EXPERIMENTAL ANALYSIS OF VAPOUR COMPRESSION REFRIGERATION SYSTEM USING NANO LUBRICANT WITH REFRIGERANT R134a

by

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It has been proved that due to addition of nanoparticals to the refrigerant results in improvement in thermophysical properties and heat transfer characteristics of the primary refrigerant, which improves the COP of the refrigeration system. In this experimental analysis of vapour compression system, the performance study has been carried out by preparing the nanolubricant. In this experimental study, three cases are considered. The compressor of the system filled with pure polyolester (POE) oil, SUNISO-3GS oil and POE + TiO_2 nanoparticles as lubricant. In the nanolubricant, the volume concentration of the nanoparticles is 0.2%. The experimental study shows that vapour compression refrigeration system works smoothly with nanorefrigerant. In this experimental study, it has observed that when nanolubricant used in place of traditional POE oil, the refrigerating effect has been increased and the compressor power consumption has reduced by 27% and the refrigeration system COP improves by 29%. The analysis shows that the enhancement factor in the evaporator is 1.2 when nanorefrigerants are used instead of pure refrigerant. The properties of refrigerant like thermal conductivity and density are also studied for the nanolubricant by using the Labview software, in which the thermal conductivity and the density of R134a and nanolubricant mixture are observed higher in comparison with the R134a and pure lubricant mixture.

Key words: vapour compression refrigeration system, R134a, nanolubricant, COP

Introduction

The rapid development of nanotechnology has led to the emergence of a new class of heat transfer fluids called nanofluids. Many researchers have recently studied the effects of nanoparticles in the different refrigerant/lubricant on the efficacy of vapour compression refrigeration systems (VCRS). Pawel *et al.* [1] studied nanofluids, they discovered that they had a significantly higher thermal conductivity than basic fluids. They also discovered that the crucial heat flux significantly increases when nanoparticles are added. Bi *et al.* [2] used TiO₂-R600a nanorefrigerant as a working fluid in experimental investigation of a home refrigerator for evaluation of performance. They demonstrated that the TiO₂-R600a system operated in the

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refrigerator normally and effectively, saving 9.6% of electricity. They too stated that the nano refrigerating system had a higher freezing pace than a system using only pure R600a. This article's goal is to present the findings of experimental research on a vapour compression device. The nanoparticle used in this research is alumina, and the refrigerant chosen is R134a. Bi et al [3] were used nanorefrigerants in experiments on a domestic refrigerator. They used R134a as a primary refrigerant and a mixture of mineral oil and TiO₂ as the lubricant in their experiments. They discovered that the nanorefrigerant-equipped refrigeration system operated regularly and effectively, consuming 21.2% less energy compared to a device using R134a/POE oil. Afterword, Bi et al. [4] discovered that the power usage had been noticeably reduced and the freezing capacity had significantly improved. They emphasised that better mineral oil thermophysical properties and the existence of nanoparticles in the refrigerant are to blame for the system's improved performance. Jwo et al. [5] studied on a cooling system using a refrigerant of hydrocarbon and mineral lubricant inplace of R134a and polyester lubricant. The Al₂O₃ nanoparticles were added to the mineral lubricant to enhance heat transmission and lubrication. According to their research, the sixty percent R134a and 0.1 wt.% Al₂O₃ nanoparticles found the best. In these circumstances, the performance coefficient rose by 4.4% while the power consumption decreased by about 2.4%. In a horizontal tube, Henderson et al. [6] performed the experimental study on heat transfer of nanofluids based on R134a. With R134a and POE oil, they discovered better dispersion of CuO nanoparticle and the coefficient of heat transfer increased by more than 100% in comparison to initial R134a/POE oil findings. In a research by Bobbo et al. [7], the effects of individual wall carbon nanohorn and TiO₂ dispersion on POE oil's tribological properties and R134a's solubility at various temperatures were examined. They demonstrated how the addition of nanoparticles can either enhance or worsen the behaviour of base lubricant. Using Brinkman's model, Mahbubul et al. [8] investigated R123-TiO2 nanorefrigerant viscosity at various nanoparticle concentrations and found that pressure drop dramatically increases as viscosity increases.

Nagihan and Kursad Ersoy [9] looked at how a two-phase constant area ejector could enhance a VCRS performance by collecting kinetic energy during the expansion process and so lessening the compressor's workload. When different blends of hydrocarbons are utilised, Sattar et al. [10] showed that the performance of VCRS using the refrigerant R134a improves. By the development of nanotechnology, numerous studies have investigated the impact of adding additives as a nanoparticles to the lubricant or refrigerant, or both, on the COP of the VCRS. Park and Jung [11] investigated how the inclusion of nanotubesmade of carbon improved the heat transfer in refrigerants. Lee et al. [12] found improved lubricating properties in mineral oil with a 0.1 vol.% of nanoparticles. The described experimental investigations Ku et al. [13] and Long et al. [14] imply that the viscosity fluctuations or the changing lubrication characteristics may be the causes of increased in the COP when nanoparticles are added to lubricating oil. According to Elcock [15], TiO₂ nanoparticles can be added to mineral oil to improve its solubility with hydrofluorocarbon (HFC) refrigerants. Additionally, according to the authors, the R134a and mineral oil refrigeration systems with nanoparticles of TiO₂ appear to operate similarly to HFC134a and POE oil systems while returning more lubricating oil from the compressor. Hindawi [16] conducted an experimental investigation on the heat transfer properties of refrigerant R22 with nanoparticles Al₂O₃ and it was discovered that nanoparticles improved the refrigerant's heat transfer qualities with smaller bubble sizes. The heat transfer properties of R11 refrigerant with nanoparticles TiO_2 were examined by Eastman *et al.* [17] who demonstrated the heat transfer augmentation reached 20% for the 0.01 g per L partical loading. The impact of nanotubes made of carbon on the heat transfer of R123 and R134a refrigerants was

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examined by Liu et al. [18]. According to authors, CNT improve these refrigerants' nucleate boiling coefficient of heat transfer. Large improvements of 36.6% were observed by the authors at very low heat fluxes. Choi et al. [19] observed that the addition of CNT made of multiwall increased the thermal conductivity of polyoil by 150%. The same type of results are reported by Yang [20], who found that polyoil containing 0.35% (v/v) CNT improved thermal conductivity by 200%. It is crucial to remember that this rise in thermal conductivity was observed by a viscosity increase of three orders of magnitude. According to Wang and Xie [21], nanoparticles of TiO_2 can be utilised as additives to improve the mineral oil's solubility in HFC refrigerant. Additionally, compared to systems employing R134a and POE oil, refrigeration systems using blend of R134a and mineral oil containing TiO₂ nanoparticles seem to operate well by returning more lubricating oil from the compressor. Skye et al. [22] studied the non-flammable low-GWP refrigerant blending for the replacement of HFC-134a. Hady et al. [23] experimentally studied the performance of chilled-water air conditioning unit using alumina nanofluids for enhancement of COP and energy saving. Majgaonkar [24] suggested nano refrigerant improvement in system performance, but its application is obstructed by some factors like highpressure drop, low specific heat, fouling and high production cost. Yildiz et al. [25] studied the impact of using nanofluids on the performance of refrigeration systems. Shewale et al. [26] conducted an experimental investigation of Ice plant using different concentrations of nano lubricant with primary refrigerant R134a. Hatami et al. [27] carried work on spherical particle in plane Couette fluid flow by multi-step differential transformation method. Song, et al. [28] investigated optical properties of TiO₂-water suspension considering particle size distribution. Hatami and Safari [29] and Hatami et al. [30] carried out numerical analysis of heated cylinder by using natural convection. Ghasemi et al. [31] has done analytical and numerical investigation of nanoparticle effect on peristaltic fluid flow in drug delivery systems. Mosayebidorcheh and Hatami [32] carried out nalytical investigation of peristaltic nanofluid flow and heat transfer in an asymmetric wavy wall channel.

After complete literature review on nanolubricant, it has been found that many researchers worked on this topic, but very few investigations are carried out on TiO₂ nanoparticals in mineral oil (MO), POE, and PAG lubricants with primary refrigerant R134a in the area of heat pump, air conditioning and domestic refrigerator. The use of various nanolubricant with mineral oil research found in substantial amount, but no research has been found on TiO₂ nanoparticals in POE lubricants with primary refrigerant R134a for VCRS application. So no attempt has been found by any researcher on this topic using the computerised test rig of VCRS with LABVIEW software. Here it is a sincere attempt to conduct experimental analysis of VCRS with TiO₂ with POE lubricant using R134a as a primary refrigerant in to the computerised VCRS test rig with LABVIEW software. In this paper, three cases are considered. The system compressor filled with pure POE oil, SUNISO-3GS oil and POE+ TiO₂ nanoparticles as lubricant and the performance of the VCRS test rig are recorded for these three cases.

Experimental set up and methodology:

Experimental set-up

The set-up of experiment, which is shown in fig. 1 and the simulation that is shown in fig. 2 mainly, consists of a hermetically sealed compressor, drier-filter, expansion device, and heat absorption chamber which work on VCRS. The test rig specifications are mentioned in tab. 1. Low pressure and low temperature vapour refrigerant coming from the evaporator are



Figure. 1. Experimental set-up



Figure 2. Simulation of experimental set-up

sucked by the compressor and in compressor its temperature and pressure increases and it releases its heat in to the condenser. After condenser it passes through the capillary tube in which liquid refrigerant is converted in to vapour and liquid which again goes to the evaporator where we get the refrigerating effect. For measuring the high pressure and low pressure separate pressure gauges are fitted in to the set-up. All temperatures are recorded with the help of temperature indicator at different states of refrigerant and digital energy meter provided to record the input power required to run the compressor. The data acquisition system is incorporated to display all the data on the PC. The specifications of instruments used for measurement are given in tab. 2.

Preparation of TiO2 and POE nanolubricant

The TiO₂ nanoparticles used in this study have an average diameter of 15 nanometers. Tables 3 and 4 provide information on the properties of the lubricant and nanoparticles used to prepare nanolubricant. The TiO₂ is dispersed in lubricant oil POE which is frequently used in R134a refrigeration and the two-step method is used to prepare the nanolubricant. Throughout the nanolubricant preparation process, no surfactant is introduced. Using a highly accurate digital weighing device, the required amount of TiO₂ nanoparticles dispersed in to the lubricant is precisely weighted (CONTECH Make). After use of a magnetic stirrer for 2.5 hours to complete

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| Sr. No. | Component/Item | Specification |
|---------|--------------------------------|--|
| 1 | Compressor | Hermetically sealed |
| 2 | Condenser | Forced convection air cooled |
| 3 | Drier / Filter | Silica gel type |
| 4 | Refrigerant flow measurement | Turbine type flow meter |
| 5 | Expansion device | Capillary tube |
| 6 | Capillary length | 2 m (approximately) |
| 7 | Evaporator | Immersed direct expansion type |
| 8 | Refrigerant | R134a |
| 9 | Pressure indication | Digital pressure transducers |
| 10 | Programming language | Labview 2017 |
| 11 | Data acquisition system module | Advantech USB-4711A |
| 12 | Temperature transmitters | 4-20 mA out-put, -50-100 °C |
| 13 | Pressure transmitters | 4-20 mA out-put, 0-20 bar pressure range |
| 14 | Flow transmitter | Flow range = 10-100 Lph, 4-20 mA out-put |

Table. 1 Test rig specification

the initial mixing process, the nanolubricant is homogenised using ultrasonic technology as shown in fig. 3 for the designated amount of time. This is crucial to ensuring that nanoparticles are evenly distributed throughout the lubricant base. Then the two step method is used to prepare the sample of nanolubricant. Prior to conducting the experiment, the prepared TiO_2 and POE nanolubricant is inserted into the compressor during the test using the service port.

Table 2. Specification of instruments used for measurement

| Sr.No. | Measured Parameter | Instruments | Range | Uncertainty |
|--------|--------------------|-----------------------------|--------------------------|-------------|
| 1 | Temperature | PT100 | −50-100 °C | ±0.5% |
| 2 | Pressure | B.T. pressure gauge | 0-15 bar LP, 0-20 bar HP | ±0.5% |
| 3 | Power of computer | Digital energy meter | 0-2000 W | ±0.2% |
| 4 | Nanoparticles mass | Digital electronic balanced | 0.001to 250g | ±0.5% |

Table 3. Details of nanoparticles

| Sr.No | Nanoparticle details | Specification |
|-------|-----------------------|------------------------------|
| 1 | Type of nano particle | TiO ₂ |
| 2 | Size | 15 nm |
| 3 | Purity | 99.6% |
| 4 | Bulk density | 0.15-0.25 g /cm ³ |
| 5 | Volume concentration | 0.2%, 0.3%, and 0.4% |

Table 4. Properties of POE lubricant

| Sr.No. | Lubricant Properties | Units |
|--------|---------------------------------------|-------|
| 1 | Oil | POE |
| 2 | ISO VG | 22 |
| 3 | Kinematic Viscosity at 40 °C [cSt] | 22 |
| 4 | Kinematic Viscosity at 100 °C [cSt] | 4.1 |
| 5 | Viscosity index | 82 |
| 6 | Pour point [°C) | -5.4 |
| 7 | Flash point [°C] | 198 |
| 8 | Density at 15 °C [gcm ⁻³] | 0.935 |



Figure 3. Ultrasonic immersible transducer with generator and samples of nanolubricant

Analysis of performance

For pull down test

Actual COP of the VCR system:

Refrigerating effect =
$$m \times C_p \times \frac{\Delta T}{\Delta t}$$
 (1)

where *m* is the mass of water, C_p – the specific heat of water (4.187 kJ/kgK), and ΔT – the temperature difference. Work input [kW per hour] = final energy meter reading – initial energy meter reading, therefore, COP = refrigerating effect/work input.

Theoretical COP of the VCRS:

Theoretical COP = refrigerating effect/work done:

$$COP = \frac{h_1 - h_4}{h_2 - h_1}$$
(2)

Results and discussion

Experimental results

In this experimental study, three cases are considered. The system compressor filled with: pure POE oil, SUNISO-3GS oil, and POE+ TiO_2 nanoparticles as lubricant. The volume concentration of nanoparticles in nanolubricant is 0.2%.

Figure 4 shows the plot of temperature verses time in which there is no pressure drop was observed due to friction in condenser and evaporator. It is evident from the figure that the POE oil + TiO₂ nanoparticle mixture requires less time to reduce cooling load temperature. For instance, it takes 60 minutes with POE oil + TiO₂ nanoparticle, compared to 80 minutes and 90 minutes with SUNISO-3GS & POE oil, to drop the temperature of cooling load from 28 °C to 3 °C which shows the more effectiveness of POE oil + TiO₂ nanoparticle mixture. Figure 5 shows the effect of refrigeration effect for the given three cases. It is evident that when compared to the other two situations, the POE oil + TiO₂ nanoparticle mixture has a better refrigerating effect. With POE oil, it takes 90 minutes to lower the cooling load's temperature from 28 °C to 3 °C; if POE oil + TiO₂ nanoparticles are used, the reduction is 24%. This is due to the nanoparticles speed up the pace at which heat is transferred from the evaporator's refrigerant side which gives the effective refrigerating effect.





Figure 6 depicts the reduction in temperature of refrigerant in the refrigeration system's condenser. When compared to other situations, nanorefrigerant causes a significant drop in temperature of the refrigerant. The refrigerant is between 75 °C and 79 °C at the condenser's intake temperature. The temperature at the condenser's outflow in the instance of the POE oil + TiO_2 nanoparticle mixture is 40 °C. The inclusion of nanoparticles in the refrigerant is what causes the condenser's increased heat transfer rate.



Figure 6. Decrease in temperature of refrigerant in condenser

The compressor power consumption is compared in fig. 7 for all three cases. When POE oil + TiO_2 nanoparticle mixture is utilised, power consumption is reduced by 27% and

reduced by 14% when SUSISO-3GS is used in place of POE Oil. The COP determined using the data of experiment displayed in fig. 8. The power input and cooling load are used to compute the real COP. For comparison, the theoretical values are also displayed. The histogram below makes it very evident that when compared to the other examples, the mixture of POE oil and TiO₂ nanoparticles has the highest COP. The nano-refrigerant in the condenser is subcooled, which lowers the compressor's power usage and raises the COP. The reading from the energy meter and the cooling load are used to compute the actual COP. Enthalpy values from the critical locations are used from the *P*-*h* chart for R134a for the computation of theoretical COP.





Figure 8. The COP comparison for given cases

Figure 9 represents the variation of thermal conductivity on suction side for the pure POE oil, SUNISO-3GS oil, POE+ TiO_2 nanoparticles as lubricant. The thermal conductivity goes on increasing for SUNISO-3GS oil & POE+ TiO_2 nanoparticles as lubricant in camparision with pure POE oil and observed higher for nanolubricant. Figure 10 shows the variation of density on suction side for the pure POE oil, SUNISO-3GS oil, and POE+ TiO_2 nanoparticles as lubricant. In this study the same trend of increasing has been observed for density as thermal conductivity.

Limitations

In this experimental study, the main limitation has been observed that as the nanoparticals are inserted in to the lubricant and the procedure of preparing nanolubricant is very costly and time consuming. Considering these things the output of enhancement of COP is not up to the mark for small capacity VCRS.







Figure 10. Variation of density for given cases

Conclusion

In this paper, the experimental analysis of VCRS has been carried out for performance evaluation using various lubricants, including nanolubricants. The R134a refrigerant and the mixture of mineral oil with nanoparticles functioned normally. The refrigerating effect of the refrigeration system is higher when POE oil & TiO_2 nanoparticles oil mixture is used than when POE oil is used. When nanolubricant is used in place of traditional POE oil, the heat transfer properties of nanolubricant enhances due to this the regrigerating effect goes on increasing and the compressor's power is reduced by 27%. Due to increase in refrigerating effect and decrease in compressor work, the refrigeration system COP also improves by 29% when nanorefrigerant is used in place of traditional POE oil. The thermal conductivity and density goes on increasing for SUNISO-3GS oil and POE + TiO_2 nanoparticles in camparision with pure POE oil. Considering the future scope, the performance of VCRS can be evaluated by using the different eco-friendly primary refrigerants and the mixture of mineral oil with nanoparticles.

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Nomenclature

| C_p | specific heat [kJkg⁻¹K⁻¹] | k | – thermal conductivity [WmK ⁻¹] |
|-------|---|---|---|
| h | specific enthalpy [kJkg⁻¹] | m | – mass [kg] |

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| 'n | – mass-flow rate [kgs ⁻¹] | HP | high pressure |
|------------|---|------|---|
| Р | – pressure [bar] | LP | - low pressure |
| RE | - refrigerating effect [kW] | MO | – mineral oil |
| Т | – temperature [°C] | POE | – polyolester |
| ΔT | temperature difference [°C] | PAG | polyalkelene glycol |
| W_{in} | – compressor power input [kW] | VCRS | - vapour compression refrigeration system |
| | | HFC | hydrofluorocarbon |

Acronyms

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