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by Dandi Irwansyah

This study has investigated the effects of silicon dioxide (SiO_2) and zinc oxide (ZnO) nanoparticles addition separately on refrigeration machine system in terms of Coefficient of Performance (COP). This study has focused on POE lubricant, R600a refrigerant, and nanoparticles (separated SiO_2 and ZnO) in the refrigeration system. SiO_2 and ZnO nanoparticle were added separately in R600a refrigerant with a mass of 0.5 g, 1.0 g, and 1.5 g, respectively. The experimental results showed that 1.5 g SiO_2 yielded an increase of 25.88% COP while 1.0 g ZnO yielded an increase of 13.6% COP, both values showed the highest increased. Moreover, 1.5 g SiO_2 caused a decrease of 25.58% energy consumption, while 1.5 g ZnO caused a decrease of 16.28% energy consumption. This study applied 20 g refrigerant and 500 ml POE lubricant. The experiment reveals that refrigerant with nanoparticles yielded better results than normal R600a refrigerator free of nanoparticles.

1. Introduction

Nanotechnology is a branch of science and technology strongly related to rearrangement of particle sizes. In general, particles sizes can be distinguished by their diameter, i.e., coarse particles (10000–2500 nm), fine particles (2500–100 nm), and ultra- fine particles or nanoparticles (1–100 nm) [1].

Nano refrigerant is a type of nanofluid, where the basic fluid is a conventional pure refrigerant. Experimental studies reported that nano refrigerants have higher thermal conductivity than conventional refrigerants. In addition, refrigeration systems using nano refrigerants have better refrigeration performance than those using conventional pure refrigerants [2].

There are three main reasons that nanoparticles are used as part of refrigerant, i.e. (i) nanoparticles can increase the solubility between lubricant and refrigerant, (ii) nanoparticles increase thermal conductivity and heat transfer of the refrigerant, and (iii) nanoparticles disperse in the lubricant reducing the coefficient of friction and wear rate [3].

Senthilkumar, et al. [4] conducted research on refrigerant R600a, mineral oil, and hybrid nanoparticles (SiO_2+ZnO) added to a refrigeration machine with a volume fraction of 0.4 g/L and 0.6 g/L and a refrigerant mass of 40 g and 60 g. The results for a mass of 40 g refrigerant with a volume fraction of 0.2 g/L and 0.4 g/L obtained an increase in COP of 30% and 45%, respectively, and for a mass of 60 g refrigerant with a volume fraction of 0.2 g/L and 0.4 g/L obtained an increase in COP of 8% and 31%, respectively.

Senthilkumar, et al. [5] reported a research on R600a refrigerant, POE lubricant, and SiO_2 nanoparticles added to a refrigeration machine with volume fractions of 0.2 g/L and 0.4 g/L and refrigerant mass fractions of 30 g, 40 g, and 60 g. For a volume fraction of 0.2 g/L and 0.4 g/L, the results of 30 g refrigerant found an increase of COP as 56% and 33%, respectively; results of 40 g refrigerant yielded COP increase as 11% and 50%, respectively; and using 60 g refrigerant caused COP increase as 43% and 14%, respectively.

Sumit Shinde, et al. [6] conducted a study on the effect of nanoparticles in vapor compression refrigeration systems (VCRS). In this study SiO2 nanoparticles (15-20 nm) was used as an additive in refrigerants and lubricating oils. SiO_2 nanoparticles were added to refrigerant and lubricant to make nano refrigerant and mineral oil with volume fractions of 0.1, 0.2 and 0.3%. The results showed that the COP of the related volume fractions increased by 6.97, 9.9, and 12.68%.

N.S. Desai, et al. [7] conducted a study on the application of SiO_2 nanoparticles as a lubricant additive in VCRS. They observed that at SiO_2 concentrations of 1, 2 and 2.5% in POE oil, the compressor worked at 0.45, 0.4245 and 0.4327 kW yielding COP increased by 7.61, 14.05 and 11.90%.

Sakshi Mishra, et al. [8] conducted research on 20 nm - 50 nm CuO nanoparticles used as nano-lubricant for refrigeration test performance studies. Nanoparticles with a mass fraction of 0.30, 0.70, 1.05 and 1.40% were added to compressor oil and showed a significant increase in the performance of refrigeration system. Compressor work was reduced, and the COP of refrigeration system increased.

Kuljeet Singh, et al. [9] has investigated the performance of nano refrigerant-based refrigeration systems (R134a + Al_2O_3). The study applied Al_2O_3 nanoparticles (diameter 20 nm) with 0.5 and 1.0% volume fractions dispersed in R134a refrigerant. Applying 0.5% Al_2O_3 the COP increased by 8.5%

and applying 1.0% Al_2O_3 the COP was reduced by 5.4%, the effectiveness of the condenser and evaporator increased in the case of R134a + 0.5% Al_2O_3.

With regard to the report of previous studies, this investigation attempts to analyze the refrigeration machine performance in terms of COP and energy consumption upon the addition of SiO_2 and ZnO nanoparticles in POE lubricant and R600a refrigerant in refrigeration system. This study used SiO_2 and ZnO with mass fractions of 0.5, 1.0, and 1.5 g, respectively, 500 ml POE (polyolester) lubricant, and 20 g R600a refrigerant (isobutane). In this study, the discussion strongly emphasized on chemical properties related to molecular interactions between nanoparticles, lubricant, and refrigerant, and therefore, it can be viewed as the strength of this study or any novelty that in authors' view such comprehensive and thorough discussion was not reported previously. In addition, the reason of using isobutane refrigerant in this study is related to issue of low global warming and zero potential of ozone depletion that currently this hydrocarbon selected as the popular choice for commercial domestic refrigerant purpose. Moreover, the reasons of using R600a are: (i) It has friendly environmental effects, (ii) It causes low energy consumption, (iii) It is compatible with any lubricant, and (iv) It shows good thermodynamic behaviour.

2. Experimental and Procedures

Initially, the nanoparticles were mixed with POE lubricant and then fed into the compressor as the refrigeration system. The POE is commonly used as lubricant in the refrigeration system due to its superiority and quality [10-12]. The mixture of nanoparticles and lubricant gives significant effect on refrigeration machine performance.

Figure 1 shows the device used in this study. The working procedures are presented by consecutive steps as follows: (i) SiO_2 nanoparticles (0.5, 1.0 and 1.5 g) were mixed with 500 ml POE lubricant, (ii) The similar step was repeated for ZnO nanoparticles, (iii) The mixture of nanoparticles and POE lubricant was stirred using a magnetic stirrer for 3h until obtained a well-dispersed nanoparticles/POE lubricant oil, (iv) The mixture from step (iii) was ready for preparation and testing using an experimental test rig and the experimental test rig was cleaned from any dust and moisture using a vacuum pump,

Figure 1. Experimental Test Rig

(v) The refrigeration machine performance was initially measured for pure R600a refrigerant (20g) as the basic data, (vi) Nano lubricant with a mass of 0.5 g, 1.0 g, and 1.5 g in 500 ml oil was then added to 20 g refrigerant R600a using a filling line attached to refrigerant system, (vii) Temperatures in several parts of the experimental test rig were measured using a digital thermometer. The suction pressure and discharge pressure on the compressor were measured with a pressure gauge, (viii) The temperature data before entering and after leaving compressor (T1 and T2), and before entering expansion valve (T3), as well as pressure data before entering and after leaving compressor (P1 and P2) were all needed for enthalpy data in the calculation of RE, WC, and COP, respectively, (ix) The temperature and pressure data were taken at 30 min. for all experiments considering the results, and (x) The COP was obtained using the temperature and pressure data from step 9 above to get the enthalpy data, i.e., h1, h2, and h3 applying a Thermodynamics & Transport Properties calculator.

The Refrigerant Effect (RE) values can be obtained from equation (1)

$$RE = h2 - h1 \qquad (1)$$

The Work Done by Compressor (WC) values can be obtained from equation (2)

WC = h3 – h2 (2)

The COP values can be obtained from equation (3)

$$COP = \frac{(h2-h1)}{(h3-h2)} \quad (3)$$

Some of the parameters used in this experiment are:
P1 = Condensing pressure (bar)
P2 = Evaporating pressure (bar)
T1 = Inlet temperature compressor (°C)
T2 = Outlet temperature compressor (°C)
T3 = Inlet temperature expansion valve (°C)
h1 = Inlet temperature compressor enthalpy (kJ/kg)
h2 = Outlet temperature compressor enthalpy (kJ/kg)
h3 = Inlet temperature expansion valve enthalpy (kJ/kg)
RE = Refrigerant Effect (kJ/kg)
WC = Work Done by Compressor (kJ/kg)
COP = Coefficient of performance

3. Results and Discussion

3.1 Results of Refrigeration Machine Performance

Table 1 shows the Refrigerant Effect (RE), Work Done by Compressor (WC), Coefficient of Performance (COP) and Energy Consumption (EC) from the testing results of refrigeration machine with the addition of nanoparticles + POE oil in R600a refrigerant where test reading times were carried out at intervals 30 min.

Table 1. Result of experiment with nanoparticles and POE Oil

Description	RE kJ/Kg	WC kJ/Kg	COP	EC Watt
Pure Refrigerant (Without Nanoparticles)	238.9	104.73	2.28	43
Refrigerant + POE Oil + Nanoparticles SiO_2 (0.5 g)	249.81	100.86	2.48	41
Refrigerant + POE Oil + Nanoparticles SiO_2 (1.0 g)	248.25	93.63	2.65	36
Refrigerant + POE Oil + Nanoparticles SiO_2 (1.5 g)	257.81	89.83	2.87	32
Refrigerant + POE Oil + Nanoparticles ZnO (0.5 g)	243.16	101.38	2.4	41
Refrigerant + POE Oil + Nanoparticles ZnO (1.0 g)	248.1	95.73	2.59	36
Refrigerant + POE Oil + Nanoparticles ZnO (1.5 g)	247.04	96.85	2.55	36

3.2 Effect on Refrigerant Effect with the addition of nanoparticles and POE Oil

There was an increase in refrigerant effect with the addition of nanoparticles + POE oil shown in Table 2.

Table 2. Increase of RE with addition of nanoparticles and POE Oil

Description	Increase of Refrigerant Effect
Refrigerant + POE Oil + Nanoparticles SiO_2 (0.5 g)	4.57%
Refrigerant + POE Oil + Nanoparticles SiO_2 (1.0 g)	3.91%
Refrigerant + POE Oil + Nanoparticles SiO_2 (1.5 g)	7.92%
Refrigerant + POE Oil + Nanoparticles ZnO (0.5 g)	1.78%
Refrigerant + POE Oil + Nanoparticles ZnO (1.0 g)	3.85%
Refrigerant + POE Oil + Nanoparticles ZnO (1.5 g)	3.41%

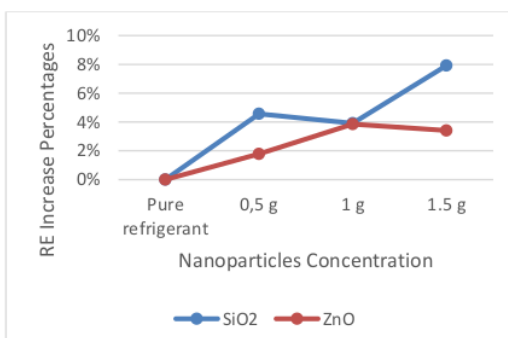

Figure 2. % Refrigerant Effect Increase

3.3 Effect of Work Done by Compressor with the addition of nanoparticles + POE Oil

There was a decrease in work done by compressor with the addition of nanoparticles + POE oil.

Table 3. Decrease of Work Done by Compressor with

Addition Nanoparticles and POE Oil

Description	Increase of Work Done by Compressor
Refrigerant + POE Oil + Nanoparticles SiO_2 (0.5 g)	-3.70%
Refrigerant + POE Oil + Nanoparticles SiO_2 (1.0 g)	-10.60%
Refrigerant + POE Oil + Nanoparticles SiO_2 (1.5 g)	-14.23%
Refrigerant + POE Oil + Nanoparticles ZnO (0.5 g)	-3.20%
Refrigerant + POE Oil + Nanoparticles ZnO (1.0 g)	-8.59%
Refrigerant + POE Oil + Nanoparticles ZnO (1.5 g)	-7.52%

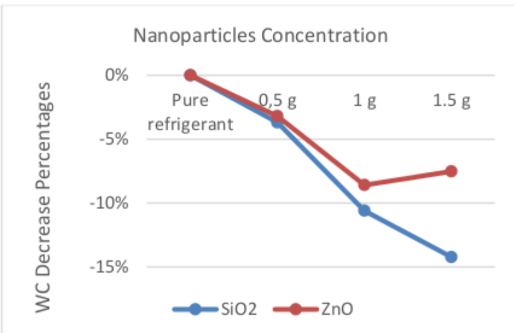

Figure 3. % Work Done by Compressor Decrease

3.4 *Effect of COP with the Addition of Nanoparticles + POE Oil*

There was an increase in COP with the addition of nanoparticles + POE oil.

Table 4. Increase in COP with addition of nanoparticle and POE Oil

Description	Increase of COP
Refrigerant + POE Oil + Nanoparticles SiO_2 (0.5 g)	8.77%
Refrigerant + POE Oil + Nanoparticles SiO_2 (1.0 g)	16.23%
Refrigerant + POE Oil + Nanoparticles SiO_2 (1.5 g)	25.88%
Refrigerant + POE Oil + Nanoparticles ZnO (0.5 g)	5.26%
Refrigerant + POE Oil + Nanoparticles ZnO (1.0 g)	13.60%
Refrigerant + POE Oil + Nanoparticles ZnO (1.5 g)	11.84%

Figure 2 shows the effect of nanoparticles addition (SiO_2 and ZnO) on Refrigerant Effect based on data of Table 2. Figure 3 shows the effect of both SiO_2 and ZnO addition on Work Done by Compressor based on data Table 3. Figure 4 shows the effect of both SiO_2 and ZnO addition on COP based on data Table 4, and Figure 5 shows the effect of SiO_2 and ZnO addition upon energy consumption using data of Table 5.

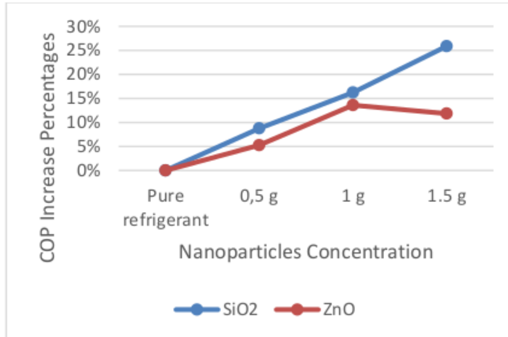

Figure 4. COP Increase Percentages

3.5 *Effect of Energy Consumption with addition of nanoparticles and POE Oil*

There was a decrease in energy consumption with the addition of nanoparticles + POE oil.

Table 5. Decrease in Energy Consumption with Addition Nanoparticles + POE Oil

Description	Decrease in Energy Consumption
Refrigerant + POE Oil + Nanoparticles SiO_2 (0.5 g)	-4.65%
Refrigerant + POE Oil + Nanoparticles SiO_2 (1.0 g)	-16.28%
Refrigerant + POE Oil + Nanoparticles SiO_2 (1.5 g)	-25.58%
Refrigerant + POE Oil + Nanoparticles ZnO (0.5 g)	-4.65%
Refrigerant + POE Oil + Nanoparticles ZnO (1.0 g)	-16.28%
Refrigerant + POE Oil + Nanoparticles ZnO (1.5 g)	-16.28%

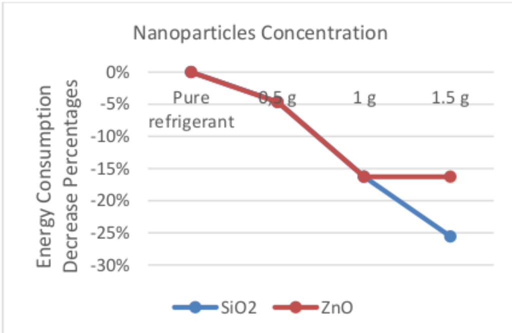

Figure 5. Energy Consumption Decrease Percentages

It should be noted that the POE lubricant displays as emulsifier in this case for inorganic nanoparticles (SiO_2 and ZnO) and R600a refrigerant. R600a refrigerant is a commercial name of isobutane as an organic alkane. The important point in this matter that all three components, i.e. the POE lubricant, inorganic nanoparticles, and R600a refrigerant should form a soluble nanofluid. Therefore, the rule "like dissolve like" should be fulfilled, polar component dissolves in polar solvent, or non polar component dissolves in non polar solvent. POE lubricant is a semi organic component with its chemical formula as polyolester is a polar organic solvent. Thus, the POE lubricant may increase the solubility of inorganic nanoparticles (SiO_2 and ZnO). As already mentioned above, nanoparticles have tremendous properties with regard to its thermal conductivity and heat transfer and therefore, nanoparticles may reduce friction effect [3, 5-6].

It is not surprising with the addition of nanopartcles (SiO_2 and ZnO) increasing the heat transfer yielding increased refrigeration machine performance in terms of COP (Table 2 and Table 4). Since the nanoparticles reduced friction factor between components involved [4, 13-14], thus, as predicted the addition of nanoparticles in this refrigeration system may decrease the work done by compressor and energy consumption (Table 3 and Table 5).

The fluctuated results and different yields of refrigerant effect (RE), work done by compressor (WC), and refrigerant machine performance (COP), as well as energy consumption (EC) between SiO_2 and ZnO nanoparticles as shown by Figures 2 – 5 are strongly influenced by different particle sizes between SiO_2 (≈ 50 nm) and ZnO (≈ 30 nm) and electronic configuration of those oxides. However, with regard to Figures 2 – 4, after the addition of 1.5g ZnO, the refrigeration machine performance showed a decline in terms of RE, WC, and COP, this finding is related to higher quantity of polar ZnO particles yielding more particles collisions increasing friction effect reducing thermal conductivity. This phenomenon was not shown for SiO_2 due to difference of polarity between ZnO and SiO_2.

Moreover, both SiO_2 and ZnO have amphoteric properties that can act as acid in base medium or as base in acid medium, therefore, both type nanoparticles have more flexibility in molecular interactions. Previous studies [4-5, 15-16] reported the utilization of SiO_2, ZnO, and Al_2O_3 that classified as flexible amphoteric oxides.

It should be noted that silicon (Si) is attributed to IVA group elements, while zinc (Zn) attributed to IIB group elements in Periodic Table. Different particle sizes and group elements between silicon and zinc significantly influence the electron affinity and interaction effect that not surprisingly yielding different results in refrigeration machine performance and energy consumption.

This study shows that both 1.5 g SiO_2 and 1.0 g ZnO yielding the highest refrigerant machine performance based on the experimental results. In the outcome, software modeling can be advantaged for optimization of the research results. Previous report [17] applied finite element method to optimize cast wheel design for motorcycles. With regard to engineering matter, Wibowo & Sebayang [18] applied HOMER software for optimization of solar wind hybrid power design. Software modeling is sophisticated for design and optimization on reasons of fast, precise and accurate.

4. Conclusion

Interesting features can be withdrawn from this studies related to the role of nanoparticles to enhance better results in refrigeration machine performance in terms of refrigerant efficiency, work done, and coefficient of performance, as well as energy consumption. The tremendous properties of nanoparticles are advantaged for enhancing refrigerant performance. This phenomenon is related to molecular interactions between inorganic amphoteric oxides (SiO_2 and ZnO), organic polyolester lubricant, and organic isobutane refrigerant following the rule of solubility to yield more soluble nanofluid to increase heat transfer and to decrease friction effects and wear rate.

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