly in merely one minute. This signifies that there is a substantial effectiveness that the compressor attains with a small span of time. Temperature difference is greatest using the second capillary tube which has the hydraulic diameter of 0.91mm.

The performance evaluation parameters are listed below:

T_{cond} = temperature of the condenser

T_{evap} = temperature of the evaporator

P_{suc} = suction pressure (before the compressor)

P_{dis} = discharge pressure (after the compressor)

COP = coefficient of performance

ΔT- temperature difference in the evaporator

The coefficient of performance is defined as the ratio between the refrigerating effect and the work of compression of the rotary compressor. The greater the refrigerating effect than to that of the work of compression makes the system efficient since the cooling capacity is greater with a use of only lesser work. The coefficient of performance stabilizes with time. The coefficients of performance were calculated using the parameters obtained from the experimental rig and plotted on a graph of coefficient of performance with respect to the angular speeds. The recorded data were then analyzed for every thirty (30) minute interval and taken the average values to plot on a coefficient of performance with respect to the angular speeds of the rotary compressor. The angular speed of the dc motor on the rotary compressor was varied from for 2,000 rpm, 3,000 rpm, 4,000 rpm, 5,000 rpm, and 6,000 rpm using speed selector.

The greatest coefficient of performance is attained with the use of capillary tube No. 2 which has the hydraulic diameter of 0.91mm. Most of the graphs on the coefficient of performance showed a reduction when the angular speed of the motor is increased from 2,000 rpm to 6,000 rpm.

The volume flow rate of the tetraflouroethane refrigerant is expressed in terms of gpm or gallons per minute. The volume flow rate of tetraflouroethane refrigerant fluctuates with the increase of the angular speed of the rotary compressor.

Specific objective No.3: To evaluate the effectiveness of the mini compressor used for the vaccine cooling by determining the COP.

The desired coefficient of performance of the vaccine transport kit is around 11.0. Based on the performance of the system using the same operation for vaccine cooling, the maximum coefficient of performance is only 10.35. It may not be the desired performance, but it falls between the range of the desirable and the attainable coefficient of performance of the refrigeration system.

In this study, the capillary tube No.2 attained a coefficient of performance nearest to the desired coefficient of performance of 11.0

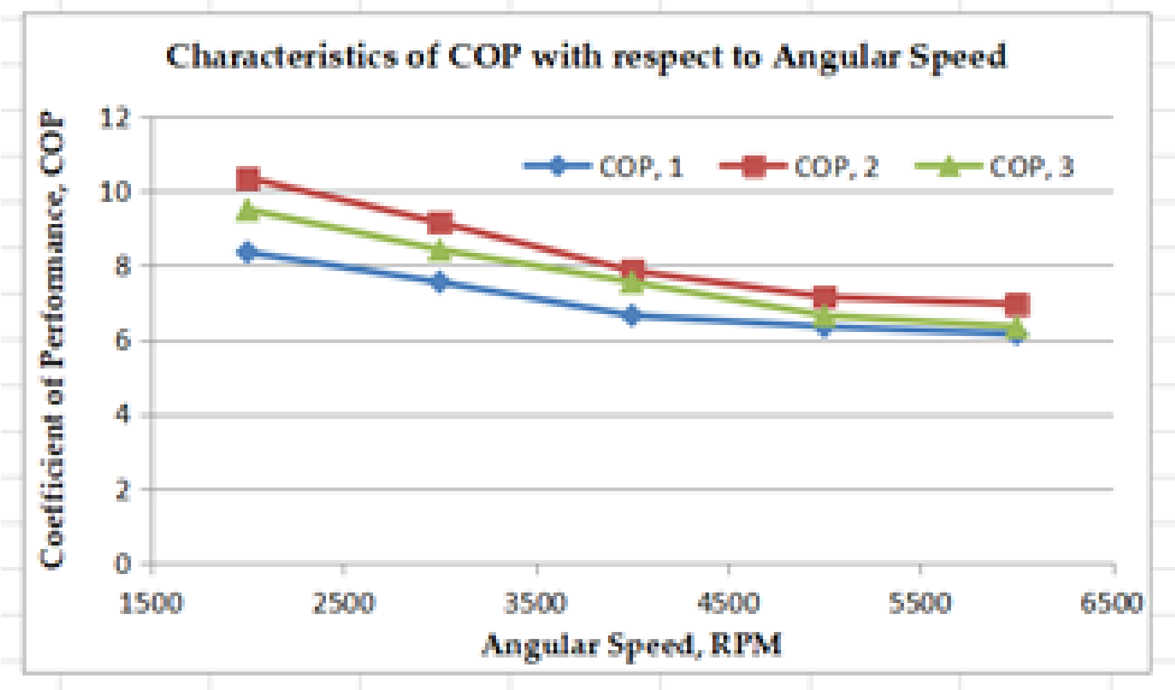

Figure 4. Characteristics of COP vs. Angular Speed

Conclusion

The manufacturer's recommended storage temperature for vaccines preservation of 2°C to 8°C was attained using the three different hydraulic sizes of capillary tubes in this study. The temperature of the vaccine compartment inside the evaporator has an average value below 0 °C and well below the minimum preservation temperature requirements of most of the vaccines. Capillary tube No.2, which has a hydraulic diameter of 0.91 mm has the highest coefficient of performance for all the angular speed of the dc rotary compressor. At 2,000 rpm of the rotary compressor, the coefficient of performance of the vaccine transport kit reached as high as 10.35 and reduces its value as the angular speed increases as high as 6,000 rpm. It is also observed in this study that the coefficient of performance for each of the three capillary tubes occurred at the lowest angular speed of the rotary compressor. Using this data for the design of vaccine transport kit for the off-grid areas will be given much important in the optimum design parameter of the kit. Without depending on the grid, this vaccine transport kit will save life to poor patients living in off grid areas. Savings on operational cost of as much as the price equal to a solar panel which can supply electricity to the battery connected to the dc motor to drive the rotary compressor. This study is therefore of great help for the preservation of vaccines and for other heat sensitive medicine transport kit with minimum operating expenses.

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