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RESEARCH ARTICLE

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ZnO nanorefrigerant in R152a refrigeration system for energy conservation and green environment

Abstract In this paper the reliability and performance of a vapour compression refrigeration system with ZnO nanoparticles in the working fluid was investigated experimentally. Nanorefrigerant was synthesized on the basis of the concept of the nanofluids, which was prepared by mixing ZnO nanoparticles with R152a refrigerant. The conventional refrigerant R134a has a global warming potential (GWP) of 1300 whereas R152a has a significant reduced value of GWP of 140 only. An experimental test rig is designed and fabricated indigenously in the laboratory to carry out the investigations. ZnO nanoparticles with refrigerant mixture were used in HFC R152a refrigeration system. The system performance with nanoparticles was then investigated. The concentration of nano ZnO ranges in the order of 0.1% v, 0.3% v and 0.5%v with particle size of 50 nm and 150 g of R152a was charged and tests were conducted. The compressor suction pressure, discharge pressure and evaporator temperature were measured. The results indicated that ZnO nanorefrigerant works normally and safely in the system. The ZnO nanoparticle concentration is an important factor considered for heat transfer enhancement in the refrigeration system. The performance of the system was significantly improved with 21% less energy consumption when 0.5%v ZnO-R152a refrigerant. Both the suction pressure and discharge pressure were lowered by 10.5% when nanorefrigerant was used. The evaporator temperature was reduced by 6% with the use of nanorefrigerant. Hence ZnO nanoparticles could be used in refrigeration system to considerably reduce energy consumption. The usage of R152a with zero ozone depleting potential (ODP) and very less GWP and thus provides a green and clean environment. The complete experimental results and their analysis are reported in the main paper.

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1 Introduction

In a tropical country like India, nearly 90% of the refrigeration systems viz., domestic refrigerators, deep freezer units, food storage devices use R134a as the working fluid owing to the thermodynamic and good thermo physical properties [1]. The global warming potential (GWP) of R134a is high of the order of 1300. The Kyoto Protocol of the United Nations suggested minimizing the usage of green house gases along with hydroflurocarbons (HFCs) to use as refrigerants in refrigeration system [2]. Moreover HFC 134a is not miscible with the lubricant oil of the compressor unit [3]. It is also reported by earlier researchers that hydrocarbon blends has got the problem of flammability and fire hazards limitations [4,5]. Some of the European countries have banned the usage of R134a as refrigerant in refrigerators [6]. The proposed refrigerant R152a in the present study has zero ozone depleting potential (ODP) and very less GWP value of 140 [7]. In this paper R152a refrigerant is mixed with CuO nanoparticles to form a nanorefrigerant. Habib Anifar et al. [8] studied the Brownian and thermophoresis effects on natural convection of alumina-water nanofluid and found that heat transfer rate decreases with an increases in nanoparticle volume fraction. Jahar Sarkar et al. [9] studied the thermodynamic analysis and optimization of a two-stage cascade system with a choice of eight natural refrigerants. Their study reported two selection charts along with tables one for higher coefficient of performance and the other for highest volumetric capacity. Aminfar et al. [10] investigated the laminar flow and convective heat transfer of water-alumina nanofluid in a rectangular microchannel numerically. The results indicated that usage of nanofluid enhances convective heat transfer and pressure drop in a microchannel in comparison with pure water. Behnaz Tajik et al. [11]

reported the ultrasonic properties of Al_2O_3 and TiO_2 particles dispersed in distilled water by ultrasonification. They reported that the continuous pulse could prepare more stable nanofluids in comparison with discontinuous pulses when the sonification time was similar. The ultrasonic velocity and attenuation were measured by two immersed piezoelectric probes at a frequency of 3.5 MHz. The attenuation coefficient of nanofluids increases with decrease in volume fraction of nanoparticles when the temperature is higher than 45°C. Liu et al. [12] investigation discovered that the thermal performance of a mesh heat pipe can be evidently strengthened by substituting CuO nanofluids for deionized water under sub-atmospheric pressures. Tsai et al. [13] employed gold nanoparticles in nanofluid as working medium for conventional circular heat pipe and predicted the thermal resistance of the heat pipes with nanoparticle solution is lower than that with DI water. Salehi et al. [14] investigated the thermal performance of a TPCT using an Ag/water nanofluid as the working fluid under a magnetic field and the findings reveal that the thermal resistance of the TPCT with the silver nanoparticle suspension under a magnetic field was lower than that absent of a magnetic field and pure water. Akhilesh Arora et al. [15] studied the second law analysis of R422 series refrigerants as an alternative to HCFC 22. The thermodynamic properties of the R442 series refrigerants were computed using Refprop and Engineering Equation Solver Software software (version 7.0). They reported that the vapor pressure exerted by R422B was lesser when compared with HCFC22, whereas R422S and R422C exerted higher vapor pressure as compared to HCFC22. COP and exergetic efficiency of R422B are higher in comparison with other R422 series refrigerants. HCFC22 gives better COP than R422. Moreover lowest compressor discharge temperature was for R422A under all operating conditions. Nithesh Mittal et al. [16] conducted a numerical simulation of mixed convection flows in a square lid-driven cavity containing porous medium filled with an Al_2O_3-water nanofluid. They reported that increase in solid volume fraction leads to decrease in both the activity of fluid motion and fluid temperature. This leads to an increase in the corresponding average Nusselt number. A large value of Nusselt number was obtained by the addition of alumina nanoparticles to the base fluid. The variation of the average Nusselt number is linear with solid volume fraction. He et al. [17] examined hydrogen storage in porous silicon (pSi)/single wall carbon nanotubes (SWCNTs) composites. It was shown that hydrogen capacity in the pSi-SWCNTs composite material was about 2–6 times higher than those in individual pSi and SWCNT samples. Liu et al. [18] performed an experimental work on the micro-grooved heat pipe using aqueous nanofluids as the working fluids and reported that addition of Cu and CuO nanoparticles in the base fluid can apparently improve the thermal performance of the heat pipe. Misheck et al. [19] studied the performance of heat pipe with coarse and fine pores wick structure. An improvement of heat pipe performance up to a factor of 2 was reported with such a type of wick. Tsai et al. [20] employed gold nanoparticles in nanofluid as working medium for conventional circular heat pipe and predicted the thermal resistance of the heat pipes with nanoparticle solution is lower than that with DI water. Manimaran et al. [21] made an experimental investigation on the heat transfer performance of heat pipe with deionized (DI) water, CuO nanofluid and TiO_2 nanofluid. They used a concentration of 1.0 wt% for their experimentation. It was reported that heat pipe operated with CuO nanofluid showed higher results compared to TiO_2 nanofluid and DI water. However only a very limited investigation has been carried out with nano ZnO refrigerant. Hence it is a worthwhile attempt to hybrid ZnO nanorefrigerant in R152a refrigerant system and in the present study extensive experiments were carried out to find out the performance of ZnO nanorefrigerant and reported.

2 Experimental setup

The vapor compression refrigeration test rig shown in Fig. 1 contains four main components which are compressor, condenser, expansion device (capillary tube) and a serpentine coiled water loaded evaporator.

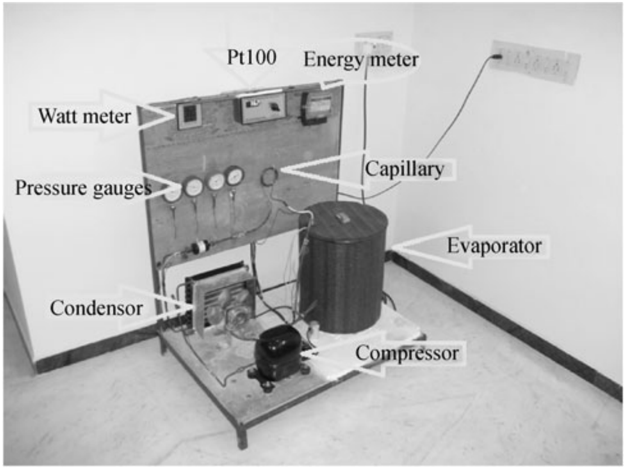


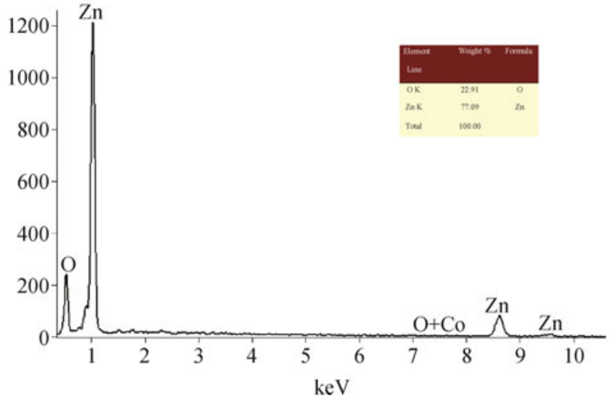
Fig. 1 Experimental test rig

Compressor is used to compress the low pressure and low temperature of refrigerant from the evaporator to high pressure and high temperature. After the compression process the refrigerant is then discharged into condenser. In the condenser, the condensation process requires heat rejection to the surroundings. The refrigerant can be condensed at atmospheric temperature by increasing the refrigerant's pressure and temperature above the atmospheric temperature. After the condensation process, the condensed refrigerant will flow into the expansion device, where the temperature of refrigerant will be dropped lower than the surrounding temperature caused by the reducing pressure inside the expansion device. When the pressure drops, the refrigerant vapor will expand. As the vapor expands, it draws the energy from its surroundings or the medium in contact with it and thus produces refrigeration effect to its surroundings. After this process, the refrigerant is ready to absorb heat from the space to be refrigerated. The heat absorption process is to be done in the evaporator. The heat absorption process is normally being called as evaporation process. The cycle is completed when the refrigerant returns to the suction line of the compressor after the evaporation process. The primary refrigerant for refrigeration systems is R-22 and R134a. R-22 and R134a are restricted due to environmental issues. A proposed replacement is R-152a has been studied in the work.

3 Preparation of ZnO nanorefrigerant

Nanoparticles of ZnO were added to the lubricant in the compressor unit of the system. The preparation and stability of this lubricant and nanoparticle mixture is very important. The desirable properties of nanolubricant were stable and durable suspension, less coagulation and it was ensured that there was no chemical reaction change in the prepared nanolubricant. The lubricant oil, a type commonly used in refrigeration and air-conditioning systems, is poly alkylene glycol (PAG). This oil was selected for its superior quality [22].

The nanoparticles of ZnO commercially available (Alfa Acer, USA) with 40 nm size with surface area 10–25 m^2/g was mixed with PAG to synthesize nanolubricant in a recommended method for nanofluid [23–25]. The EDX diffractogram and SEM micrograph of ZnO nanoparticle are shown in Fig. 2 and Fig. 3. PAG oil was used as supply by supply without further purification. In this work two-step process of preparation of nanolubricant was followed [25]. The nanoparticles of ZnO and PAG mixture were initially prepared with the aid of magnetic stirrer for 10 h. The mixture was then further kept vibrated with an ultrasonic homogenizer for 15 h to fully separate the nanoparticles and to prevent any clustering of particles in the mixture to obtain proper homogenization. Proper agitation in sonication process was done to ensure uniform dispersion and stability of the prepared nanolubricant in the refrigeration system. No surfactant was added in this work as there may be any influence in reduction of thermal conductivity and performance. The thermal conductivity of the ZnO nanolubricant has been measured using KD2 Pro thermal analyzer (Decagon Devices, Inc., USA) and the values are found to be 0.534 W/mK which is slightly more than the pure lubricant oil with thermal conductivity 0.496 W/mK [21,26–28].The prepared nano ZnO lubricant was then transferred into the compressor through the service port provided and the nano ZnO lubricant held in conical flask is shown in Fig. 4.



Element Line	Weight %	Formula
O K	22.91	O
Zn K	77.09	Zn
Total	100.00	

Fig. 2 EDX diffractogram of ZnO nanoparticles

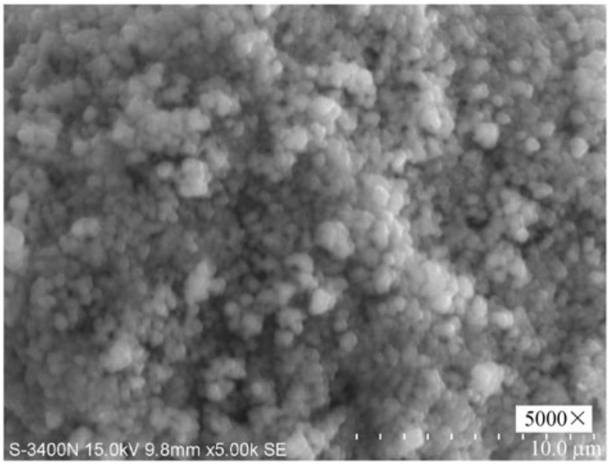


Fig. 3 SEM micrograph of (5000×) ZnO nanoparticles

4 Charging of experimental setup

The fabricated experimental setup was filled with N_2 gas at a pressure of 5 to 7 bar and this pressure is maintained for 5 h. Thus the system was ensured for no leakages. The system was evacuated by removing N_2 gas. A vacuum pump was connected to the port provided in the compressor and the system was completely evacuated for the removal of any impurities. This process was carried out for all the trials. The refrigerant R152a was charged through the charging line to the compressor. Precision electronic balance with accuracy±1% was used to charge into the system. Every time the system was allowed to stabilize for 10 min.

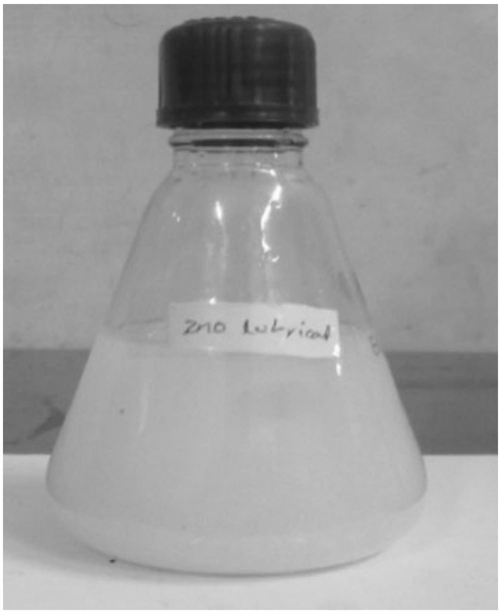


Fig. 4 Uniformly dispersed ZnO nanolubricant

5 Experimentation

The nanolubricant prepared with 0.1%v of ZnO nanoparticles was loaded in the compressor. The setup was charged with 150 g of the working fluid R152a and the performance tests were conducted. Similar tests were conducted with 0.3%v and 0.5%v concentration of ZnO. The suction temperature, discharge temperature, suction and discharge pressures were noted. The power consumption was measured with the help of digital watt-hr meter. The ratio between discharge pressure and suction pressure of the compressor is termed as pressure ratio of the refrigeration system. The concentration of ZnO nanofluid was varied from 0.1%v to 0.5%v.

6 Results and discussion

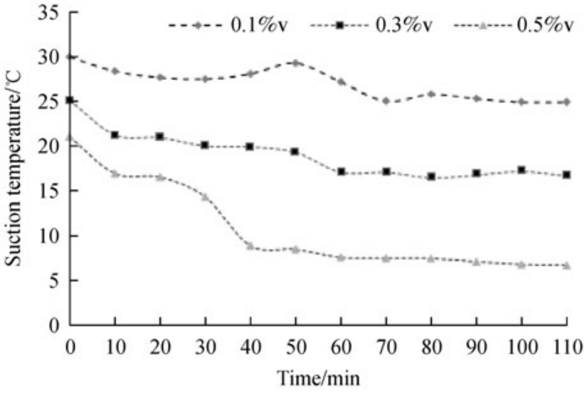


Fig. 5 Variation of suction temperature versus time

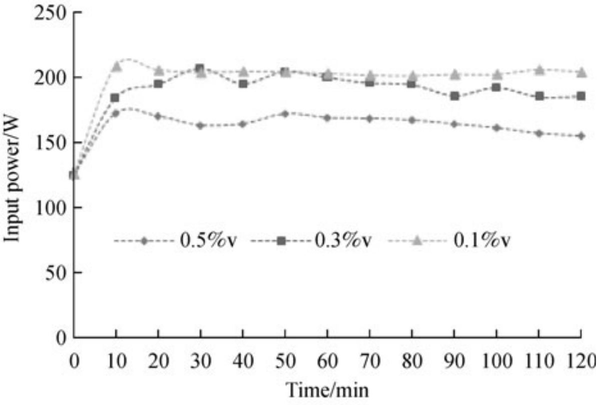


Fig. 6 Variation of power consumption versus time

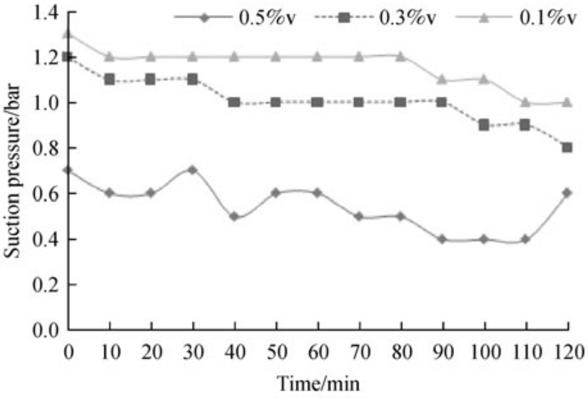


Fig. 7 Variation of suction pressure versus time

The suction temperature decreases with the addition of nano ZnO in the refrigerant. Figure 5 shows a lowest suction temperature with 0.5%v of nano ZnO. The input power to the compressor unit was found to be lesser for a nanoconcentration of 0.5%v as shown in Fig. 6. The suction and discharge pressure were found to decrease with increase in concentration of nano ZnO as shown in Fig. 7 and Fig. 8. The COP increases with increase in nanoconcentration because of the uniform distribution of nano ZnO particles in the lubricant. The Brownian motion of ZnO nanoparticles in the lubricant oil was found to be the reason for this increase in COP. Figure 9 shows enhanced increase in COP with a concentration of 0.5%v of ZnO. Higher value of 3.56 was obtained with 0.5%v of nano ZnO as against 3.12 without nano ZnO. Figure 10 shows the pull down temperature of the evaporator with time. With 0.5%v of ZnO there was a notable pull down effect. Increase in the concentration of the nanoconcentration decreases the pressure ratio as presented in Fig. 11. This reduction leads to reduction in compressor work input. Thus the life of the compressor extends in the

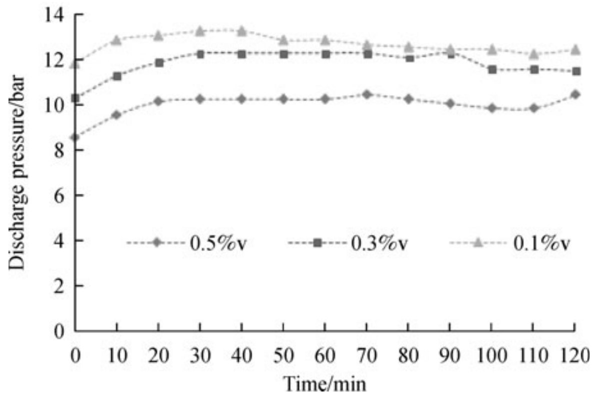


Fig. 8 Variation of discharge pressure versus time

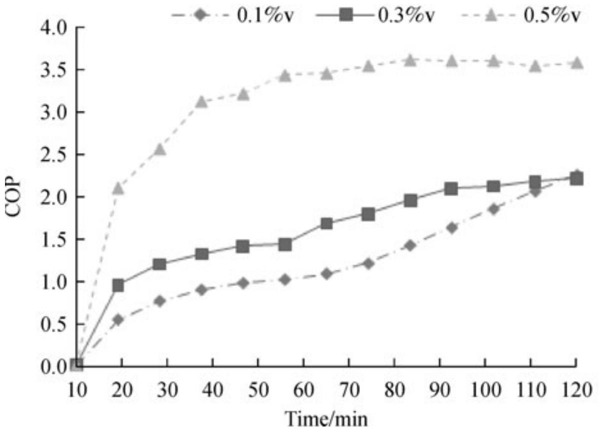


Fig. 9 Variation of coefficient of performance versus time

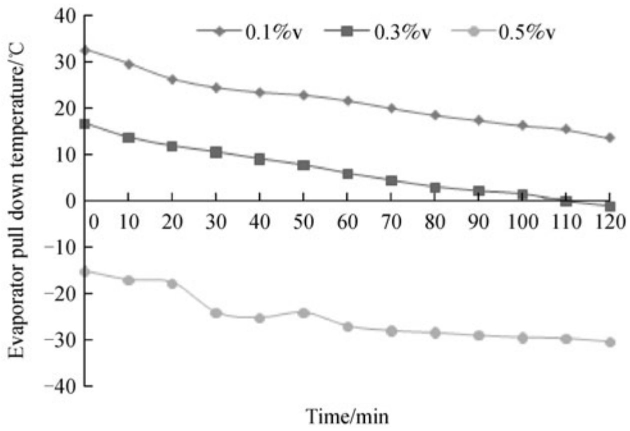


Fig. 10 Variation of pull down temperature versus time

system. The results obtained in the present study matches with the trend obtained by Sendil Kumar et al. [25]

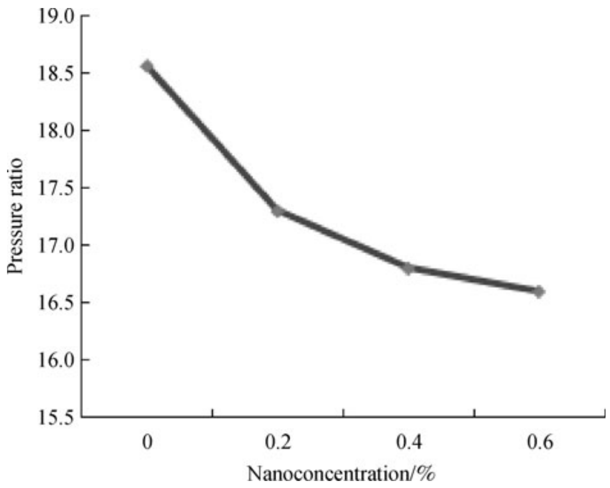


Fig. 11 Variation of pressure ratio with nanoconcentration

7 Conclusions

Based on the experimental results and discussion, the following conclusions have been drawn. The results showed that after adding nano ZnO refrigerant the performance of the refrigeration system was significantly improved and the results obtained matches with earlier research works [29,30].

- The system works safely with the replacement of R152a with the conventionally used R134a.
- No system modification was done for the retrofitting process which is a major advantage of the work.
- Increase in the concentration of nano ZnO increases the system performance.
- The COP increases with the increase in nanoconcentration of ZnO.
- Maximum COP of 3.56 was obtained with 0.5%v of ZnO.
- The suction temperature decreases with the increase in nanoconcentration.
- The input power decreases with increases in nanoconcentration. A reduction of 21% of power was obtained.
- The pull-down temperature of the evaporator decreases with time.
- The usage of R152a with very low GWP ensures safe and clean environment with low power consumption.
- The pressure ratio decreases with the increase in nano ZnO concentration. The pressure ratio was lowest for 0.5%v.

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