CuO-nano based Biodegradable Refrigeration Oil in R134a Refrigeration Systems for Energy Conservation and Green Environment

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Abstract. The present study experimentally investigated the reliability and performance of a vapour compression refrigeration system with CuO nano based biodegradable refrigeration oil. The pentaerythritol ester biodegradable refrigeration oil (PE) is blended with synthetic refrigeration oil (ISO 68 grade-POE oil) in the fraction of 50% by volume. Nanolubricant was synthesized on the basis of the concept of the nanofluids, which was prepared by mixing CuO nanoparticles with pentaerythritol ester based biodegradable refrigeration oil blend (PE50). The concentration of nano CuO ranges in the order of 0.1% to 0.3% by weight with particle size of 40 nm to prepare CuO nano biodegradable refrigeration oil. An experimental test rig is designed and fabricated indigenously to carry out the investigations. The results indicated that CuO nano based biodegradable refrigeration oil works normally and safely in the system. The compressor power consumption was reduced by 5.02% with the use of 0.3% CuO nano biodegradable oil. The PE50 with 0.3% CuO nano has a considerable rise in coefficient of performance (COP) of about 45%. Hence CuO nano based biodegradable refrigeration oil in refrigeration system considerably reduces the energy consumption and increases the COP of the refrigeration system.

1. Introduction
A lubricant is a substance introduced between two surfaces in relative motion in order to reduce the friction and wear produced by contact surfaces [1]. The main purposes of lubrication are to decrease wear and heat loss that results owing to surfaces contact in motion, and to prevent from corrosion and minimize the oxidation [2]. There has been huge attraction and interest developed in the use of lubricants from vegetable oil. Vegetable oils are biodegradable, non-toxic and have excellent lubricity properties. Earlier research findings concluded that the transesterification of vegetable oil has an increased possibility for the synthesis of lubricant with enhanced temperature and significant fluidity [3]. Janusz Nowicki et al [4] studied the synthesis of esters from oleic acid with pentaerythritol and TMP dimer using homogeneous metallic catalysts such as Sn, Ti and Zr catalysts and stated that obtained esters have superior lubrication properties in terms of low pour point of −22°C to −32°C, good viscosity index of 72.8 to 130.5mm²/s at 40°C and improved tribological properties in terms of wear scar diameter of 0.66mm. Tirth et al [5] reviewed the present status of vegetable oil based lubricants. Vegetable oils are the primary outrider by its uses and because of their sustainable energy
resources; they offer energy independence. Arianti et al [6] reported lubricants from vegetable oil provide a renewable source of ecologically associate lubricants, relating to biodegrade into harmless products. Studies show that bio lubricant derived from the various vegetable oil possesses promising lubrication characteristics. Owuna et al., (2019) re-evaluated the development of vegetable oils using polyols through various chemical modification techniques; analysed the rheological of bio lubricants and stated that TMP ester based stocks are renewable, eco-friendly and have potentials to be used for the formulation of hydraulic oils, gear oils and engine oils.

Energy demand and environmental issues of refrigerants are the major crisis of refrigeration industry. The energy consumption by refrigerators is increasing day by day due to their rapid usage. Such an increasing energy requirement will aggravate energy shortage and environment pollution [7]. The researchers proposed a number of models to predict the behaviour of a hermetically sealed compressor under different conditions. There have been many investigations on the role of refrigerant and lubricants in the working and performance of a compressor, also assumptions being different in each case. Kiranmai et al [8] investigated the refrigeration compressor work using mineral oil ISO 32, Polyolester oil ISO 22 and poly alkylene glycol oil ISO 46. The results demonstrate that the PAG oil and POE oil had the good compatibility with R134a and coefficient of performance of PAG oil is increased by 3.1% and 14.5% compared to POE oil and mineral oil respectively. Akhavan-Behabadi et al [9] assessed the influence of CuO nanoparticles on boiling and two phase phenomenon of POE oil/ R-600a mixture within a smooth horizontal tube and observed that 1.5% mass fraction of nanoparticles amplifies the heat transfer to 63% comparative to the heat transfer performance with pure POE oil/ R-600a mixture. Omer et al [10] reviewed the thermo-physical performance of nano refrigerants and nano lubricants, two phase flow boiling phenomena of nano lubricants in refrigerating systems and reported that 0.1% (w/w) of TiO₂ nanoparticles in mineral oil and HFC134a refrigerant declines the 26.1% usage of energy consumption evaluated to the R134a and polyolester oil. Vaishali et al [11] overviewed the improvement of heat transfer using nano refrigerants and nano lubricants in refrigeration systems and stated that the improvement of thermal conductivity of nano fluids augment the heat transfer rate and freezing capacity of refrigeration systems. Mohammed Ajmal et al [12] presented the impact of 0.025, 0.05 and 0.10 % mass concentrations of CuO nanoparticles on the tribological performance of Polyol ester oil through pin-on disc tribo-machine. The tribological results showed that inclusion of 0.10% CuO nanoparticles of polyol ester oil reduces the coefficient of friction from 0.18 to 0.06. The improvement of friction characteristics optimizes the energy consumption in refrigeration systems. The present study is focused on performance investigation to study the effect of addition of CuO nanoparticles (0.1% to 0.3%) on weight basis in the pentaerythritol ester based biodegradable refrigeration oil blend (PE50) on the coefficient of performance of the refrigeration system.

2. Experimental

2.1. Synthesis of Biodegradable Refrigeration oil and blend sample preparation

Rapeseed oil is used for the formulation of polyolester-based bio lubricant. A successive transesterification process was adopted for the formulation of pentaerythritol ester of rapeseed oil. Fig.1 shows the chemical reaction of successive transesterification process. The detailed procedure for the formulation of Pentaerythritol ester has adopted from Hashem et al. [13]. A synthetic grade polyl ester (POE68), a widely used lubricant in refrigeration plant was selected as a base fluid for the preparation of various lubricant blends. The pentaerythritol ester of rapeseed oil was blended with POE68 grade refrigeration oil in the fraction of 50% by volume. The blend preparation was conceded in a round bottom glass reactor and the mixture was heated up to 60°C at a stirring speed of 300 rpm for about one hour [14]. The rheological properties of different refrigeration oil samples such as kinematic viscosity, viscosity index, flash and pour point and total acid numbers was measured in accordance with ASTM standards and are listed in Table 1.
Fig.1. Chemical reaction of successive transesterification process

Table 1. Properties of CuO nano based bio degradable refrigeration oil

| Test parameters          | Standard | POE 68 | PE | PE50  | PE50 CuO 0.1 | PE50 CuO 0.2 | PE50 CuO 0.3 |
|--------------------------|----------|--------|----|-------|--------------|--------------|--------------|
| Kinematic viscosity @ 100°C (cSt) | ASTM D445 | 9.3    | 11 | 10.54 | 11.4         | 11.9         | 12.5         |
| Viscosity index          | ASTM D2270 | 114  | 248 | 244   | 249          | 252          | 257          |
| Flash point(˚C)          | ASTM D92 | 270   | 242 | 220   | 224          | 226          | 229          |
| Pour point(˚C)           | ASTM D97 | -39   | -25 | -28   | -29          | -29          | -29          |
| Total Acid Number mg KOH/g | ASTM D974 | 0.3   | 1.2 | 0.79  | 0.76         | 0.83         | 0.70         |

2.2. Preparation of Nano-CuO based biodegradable refrigeration oil
The additive used in the synthetic and refrigeration oil was CuO in the nanoparticle form. Fig.2(a) depicts the SEM image of the CuO nanoparticles.

Fig.2(a) SEM image of CuO nanoparticles (b) Ultrasonic Agitator
The CuO nanoparticles of 40nm were procured from M/S Nano Research US. The nanoparticles of 40nm were supplied by US Nano Research Limited. The ultrasonication process was utilized to prepare the nano refrigeration oil samples of concentration of 0.1, 0.2 and 0.3 (w/w) for accomplish the excellent dispersion stability of the nanoparticles without any agglomeration. Fig. 2(b) shows the photograph of the preparation of biodegradable refrigeration oil sample containing 0.3% CuO nanoparticles.

2.3. Test of Compressor performance using Nano-CuO based biodegradable refrigeration oil

The hermetically sealed reciprocating compressor (AQAW77X thermally protected) for R134a was procured from M/S Shangzhure Refrigeration Co. Ltd. The power input of the compressor was \( \frac{1}{2} \) HP. The condenser was air cooled and the capillary tube expansion valve was used for expansion process, the evaporator cabin dimensions are height 0.65m, length 6.54m and breadth 0.42m.

![Photographic view of the vapour compression refrigeration system](image)

The thermocouples used were calibrated T type for observing the temperature of the refrigerant. Fig.3 shows the photographic view of the vapour compression refrigeration system test rig. The consumed power of the whole test rig and the compressor were measured using energy meter and compressor sensor respectively. The system was evacuated first to remove the moisture content inside it for 30 minutes. Then the refrigerant R134a was charged through the charging line and ISO 68 grade oil was filled through the lubrication line of the compressor. The experiment was conducted and temperatures were observed continuously until the steady state reached. Now the test rig should be powered off for discharging the refrigerant and lubricant. The same procedure is repeated for all biodegradable and blended lubricant samples. The experiment was conducted and temperatures were observed continuously until the steady state reached. Now the test rig should be powered off for discharging the refrigerant and lubricant. The same procedure is repeated for all biodegradable and blended lubricant samples. The temperature \( T_1 \) is the inlet/outlet temperature of the compressor/evaporator, \( T_2 \) is the inlet/outlet temperature of the condenser/compressor, \( T_3 \) is the inlet/outlet temperature of the expansion/condenser, and \( T_4 \) is the inlet/outlet temperature of the evaporator/expansion valve. The performance of the refrigeration system was calculated using the standard refrigeration formulae.
3. Results and Discussion

3.1 Viscosity of Nano-CuO based biodegradable refrigeration oil

The kinematic viscosity of biodegradable refrigeration oil and nano added biodegradable refrigeration oils were measured using a Redwood viscometer. Fig.4 evaluates the result of kinematic viscosity as a temperature function. The results signify that the augment in viscosity due to the inclusion of nanoparticles. It is observed from the results that the addition of 0.3% CuO is more than that of other refrigeration oil blend samples. Fig. 4 shows that at 100°C, the increase in viscosity are 18% and 22% for a CuO nanoparticle concentration in PE50 of 0.1% and 0.2% respectively, whereas, for 0.3% CuO nanoparticle concentration in PE50, the increase in the viscosity was 26%. The results also indicate that the increase in viscosity index due to the addition of CuO nanoparticles up to 0.3% (w/w) in PE50. The results also indicate that the increase in viscosity due to the addition of nanoparticles at higher temperatures be attributed to a decrease in the fluid layer resistance. The tendency of viscosity deviation acquired is in accordance with the results concluded by Sabereesh et al and Kedzierski [15,8]

![Fig.4 Variation of kinematic viscosity with temperature of refrigeration oils](image)

3.2. Performance of Compressor using Nano-CuO based biodegradable refrigeration oil

3.2.1 Effect of Compressor shell temperature

The continuous rise of compressor outlet temperature may also cause possibility of breakdown of the lubricating oil leads to the higher friction, wear and reduction in the life span of the compressor. Fig. 5 shows the compressor shell temperature of POE68, PE and PE50 oil and nano based biodegradable refrigeration oil samples. Examination of the temperature of the compressor shell indicates that the CuO nano biodegradable refrigeration oil samples shows decrement in the value than that of synthetic lubricant which consecutively raises the performance of the system [16]. The compressor shell temperature of 0.3% CuO nano biodegradable refrigeration oil was reduced about 23%, 20% and 14% as compared to POE68, PE and PE50 respectively. The decline of friction coefficient between the compressor parts because of less frictional heating produced using nano biodegradable refrigeration oil decreases the compressor shell temperature.
3.2.2 Power Consumption

Compressor power reduction is achieved by the refrigeration capacity increment, which in turn had a considerable effect in improving the compressor efficiency, lead to the COP enhancement. Fig. 6 shows the compressor power input using POE68, PE and PE50 oil and nano based biodegradable refrigeration oil samples. It is noted that the power consumption of 0.3% CuO nano biodegradable refrigeration oil is lower than that of all refrigeration oils.

The result measured from the testing of compressor shows that the power input of 0.3% CuO nano biodegradable refrigeration oil was decreased by 5.02%, 3.95% and 2.85% as compared to POE68, PE and PE50 respectively. Compressor input power was reduced due to the higher viscosity index, which in turn improves the wear characteristics [17]. Increase in refrigeration capacity of the system using nano biodegradable refrigeration oil in comparison with the synthetic refrigeration oil is achieved by the compressor power loss reduction. The heat transfer losses up to 50% take place, as the lubrication film thickness is lowered.
3.2.3 Coefficient of Performance

The coefficient of performance of the refrigeration system was determined by knowing the refrigeration effect and power input. Fig. 7 shows the Coefficient of performance of POE68, PE and PE50 oil and nano based biodegradable refrigeration oil samples. The results measured from the testing of compressor shows that the coefficient of performance of 0.3% CuO nano biodegradable refrigeration oil was increased by 45%, 36% and 24% as compared to that of POE68, PE and PE50 respectively. Testing results of experimentation elucidate that the 0.3% CuO nano biodegradable refrigeration oil have a considerable rise in COP of about 45% compared with synthetic lubricant owing to the reduction of input power of the compressor and the improvement of heat transfer characteristics.

![Fig. 7 Effect of CuO-nano in refrigeration oil on the COP](image)

The biodegradable refrigeration oil (PE50) added with 0.3% CuO nano having a higher viscosity to that of POE68, which produces protective tribo-film and resulted in superior lubrication behaviour[12,18]. This is due to the reason of protective film developed by the bio lubricant provide better friction reduction between the metal surfaces.

4. Conclusions

Based on the investigations, the following conclusions are drawn:

- The viscosity of 0.3% CuO nano biodegradable refrigeration oil is higher than synthetic refrigeration oil. All the biodegradable refrigeration oil blends satisfy the ISO 68-grade requirements.
- The compressor shell temperature of 0.3% CuO nano biodegradable refrigeration oil was reduced about 23% as compared to POE68.
- The power input of 0.3% CuO nano biodegradable refrigeration oil was decreased by 5.02% as compared to POE68.
- The coefficient of performance of 0.3% CuO nano biodegradable refrigeration oil was increased by 45% as compared to that of POE68.

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