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Experimental Performance of R134a/SiO_2 in Refrigeration System for Domestic Use

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ABSTRACT

Nanofluids are considered as a new invention of fluids having superior thermal physical properties to improve efficiency of the refrigeration system. Nanofluids are the colloidal suspensions of nanoparticles in base fluid. Nanoparticles having higher thermal conductivity compared to pure refrigerant such as R134a can be added to pure refrigerant to improve the performance of refrigeration system. This study focuses on producing nanolubricant (SiO_2/POE) and implementing the nanolubricant into refrigeration system. The nanoparticles will be homogenized in refrigerant to produce nanoRefrigerant (R134a/SiO_2) at the attached reservoir. The aim of the research is to study the thermal physical properties of nanolubricant and to find the relationship between nanoparticles' volume fraction to the Coefficient of Performance (COP) of the refrigeration system. The investigations are focused on the effects of nanoparticles with 0.1, 0.3%, 0.7% and 0.9% volume fraction to the performance of the refrigeration system. The results show that the usage of nanolubricant creates higher thermal conductivity with slightly higher dynamic viscosity which eventually increase the performance of the refrigeration system by 8.62% in term of COP.

1. Introduction

Refrigeration system is widely applied in various sectors and applications including industry, automotive, domestic and solar system. The usage of this system causes high energy consumption and it will continue to increase until 2050 [1]. Besides that, the use of refrigeration system can lead to global warming. Hence, there is a need to create higher performance refrigeration system in order to control the mass usage of energy. One of the ideas to create a higher performance refrigeration system is by increasing thermal physical properties of the working fluid through nanoparticles' addition. This method is promising because the performance of refrigeration system can be increased without any changes in the systems' design or configuration that can lead to easy maintenance and low cost. 1,1,1,2-Tetrafluoroethene (R-134a) is the most common refrigerant that is used in air conditioner system and domestic refrigeration system. There are three main cycle of refrigeration

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system including vapour compression refrigeration system, vapour absorption refrigeration system, and gas cycle refrigeration system [2]. The vapour compression cycle is widely used because it exhibits higher Coefficient of Performance (COP) compared to other cycles. The addition of nanoparticles into the refrigeration system will improve the COP of refrigeration system due to higher thermal conductivity and viscosity, and lower specific heat and density [3]. In order to enhance the development of the energy transfer coefficient and also to increase COP, Choi and Eastman [4] has defined nanofluid as a conventional heat transfer fluid that contains 100 nanometer sized suspended particles. In order to get an optimum result for heat transfer performance, there are many researchers who have done their research based on the performance of refrigeration system, obtaining their results according to experimental based methods. Nanofluids are the mixture of solid nanoparticles with a base fluid. The presence of nanoparticles in nanofluid enhanced thermal physical properties such as thermal diffusivity, thermal conductivity, viscosity and convective heat transfer rate compared to the base liquids like oil refrigerant or water [5]. Based on the study, thermal conductivity of nanofluid is increases with increased nanoparticle volume fraction [6]. Selecting the suitable nano particles with optimum particle volume fraction is crucial to enhance the performance of thermal system in which result to higher COP [7]. Silver nanofluid requires less pumping power by generating less entropy to produce the same cooling effect as using water as working fluid [8]. Since then, numerous studies on thermal physical properties, rheological behavior and thermal performance of nanofluid have been widely studied and investigated.

Ahmed *et al.,* [9] experimentally investigates the effect of particle volume fraction, mass flow rate and nanofluid inlet temperature to the COP of the refrigeration system. They conducted experimental studies by adding Al2O3 nanoparticles into mineral oil and produce a nanolubricant. The R134a/Al_2O_3 nanorefrigerant was produced when pure conventional refrigerant circulated through the system. Highest COP of 6.5 is achieved at inlet temperature of 40 C, 80 g/s mass flow rate with 15% volume concentration. Jwo *et al.,* [10] researched on the effects of a refrigeration system by replacing R-134a refrigerant and polyester lubricant with a hydrocarbon refrigerant and mineral lubricant. The experiment was conducted by mixing Al_2O_3 nanoparticles with mineral lubricant and put it in the system. The result has shown that the heat transfer performance of nanofluid continuously increases until optimal condition of 60% R-134a and 0.1 wt % Al_2O_3. They also found that, the system worked normally under these conditions and the power consumption was reduced by about 2.4%, and the coefficient of performance was increased by 4.4%. Bobbo *et al.,* [11] experimentally studied on the performance of nanorefigerants at different temperature. In the experiment, R134a refrigerant and the mixture of polyester (POE) oil with nanoparticles TiO_2 and carbon nanohorns (SWCNH) were used. They found that the system worked normally and concluded that the conditions of base lubricant can be improved or worsen by adding nanoparticles.

However, Sanukrishna *et al.,* [12] showed the effect of SiO_2 nanoparticles with a volume fraction of 0.1%, 0.6% and 0.8% in polyalkylene glycol and R-134a refrigerant. The investigation was carried out to determine the effect of particle volume fraction, heat flux and vapour quality to the heat transfer performance and lubricant capabilities to the refrigeration system. It was found that the excellent result of heat transfer performance in the dispersion of SiO_2 nanoparticle with R134a and PAG oil. Based on the result, the heat transfer coefficient increases more than 100% by increasing volume fractions of nanofluids. Subramani and Prakash [13] has experimentally studied the enhancement of the COP in refrigeration system. The experiment was conducted by applying two conditions of refrigerant which are pure conventional refrigerant R-134a and R134a/Al_2O_3 nanorefrigerant. They come out on theoretically analysis for both conditions and found that the COP of pure conventional refrigerant R-134a increases by 10.11% while the R134a/Al_2O_3 nanorefrigerant also increase about 9.74%. Deokar and Cremaschi [14] carried out an investigation on pool boiling performance of the nanorefrigerant that contains the effects of γ-Al_2O_3 nanoparticles and R410A/polyolester lubricant (RL68H) mixture. In the experiment, the refrigerant and lubricant are mixed in the two-phase region at the vertical downward sections. The apparatus loop is designed in the specific way to prevent oil traps or nanoparticles debris. The result shown, R410A-Al_2O_3 gives higher heat transfer coefficient compared to R410A-ZnO mixture.

Mahbubul *et al.,* [15] has also investigated nanorefrigerant performance based on the Al_2O_3 nanoparticles concentration of 1 to 5 vol.%. The result shows that the thermal conductivity of Al2O3/R-134a nanorefrigerant significantly increases with the particle volume fraction. It can be concluded that the volume fractions of nanoparticles concentration play a big role during experiments, including increased thermal conductivity of nanorefrigerant and good results on heat transfer coefficients. Besides that, they have also shown the significant improvements results of viscosity, pressure drop and heat transfer coefficients by increasing volume fraction. Nanoparticles concentration and the pumping power also increase with the increase of pressure drop. Therefore, it also can be concluded the pressure drop due to nanorefrigerant causes low pumping power. Yee *et al.,* [16] investigates four themophysical properties that influenced COP including viscosity, thermal conductivity, density and heat capacity.

Even though the dispersion of nanoparticles into the refrigeration system have been studied by many researchers. But, most of the them do not emphasize on the relationship between thermal physical properties of nanolubricant to the COP of the refrigeration system. Hence, this research will focus on the relationship of four thermal physical properties of nanolubricant and how the nanoparticles in nanolubricant is transferred into the refrigeration system. Then, the performance analysis will be conducted in order to find the most optimum nanoparticles volume fraction for highest COP of refrigeration system. Based on the potential of the nanoparticles that have been studied, it is envisaged that nanoparticles can enhance thermal conductivity, viscosity and reduce specific heat and density of the conventional base fluid, thus increasing the heat transfer performance and lower energy consumption can be achieved [17]. However, adding nanoparticles straight into refrigerant tank is impossible due to evaporation issue. So, in this project, the first stage of the methodology is dispersing nanoparticles (SiO_2) into lubricant (POE oil). The homogenized SiO_2 nanoparticles in POE lubricant called nanolubricant (SiO_2/POE) will be mix with refrigerant at the reservoir for the second stage. The aim of this investigation is to increase the coefficient of performance of refrigeration system through experimental investigation. The results from this study can be used in refrigeration equipment such as domestic refrigerators and air conditioners.

2. Methodology

2.1 Experimental Procedure

Thermal performance analysis of R134a/SiO_2 at four different nanoparticle volume fractions are analyzed through experimental method. Four K-type thermocouples are brazed at four locations of copper tube. The high pressure (HP) and low pressure (LP) of manometer pressure gauge have been installed in this test rig. There are two points for pressure measurement; the high pressure located at the suction of the compressor and the low pressure located at discharge pressure of the compressor. A copper tube with inner diameter 6.35 mm is used to connect the refrigerant tube to each pressure gauge. Figure 1 shows the schematic diagram of the experimental set-up and Figure 2 shows the development of the test rig. The experimental set-up consists of compressor, condenser, liquid reservoir, filter and drier, expansion valve or capillary tube and evaporator. The high pressure (HP) and low pressure (LP) of manometer pressure gauge have been installed in this test rig. So, there are two points of pressure measurement have been placed in the system where the high pressure located at the suction of the compressor and for the low pressure located at the discharge pressures of the compressor. A copper tube with diameter 6.35 mm was used to connect the refrigerant tube to each pressure gauge.

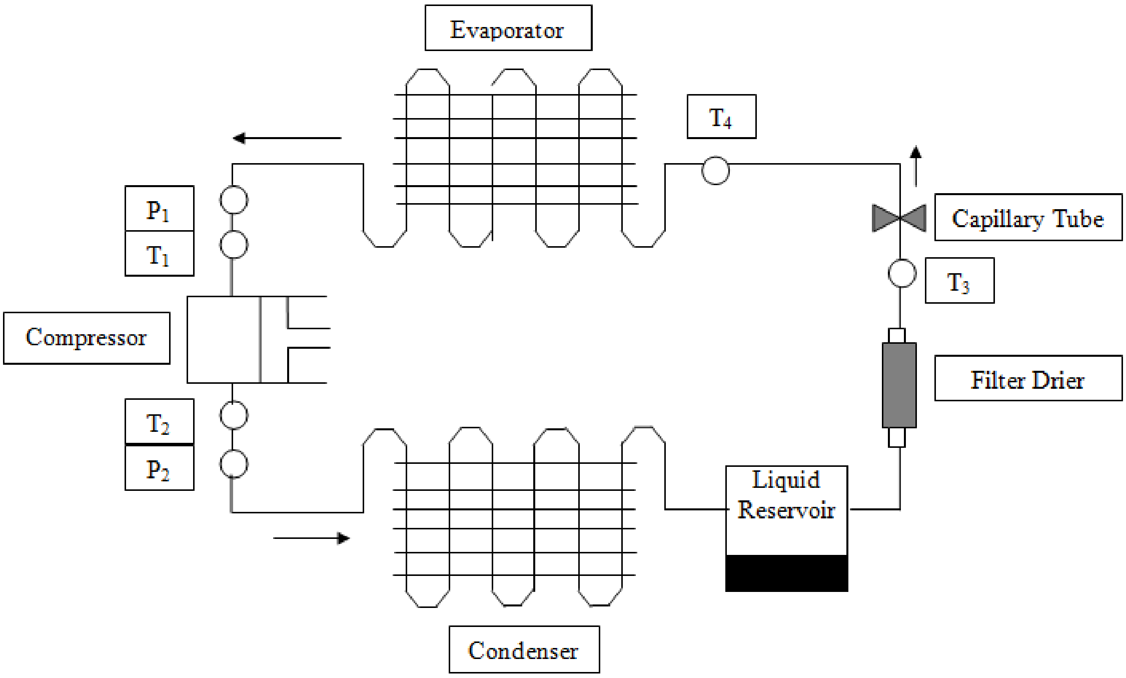

Fig. 1. Schematic diagram of the experimental set-up

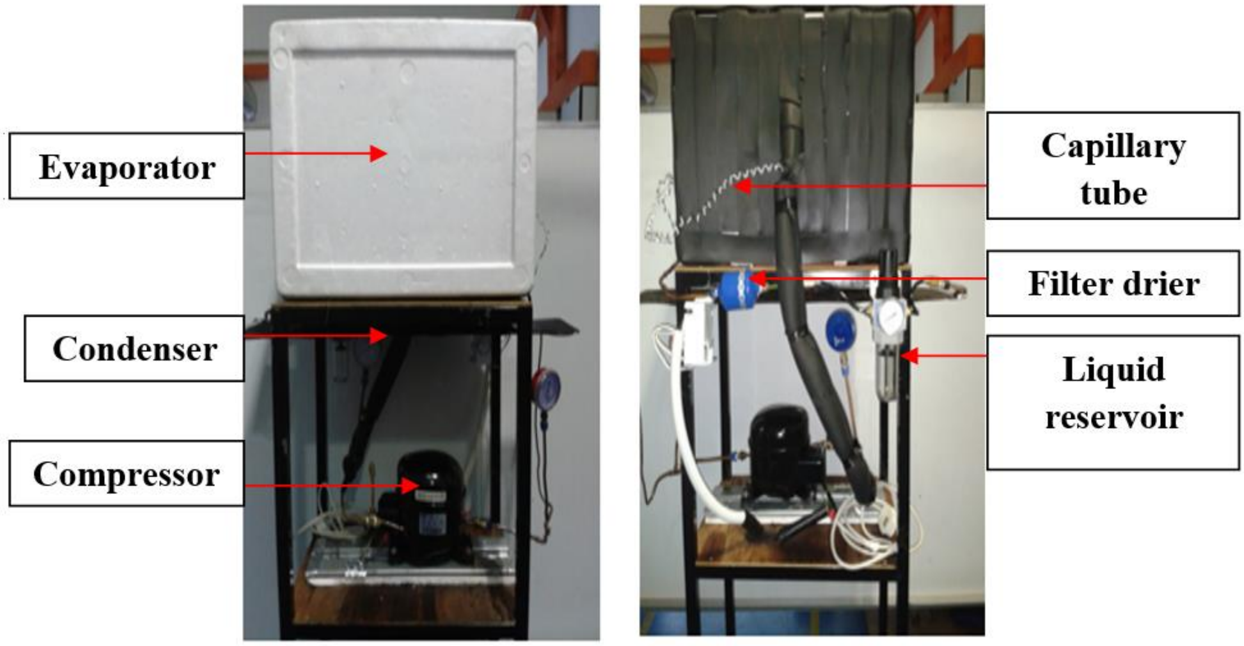

Fig. 2. Experimental test rig

The compressor is used to compress low vapour refrigerant gas and discharged out the higher-pressure gas to the condenser. The temperature will raise with the raise of pressure in the compressor. The condenser is a type of heat exchanger where the heat from the hot compressed air is removed and condensed into a liquid. The high-pressure liquid leaves the condenser and then enters the liquid reservoir. The liquid reservoir acts as a tank to insert nanolubricant and mix with refrigerant to produce nanorefrigerant to the entire system. The high-pressure liquid then flows through the filter drier before entering to the capillary tube. At the filter drier any particles/debris will be filtered out from entering /circulating into the refrigeration system. Inside a capillary tube, the liquid refrigerant flows through a small hole which causes a pressure drop. In the evaporator, heat from the surrounding is absorbed and the refrigerant begin to change it state from liquid to vapour. The low-pressure vapour refrigerant is then moved back to the compressor to complete the cycle. This cycle repeats so that the performance of refrigeration system in the system can be studied and analyzed. The temperature of the refrigerant in the evaporator can be set to a limit where it will be kept constant by the compressor being switched on and off by a thermostat in the system.

The power supply is powered by 220 volts to 240 volts to power the compressor with the current flow about 0.67 amps. The output voltage and current are measured using a multimeter. Thermocouples are used to get the temperature reading of refrigerant before entering the compressor and discharge out of the compressor. Thermocouples are also used to measure the temperature reading of the refrigerant at the line before entering the capillary tube and at the evaporator outlet. K-type thermocouples were used to measure all the temperature that is needed in this investigation. These thermocouples are then connected to a data logger for temperature monitoring with 0.1°C temperature drop. The potential difference is recorded and stored in the laptop for further analysis.

2.2 Nanofluid Preparation and Thermal Physical Properties Characterization

Nanolubricant is prepared using 2 step-method. Nanoparticles at certain nanoparticles volumetric weight is dispersed into the base fluid (lubricant) using Branson Sonifier Ultrasonic Liquid Processor for 1 hours, 450 W with 70% magnitude as shown in Figure 3. Figure 4 shows the steps for nanolubricant preparation. Nanolubricant is the mixture of base oil and nanoparticles which has its own mixing proportion to be able to obtain its concentration level of the nanolubricant.

Fig. 3. Sonication machine for nanofluid preparation

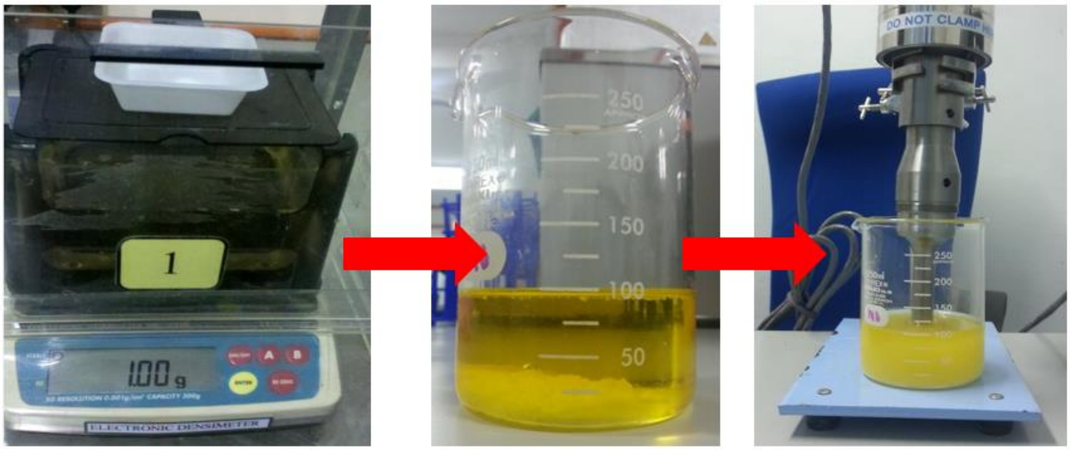

Fig. 4. Steps for nanofluid preparation

Eq. (1) and Eq. (2) are used to calculate the mass fraction of nanoparticles and volume fraction of nanolubricant [18]:

Mass fraction in the nanoparticle oil suspension,

$$\omega_{\mathrm{n}} = \frac{m_{\mathrm{n}}}{m_{\mathrm{n}} + m_{\mathrm{o}}} \tag{1}$$

Volume fraction of nanoparticle in the nanoparticle oil suspension,

$$\varphi = \frac{\omega_{\mathrm{n}}\rho_{\mathrm{o}}}{\omega_{\mathrm{n}}\rho_{\mathrm{o}} + (1-\omega_{\mathrm{n}})\rho_{\mathrm{n}}} \tag{2}$$

where ω is nanoparticle concentration in nanoparticle oil suspension, φ is volume fraction of nanoparticle in the nanoparticle oil suspension, m_{n} is mass nanoparticles used in grams (g), m_{o} is mass oil used in grams (g), ρ_{n} is the density of nanoparticles and ρ_{o} is density of oil.

Table 1 shows the mass of nanoparticles used to produce 0.1%-0.9% volume fraction of SiO_2/POE nanolubricant. Thermal physical properties of nanolubricant including thermal conductivity, viscosity, specific heat capacity and density are measured using Kd2Pro Thermal Properties Analyzer, Brookfield Rheometer DV3T-7-inch, electronic densimeter DH-300L and Differential Scanning calorimeter (DSC), respectively. During this investigation, the type of nanolubricant that is used and the base oil for the whole experiment are constant to avoid any errors during measurement process. The based oil which was used is polyolester (POE) oil. The detail properties of the base oil and nanoparticles are listed in Table 2 and Table 3, respectively. Figure 5 illustrates the flow chart of the methodology process.

Table 1
The mass of nanoparticles to produce the desired nanoparticles volume fraction (%)

	Volume fraction in the nanoparticle oil suspension, φ				
	0.001	0.003	0.005	0.007	0.009
Volume of oil (ml)	170	170	170	170	170
Nanoparticle concentration in the nanoparticle oil suspension, ω_{n}	0.0022	0.0068	0.0111	0.0156	0.0200
Mass of nanoparticles used (g)	0.37	1.14	1.87	2.64	3.40

Table 2
Emkarate® RL 68H refrigeration lubricant properties

Types	Emkarate® RL 68H
Density at 20°C	0.980 g ml^{-1}
Viscosity at 40°C	65.5 cSt
Flash point (COC)	270 °C

Table 3
Silicon dioxide nanoparticles properties

Chemical symbol	SiO_2
Size	<10nm
Chemical element composition	Content (%)
i. Silicon	46.83
ii. Oxygen	53.33
Density at 20°C	2.2 g cm^{-3}
Molar mass	60.08 g mol^{-1}
Melting point	1726°C
Boiling point	2230°C
Thermal conductivity at 300 K (W/cm·K)	0.014

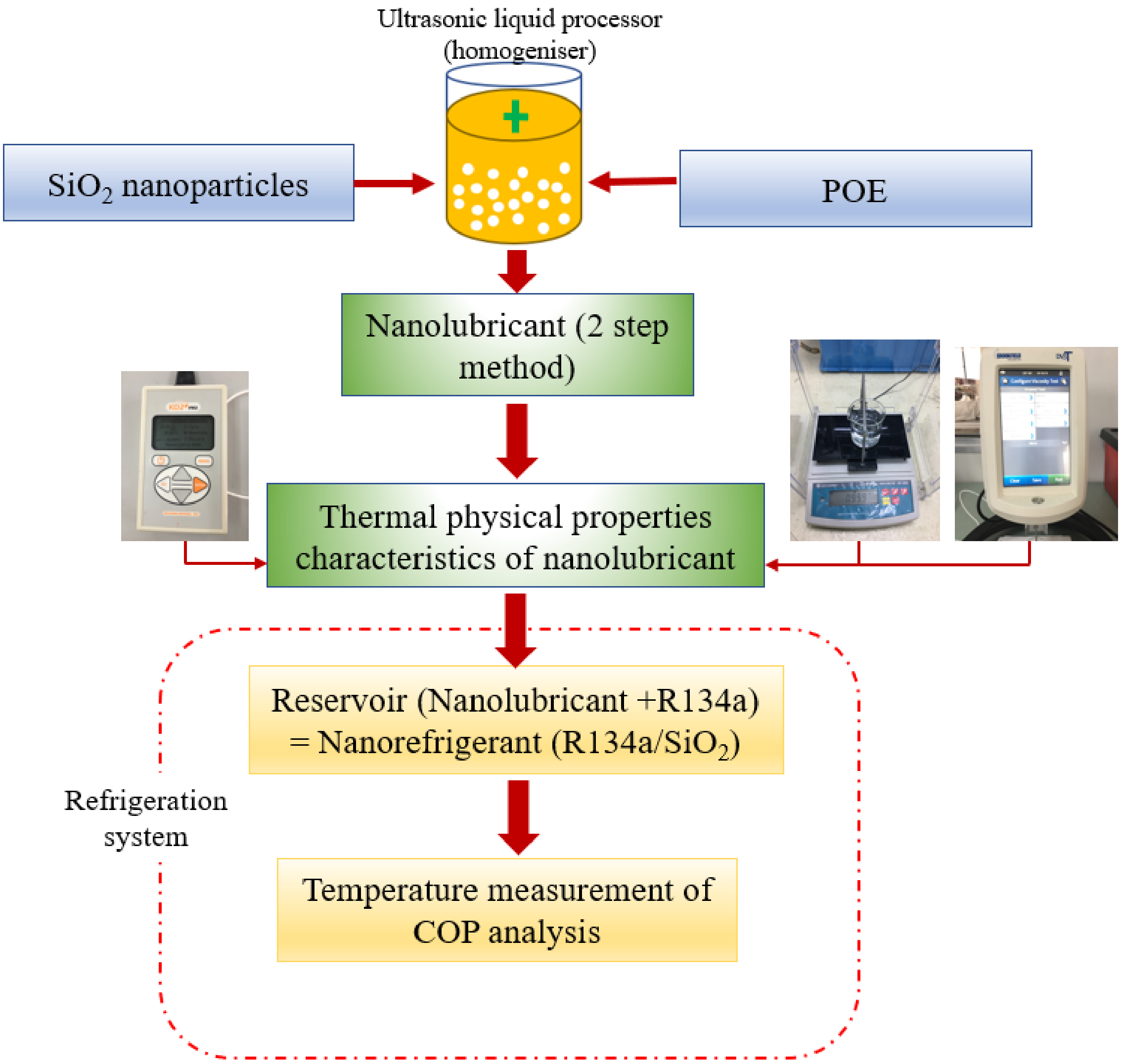

Fig. 5. Flow of nanolubricant and nanorefrigerant preparation and testing

2.3 Analysis Equation

Since the change of kinetic and potential energy of the fluid is negligible, and the compressor is adiabatic. Compressor work is calculated as follows [19]

$$W_\mathrm{c} = h_2 - h_1 \tag{3}$$

The heat rejection is calculated as

$$Q_\mathrm{c} = h_2 - h_3 \tag{4}$$

The Refrigerating effect is calculated as

$$Q_\mathrm{H} = h_1 - h_4 \tag{5}$$

Coefficient of performance (COP) is calculated as

$$\mathrm{COP} = \frac{Q_\mathrm{L}}{W_\mathrm{c}} = \frac{h_1 - h_4}{h_2 - h_1} \tag{6}$$

where, Wc is compressor work per unit mass [kJ kg^{-1}] and Q_L is refrigerating effect [kJ kg^{-1}].

3. Result and Discussion

3.1 Thermal Physical Properties of Nanolubricant Analysis

In order to make sure that all the equipment and sensors are in a good accuracy condition, calibration test have been conducted prior to use. All the uncertainties of the sensors and measurement equipment are listed in Table 4.

Table 4
Uncertainty of experimental instrument and sensors

Sensor	Number	Variable Measured	Model	Uncertainty
Thermocouple	8	Fluid temperature	K-type	0.1%
Pressure Gauge	2	Local liquid pressure	WIKA RS Pro	0.1%
Flow meter	1	Volumetric flow rate	Tube type	0.2%

From the sensors uncertainties, equation (7) is used to calculate the uncertainties of the COP and obtained value is 3.99% [20]. The value is lower than 10% in which indicates that the sensors and equipment for experimental setup is valid for analysis.

$$\delta_R = \pm\sqrt{\left(\frac{\partial R}{\partial x_1}\delta_{x_1}\right)^2 + \left(\frac{\partial R}{\partial x_2}\delta_{x_2}\right)^2 + \cdots + \left(\frac{\partial R}{\partial x_n}\delta_{x_n}\right)^2} \tag{7}$$

Figure 6 indicates the comparisons of thermal conductivity ratio values at 300 K. The values obtained from experimental are validated with Hamilton and Crosser model [21] and experimental data obtained from previous studies [22-24]. Based on the plots, the present experimental results are in good agreements with the previous studies which indicates that the thermal physical properties measurement and nanolubricant preparation process is valid for further analysis. All thermal physical properties of nanolubricant including thermal conductivity, viscosity, specific heat and density are shown in Figure 7 - Figure 10, respectively.

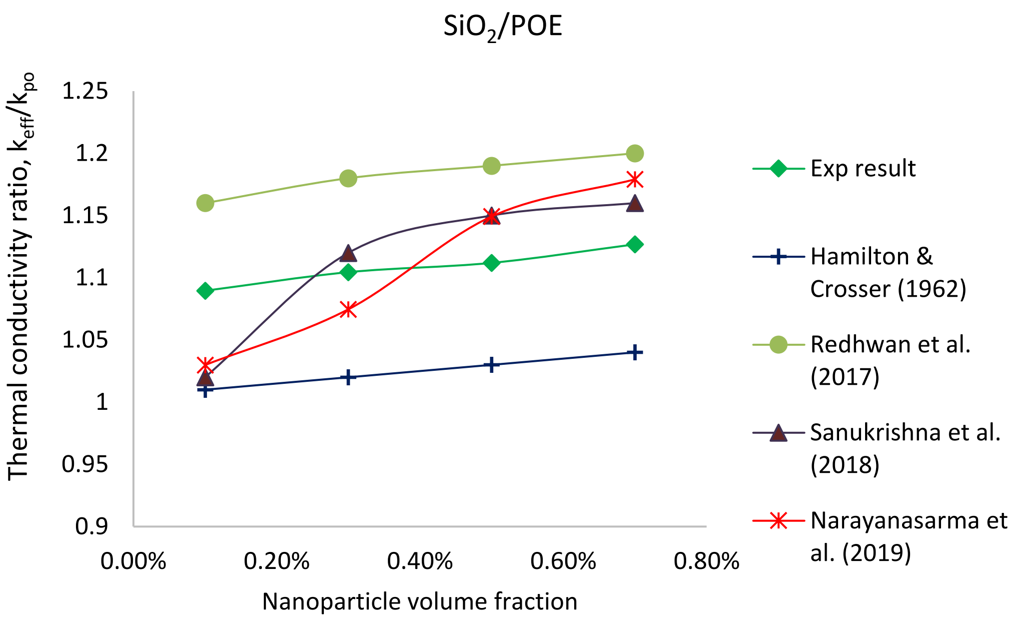

Fig. 6. Comparisons of thermal conductivity ratio for SiO_2 nanolubricant at 300 K

Thermal conductivity of nanolubricant is directly proportional to the heat transfer performance. From the experimental analysis, it shows that thermal conductivity of nanolubricant increased with increases of nanoparticle volume fractions. The enhancement of thermal conductivity can be varied due to the effects of volume fraction, nanoparticle types, refrigerant, particle sizes and particle shapes [25]. Figure 8 shows that thermal conductivity of SiO_2/POE nanolubricant decreases with increasing temperature and the values is increases with increasing particle volume fraction. Thermal conductivity is decreases due to expansion in liquid molecules at higher temperature and rapid Brownian motion at higher nanoparticles volume fraction causes higher thermal conductivity. Higher thermal conductivity of working fluid can give higher cooling rate to the refrigeration system [26].

The enhancement of viscosity of nanolubricant can be varied due to the size, shape and volume fractions of nanoparticles in nanolubricant. Figure 8 shows the variation of viscosity of nanolubricant with increasing volume fraction and temperature. The viscosity of nanolubricant increased with the increases volume fraction. However, if the nanofluids are not well-dispersed, then clogging occur in which effect the viscosity of a particular nanofluid [27]. The increase in viscosity causes higher pumping power and pressure drop of a fluid in which they are directly proportional to each other. For example, with R134a+0.9%SiO_2 nanorefrigerant, the cooling load temperature is reduced from 29.1°C to -4.4°C. It shows that, the temperature drop at evaporator inlet is smaller compared to other nanoparticles volume fraction because of higher viscosity of the nanolubricant. It can be concluded that, the viscosity of nanofluids has a strong relationship with base fluids and volume fraction of nanoparticles used in order to produce the most optimum viscosity value. Hence, determining the optimum value of nanoparticle volume fraction is crucial in the effort to find the balance between the increase in thermal conductivity and viscosity. Increase in particle volume fraction also causes higher density of nanolubricant as shown in Figure 9. This is because SiO_2 nanoparticles are initially having much higher density compared to POE. However, as temperature increases, the density of nanolubricant are decreasing. This is because, as the temperature is slightly increases, the nanolubricant molecules will be rapidly moves, bumping into each other and creates higher distance between the molecules. Hence, the liquid will be less dense. Specific heat capacity of nanolubricant is increases with increased temperature as shown in Figure 10 because the energy need to be released as temperature increases [28]. However, specific heat of POE lubricant is initially lower than SiO_2 nanoparticles. Hence, adding more nanoparticles into the base oil will cause lower specific heat to the nanolubricant. Saeedinia *et al.,* [29] carried out an investigation for the suspension of CuO nanoparticles in Pure Engine Oil (PEO). From the result, specific heat of that nanofluids decreases with the increase of nanoparticle volume fraction. Shin and Banerjee [30] also shows the similar trend in result in which they reported that the specific heat capacity of alkali metal chloride salt mixed with SiO_2 nanoparticles increased up to 14.5% by using 1% nanoparticle volume fraction compared to pure salt.

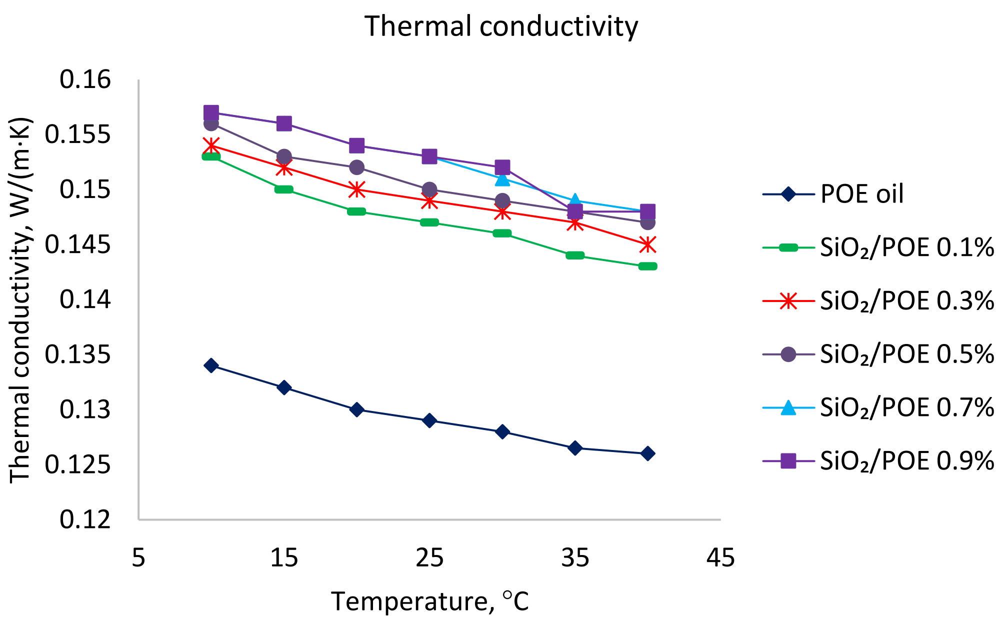

Fig. 7. Variation of thermal conductivity of nanolubricant with increasing temperature

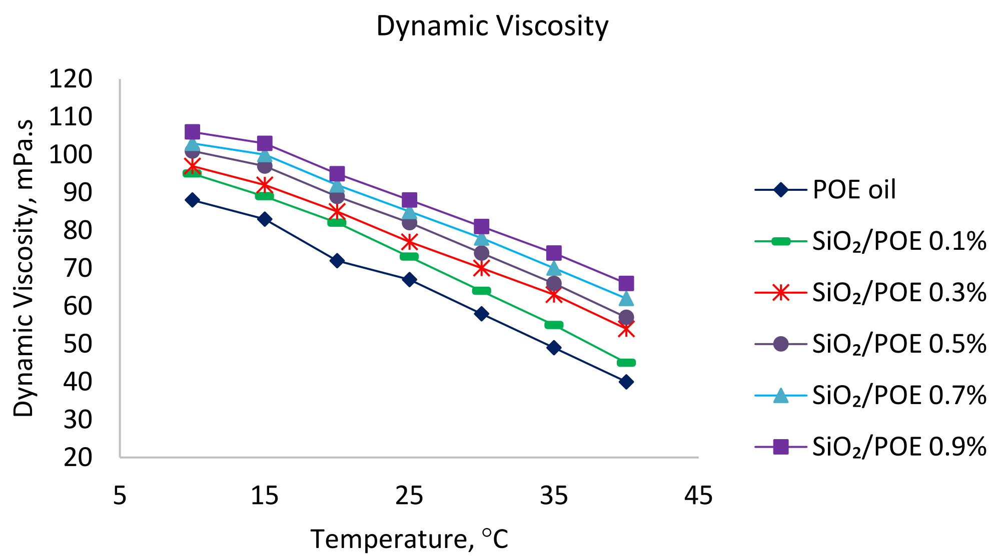

Fig. 8. Variation of dynamic viscosity of nanolubricant with increasing temperature

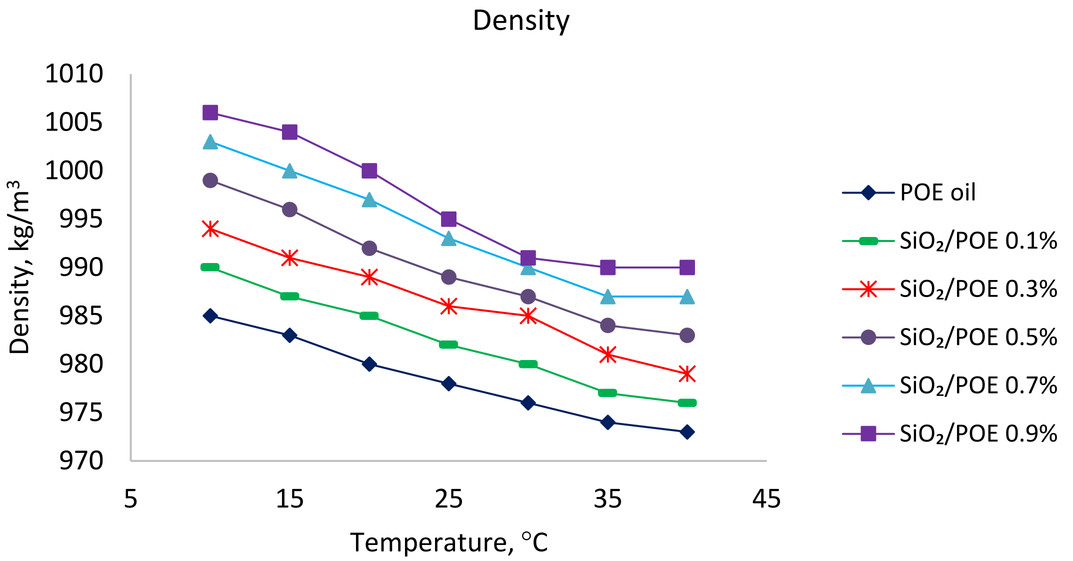

Fig. 9. Variation of density of nanolubricant with increasing temperature

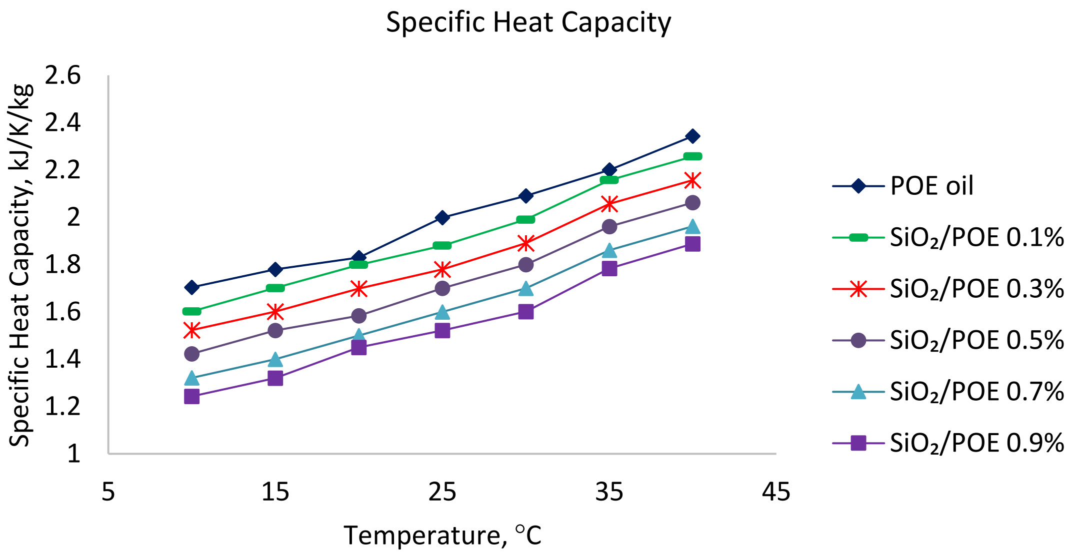

Fig. 10. Variation of specific heat capacity of nanolubricant with increasing temperature

3.2 Thermal Performance of Nanorefrigerant Analysis

After analyzing thermal physical properties of nanolubricant, it will be then transferred into the refrigeration system. The temperature analysis in the refrigeration system will be focused on the working fluid of the refrigeration system which is (R143a/SiO_2) nanorefrigerant. Figure 11 shows the comparison between pure refrigerant R134a with nanorefrigerant at five different volume fractions. From the plots, R134a+0.5%SiO_2 nanorefrigerant gives the highest cooling rate, followed by by R134a+0.3%SiO_2 nanorefrigerant and lastly is R134a+0.1%SiO_2 nanorefrigerant which means that nanorefrigerant has a very good potential for future usage in industries to increase the efficiency of COP. Nanoparticle volume fraction effect the variation of cooling load temperature with respect to time. The temperature decreases as the time increases. This is because as the liquid refrigerant enters the evaporator, the liquid refrigerant at a sufficiently low pressure and low temperature from the expansion device will drop the temperature at evaporator. In expansion device which is capillary tube, a large amount of heat has been extracted from the liquid refrigerant through the process. Regarding from the figure above, the time required for reducing the temperature of the cooling load of R134a+0.5%SiO_2 nanorefrigerant is less compared with pure refrigerant and others. For example, with R134a+0.5%SiO_2 nanorefrigerant and the time required is 40 minutes, the cooling load temperature reduce from 30.9°C to -12.5°C whereas that with pure refrigerant and R134a+0.1%SiO_2 is reduce from 29.8°C to -10.8°C and from 29.2°C to -11.4°C, respectively. A large amount of heat loss within 40 minutes is occurred at evaporator inlet when the volume fraction of nanorefrigerant is added up to 0.5% of nanorefrigerant. This is because of the good potential of nanofluids in heat transfer coefficient by using silicon dioxide, SiO_2 nanoparticles. Since the SiO_2 nanoparticles have much higher thermal conductivity than refrigerant, the suspension of nanoparticles will produce higher thermal conductivity and enhance the heat transfer performance.

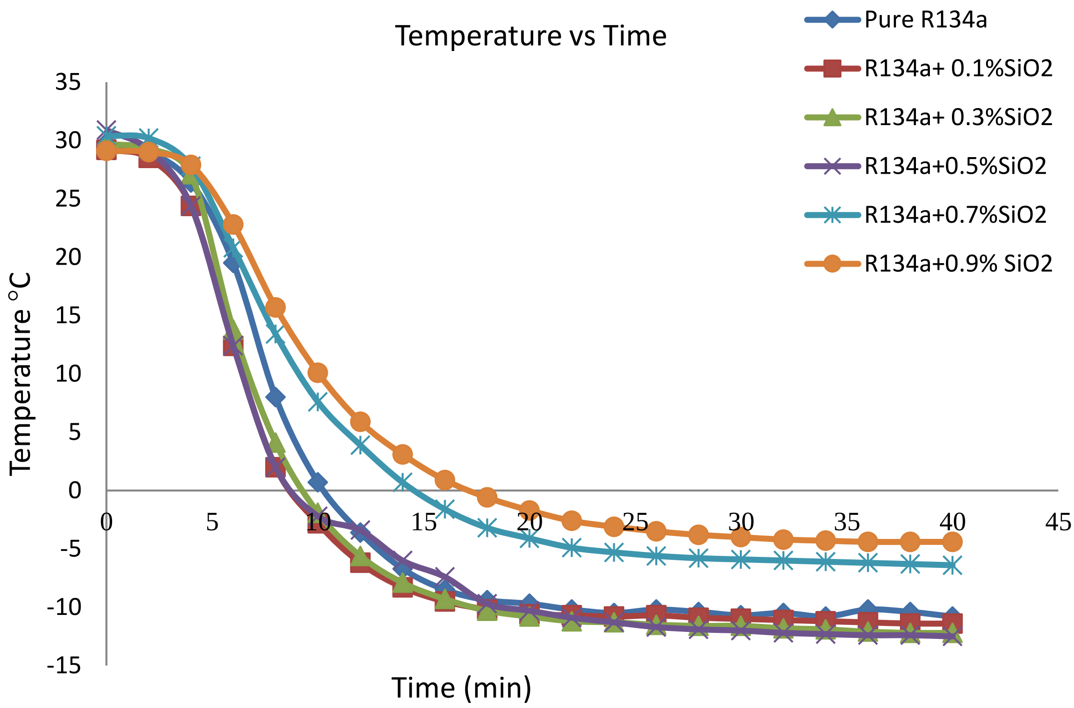

Fig. 11. Variation of temperature with time

Figure 12 shows the variation of temperatures at the compressor dome at five different nanoparticles volume fraction. From the chart, temperature at compressor dome shows a decreasing pattern when the nanoparticles volume fraction is increased up to 0.5%, and after the limiting value, the temperature is increase. The result shown that, the temperature of the compressor dome is decrease about 1°C for R134a+0.1%SiO_2 nanorefrigerant, 1.7°C for R134a+0.3%SiO_2 nanorefrigerant and the corresponding decrease in temperature about 2.3°C with R134a+0.3%SiO_2 nanorefrigerant, respectively. This is caused by the reduction of friction with nanolubricant inside the compressor. The friction occurred due to higher viscosity of working fluid that causes higher internal resistance within the working fluid. Results indicate that the temperature of the compressor dome decreases as the particle volume fractions increase. Hence, lowering the temperature of the compressor dome, will give better stability of the compressor oil that increase the compressor life.

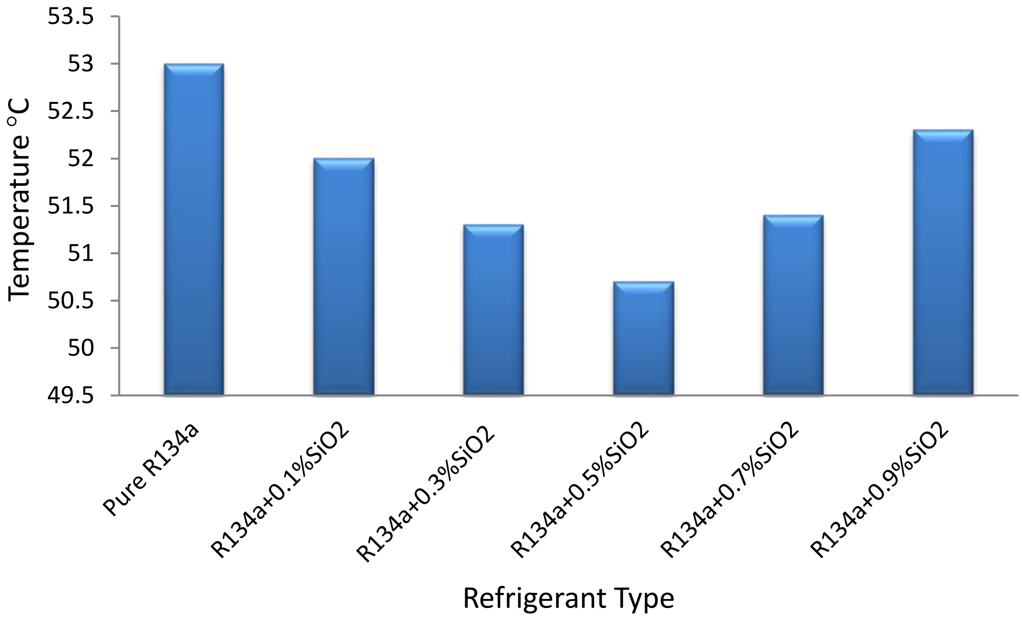

Fig. 12. Variations of temperature at the compressor dome

By increasing nanoparticle volume fraction up to 0.7%, the temperature of the compressor dome increases from 50.7°C at 0.5%SiO_2 to 51.4°C while for nanoparticles volume fraction of 0.9% increases the temperature from 50.7°C to 52.3°C. It can be concluded that the maximum of the SiO_2 nanoparticles that can be added in this experiment is 1.87 gram which equals to 0.5%SiO_2 of volume fractions. This is because when added more than 0.5% of volume fractions, the stability and nanoparticles' dispersion in base fluid become poor due to partial homogeneity. Besides, if the nanoparticles are not well-dispersed in the lubricant, then agglomeration or clogging would occur and result to higher temperature of the compressor dome.

Condensation is a process of changing a vapour into a liquid by removing heat of the high-pressure vapour refrigerant discharged from the compressor. This process is known as an internally reversible condensation [31]. The high-pressure vapour refrigerant is then condensed by the condenser coils at constant pressure and it will become high-pressure liquid. Therefore, the experiment was conducted to calculate the reduction in refrigerant temperature while passing through the condenser by using a pure refrigerant and nanorefrigerant at five different volume fractions. The results of the reduction in refrigerant temperature while passing through the condenser is measured by subtracting the temperature at compressor outlet with temperature at before entering capillary tube (T_2-T_3). The results are shown in Figure 13. The chart shows the reduction in refrigerant temperature while passing through the condenser for a pure refrigerant and nanorefrigerant with five different nanoparticles volume fraction. From the chart, temperature passing through the condenser is increases with increasing nanoparticles volume fraction up to 0.5% and after the limiting nanoparticle volume fraction value, the temperature is decreases.

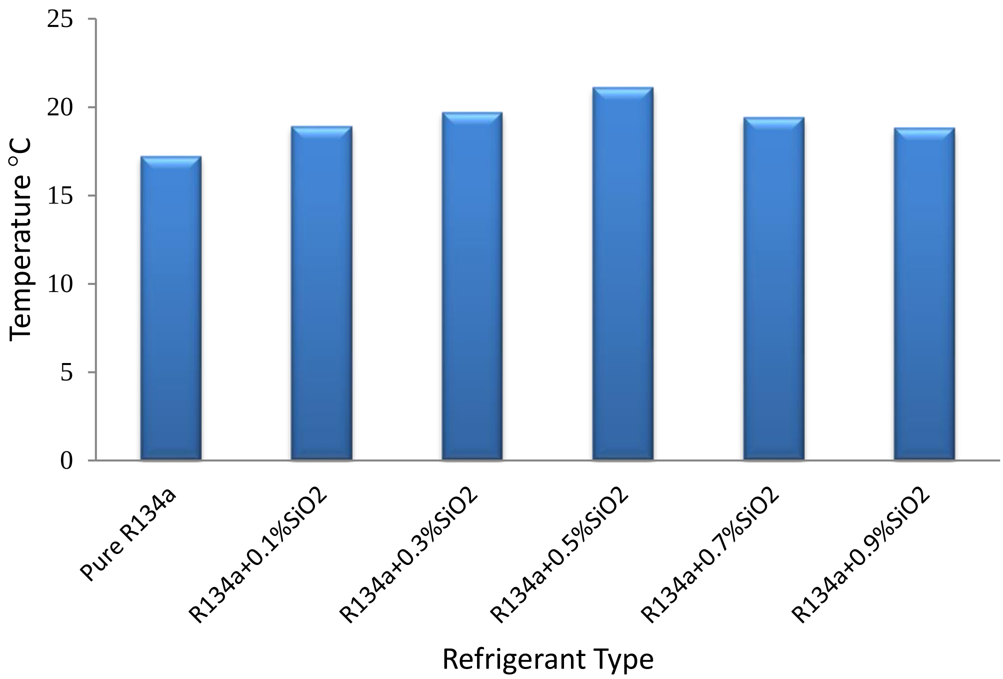

Fig. 13. Reduction in refrigerant temperature while passing through the condenser

The temperature of the refrigerant at the inlet of the condenser is in the range between 52°C to 59°C. For instance, with R134a+0.5%SiO_2 of nanorefrigerant, the temperature at the outlet of condenser is 31°C and the reduction from the inlet of condenser obtained is 21.1°C. It clearly shows that the enhancement of heat transfer in the condenser is due to the presence of nanoparticles in the refrigerant. In actual condensers, the pressure drop is usually very small caused by fluid friction and heat transfer from the surroundings to the refrigerant can be very significant. When the volume fractions of nanorefrigerant is increases, the reduction in refrigerant temperature while passing through the condenser is also increase due to the low pressure at the condenser. Therefore, lowering the operating pressure of the condenser will consequently result to lower temperature of the nanorefrigerant.

For refrigeration performance analysis, temperature at four points of interest are measured and analyzed. The temperatures values at four points of interests are listed in Table 5. T_1 and T_2 refer to the temperature at compressor inlet and temperature at compressor outlet. Whereas T_3 is temperature at outlet condenser or temperature at before entering the capillary tube and T_4 is temperature at evaporator outlet. Then, the experimental setup is run under the ambient temperature by using different type of refrigerant. The results show that by using R134a+0.5%SiO_2 nanorefrigerant, the temperature at compressor outlet and condenser outlet are lower than pure R134a. The reduction in refrigerant temperature while passing through the condenser is also increased by 9.0%, 12.7% and 18.5% by using R134a+0.1%SiO_2, R134a+0.3%SiO_2 and R134a+0.5%SiO_2 naorefrigerant. The temperature at evaporator inlet is similarly increased for those cases. But, with the same operating parameters which is different type of refrigerant used, the COPs values are higher for R134a+0.1%SiO_2, R134a+0.3%SiO_2 and R134a+0.5%SiO_2 nanorefrigerant, whereas lower for R134a+0.7%SiO_2 and R134a+0.9%SiO_2 nanorefrigerant. When the volume fraction increased up to 0.9%, the reduction in refrigerant temperature while passing through the condenser is increasing causes lower COP values obtained as compared to pure R134a. So, larger drop of temperature across the condenser does not guarantee that COP of the refrigeration system will increase.

Table 5
Result at four points of interest

Description	Pure R134a	R134a+ 0.1% SiO_2	R134a+ 0.3% SiO_2	R134a+ 0.5% SiO_2	R134a+ 0.7% SiO_2	R134a+ 0.9% SiO_2
Temperature at compressor inlet, (T_1)	-15.2	-15.6	-16.0	-14.0	-17.2	-16.9
Temperature at compressor outlet, (T_2)	58.5	54.5	56.2	52.1	54.5	56.0
Temperature at before entering capillary tube, (T_3)	41.3	35.6	36.5	31.0	35.1	37.2
Temperature at evaporator outlet, (T_4)	-10.8	-11.4	-12.2	-12.5	-6.4	-4.4

Table 6. shows all the enthalpies at four points of interest for each condition that is obtained from experimental. The enthalpies values are then used to calculate COP. Figure 14 shows the comparison of all six different types of refrigerants in this investigation of performance of refrigeration system. From the chart, increasing nanoparticle volume fraction up to 0.5%, the COP value is increase, and later decrease when the nanoparticle volume fraction is increase up to 0.9%. The use of R134a+0.5%SiO2 shows 19% increment in the COP value compared to pure refrigerant. The enhancement of COP of refrigeration system is due to the effectiveness of compressor and evaporator. This is because by eliminating the highest heat produced in the evaporator and lowering the net work done by compressor, it will increase the cooling effect. The coefficient of the net work done by compressor is drop causes the reduction in temperature and pressure of discharge compressor.

Figure 15 illustrates the differences between pure refrigerant R134a with R134a+0.5%SiO_2 nanorefrigerant on *P-h* diagram. Enthalpy is shown as enthalpy per unit mass. COP is calculated by dividing the enthalpy change in evaporation, dh_1 to the enthalpy change in compression, dh_2. Four points of interest are focused for the performance analysis in which the combination of two sequence points produces one phase in the system. Based on the diagram, there are four major phases including compression, condensation, expansion and evaporation. Two major phases that shows a significant difference between pure and nanorefrogerant are compression and evaporation. The first phase is from point 1 to point 2 which is a reversible adiabatic compression. Compressor will compress the refrigerant/ nanorefrigerant vapour and caused the raising in pressure value.

Table 6
Enthalpy values at four points of interest

	Enthalpy (kJ/kg)				Pressure (psi)		Coefficient of Performance (COP)
	h_1	h_2	h_3	h_4	P_1	P_2	
Pure R134a	394	436	258	258	3	168	3.24
R134a+0.1%SiO_2	393	435	249	249	3	165	3.43
R134a+0.3%SiO_2	395	434	250	250	3	159	3.72
R134a+0.5%SiO_2	395	433	243	243	3	158	4.00
R134a+0.7%SiO_2	392	435	248	248	3	160	3.43
R134a+0.9%SiO_2	393	437	251	251	3	170	3.23

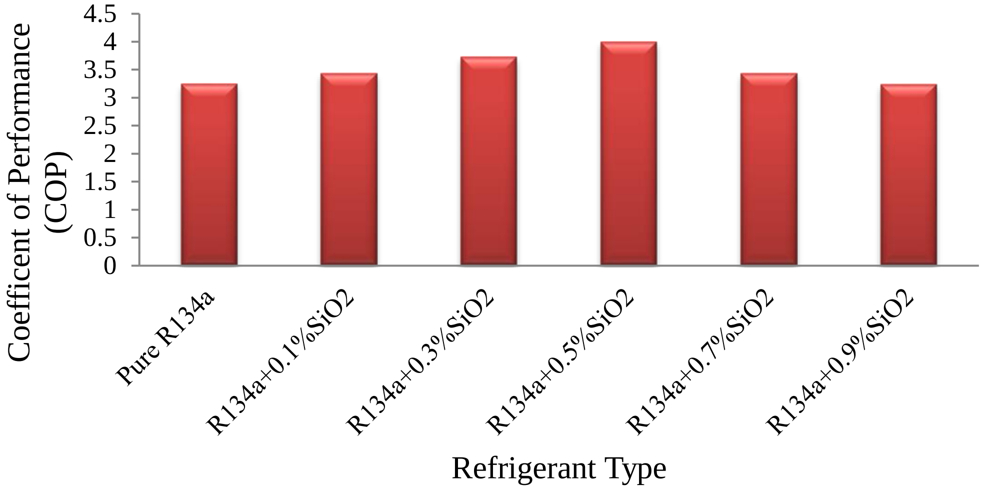

Fig. 14. Comparison of coefficient of performance of the six different types of refrigerants

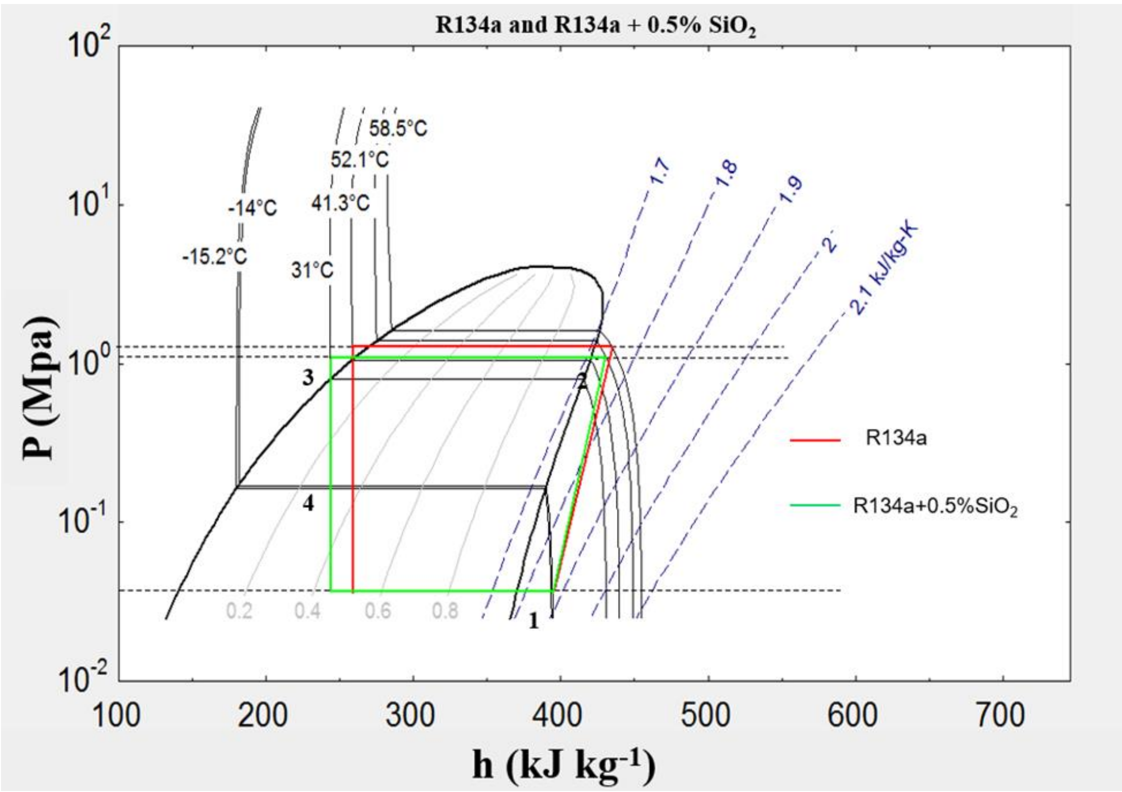

Fig. 15. P-h diagram of vapour compression refrigeration cycle for pure refrigerant R134a with R134a+0.5%SiO_2 nanorefrigerant

When experiment is conducted using pure refrigerant R134a, the low pressure is 0.02 MPa at inlet of compressor and then the refrigerant pressure discharge from compressor is 1.16 MPa. When the same experiment is conducted using R134a+0.5%SiO_2 nanorefrigerant, the low pressure at inlet of compressor is maintain around 0.02 MPa but the pressure discharge from compressor is reduce to 1.09 MPa. Hence, R134a+0.5%SiO_2 nanorefrigerant shows the improvement in pressure drop by 6.4%. Therefore, the enthalpy is decrease as the pressure is reduced. The enthalpy decrease would be due the lower heat gain by the refrigerant in the compressor. The heat is produced when the compressor is running cause of internal resistance in lubricant oil inside the compressor. The existing heat may play a role in raising the pressure of refrigerant. The result also shown that, the temperature of discharge compressor for pure refrigerant R134a is 58.5°C and for R134a+0.5%SiO_2 nanorefrigerant is 52.1°C. So, it observed that by using R134a+0.5%SiO_2 nanorefrigerant, the temperature of discharge temperature is lower than using pure R134a. The temperature drop through the compressor is also increased by 12.3% for R134a+0.5%SiO_2 nanorefrigerant. This is due to the reduction of friction with nanolubricant inside the compressor. Lowering the friction, reduce heat generated by compressor and automatically lowers the temperature of the refrigerant. Therefore, the lower the temperature of the compressor the higher the stability of the compressor oil and reduce the operating pressure of the compressor. So, based on these both factors which is pressure and temperature of discharge compressor, it will affect the enthalpy change in compression. The results show that, the enthalpy change in compression, dh_2 for R134a+0.5%SiO_2 naorefrigerant is lower compared to the pure refrigerant R134a. It can be concluded that the higher efficiency of compressor can be shown by the decrement of the enthalpy change in compression.

Second phase is between points 4 and 1, this process is known as an internally reversible. Constant pressure heat interaction in which the working fluid is evaporated to be a saturated vapour at point 1. In the evaporator of a refrigeration system, the refrigerant absorbs heat and boils, producing a low-pressure saturated vapour. For R134a+0.5%SiO_2 nanorefrigerant, the enthalpy changes in evaporation, dh_1 increases compared with pure refrigerant R134a due to the decrease of temperature at outlet condenser. For instant, with R134a+0.5%SiO_2 nanorefrigerant, the temperature at the outlet of condenser is 31°C. Whereas, for pure refrigerant R134a, the outlet of condenser temperature obtained is 41.3°C. It clearly shows that the enhancement of heat transfer in the condenser is due to the presence of nanoparticles in the refrigerant.

4. Conclusion

The aims of the research are to find the relationship between nanoparticle volume fraction to the COP of the system. Hence, the conclusions that are obtained from the research are

i. Through this experiment, COP of nanorefrigerant in refrigeration system is possible to be analysed by dispersing nanoparticles into lubricant and mixing the nanolubricant with refrigerant in the reservoir attached to the experimental rig.
ii. Increase particle volume fraction of nanolubricant result to higher thermal conductivity, viscosity and density, and lower specific heat capacity. Hence, finding the most optimum particle volume fraction is crucial in order to find the balance value between thermal conductivity and viscosity.
iii. Highest COP of 4 is obtained for R134a+0.5%SiO_2. Increasing nanoparticle volume fraction up to 0.9% causes decrement in COP values. R134a+0.9%SiO_2 shows 0.01% lower COP compared to pure refrigerant.
iv. The results of R134a+0.5%SiO_2 nanorefrigerant increase in the effectiveness of compressor and evaporator by eliminating the highest heat and lowering the net work done, respectively.
v. The results of R134a+0.9%SiO_2 shows that when the volume fraction is increased to 0.9%, the temperature at the evaporator inlet has been decreased. Therefore, the specific heat of refrigerant also decreased. Hence, cooling effect and COP of refrigeration system is further reduced.

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