Performance improvement of vapour compression refrigeration system using Al$_2$O$_3$ nanofluid

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Abstract. Vapour compression refrigeration systems are widely used in the areas which experience hot climatic conditions. Performance improvement of vapour compression refrigeration system has been done before by using several designs and methods. But due to advancement in nanotechnology, nowadays nanofluids are considered as the most effective heat transfer fluids, having better heat transfer properties than the vintage fluids. In this paper, performance improvement of the vapour compression refrigeration system has been done by using Al$_2$O$_3$ nanofluid. Here three different concentrations 0.01%, 0.005% and 0.001% by wt. of Al$_2$O$_3$ have been used at three different operating temperatures i.e 28°C, 32 °C and 36°C. The results of the experiment showed that at 28°C the COP of the VCRS using Al$_2$O$_3$ nanofluid was enhanced by 25.7%, 17.46% and 11.74% for 0.01%, 0.005% and 0.001% by wt. of Al$_2$O$_3$ respectively as compared to the conventional system.

1. Introduction

Refrigeration systems have become one of the most important utilities for people's daily lives. With the advancement and technological developments in the field of refrigeration new methods are developed to increase the COP of the systems.[1] Traditional methods for exchanging heat from the system involves increment in the surface area but this leads to the increase in the size of the system, so there was need of some efficient way that can enhance the heat transfer. The inventive idea of using nanofluids, fluids which consist of suspended nanoparticles are used to remove such kind of barriers.[2] Nano particles of Al$_2$O$_3$, TiO$_2$ and CuO are used due to their higher thermal conductivity to achieve better efficiency.[3] Mishra et al. [4] experimentally evaluated the performance of a vapour compression refrigeration system by using Cu, Al$_2$O$_3$, CuO and TiO$_2$ based nano refrigerants in the primary circuit. The experimental results showed that the C.O.P of the system using Al$_2$O$_3$/R134a nano refrigerant was enhanced by 35% which was highest among all other nanorefrigerants. Shengshan Bi et al. [5] tested on a domestic refrigerator in which they mixed mineral oil TiO$_2$ as the lubricant with refrigerant R600a. They found that the system when operated with the nano refrigerant, it worked efficiently and the performance of the system was improved when it was compared to a system that uses only R600a. Subramani & Prakash [6] used Al$_2$O$_3$ at 0.06% weight in the mineral oil. They concluded that there was the reduction in power consumption up to 25% when POE oil is replaced by a mixture of mineral oil and alumina nanoparticles. Kumar et al. [7] examined heat transfer enhancement using nanofluid Al$_2$O$_3$ & R600a/mineral oil as working fluid in a domestic refrigerator, their result showed an increase in COP by 19.6% and reduction in power consumption by 11.5%. Abbas et al. [8] performed the analysis of an air conditioning system by using a concentration of 0.01-0.1 wt% of CNT Polyester oil with refrigerant R134a. The results concluded that usage of CNT particles concentration of 0.1% by weight results in highest heat transfer and the COP was enhanced by 4.2%. Sabareesh et al. [9] investigated experimentally the effects of using nanofluids in VCRS as a lubricant additive, the nanoparticle used in the experiment was TiO$_2$. The results of the experiment showed that the when nanofluid used in 0.01% by volume concentration the heat transfer of the system was enhanced by 3.6% that leads to the increase in COP by 17%.
In this paper, the experiment was performed to enhance the COP of VCRS using Al$_2$O$_3$ nanofluid. Here Al$_2$O$_3$ nanoparticles were mixed with distilled water to prepare three different solutions (0.01, 0.005 and 0.001% by wt.). Evaporator coil was then dipped in each solution and their effect on system performance was examined at three different operating temperatures (28°C, 32°C and 36°C). Further, the results were compared with those for conventional system i.e when evaporator coil is fully immersed in 100% water.

2. Preparation of Nanofluid

The nanofluid was prepared by a two-step method, the Al$_2$O$_3$ nanoparticles were purchased from Sisco Research Laboratories, India. The desired amount of Al$_2$O$_3$ nanoparticles were dissolved to prepare three solutions (0.01%, 0.005% and 0.001% by weight) in distilled water. After preparing the suspension it was kept in the ultrasonic bath for 60 minutes to prevent agglomeration of the particles.

3. Experimental setup

The experimental setup consists of four main parts. These are compressor, condenser, expansion valve and evaporator (shown in the figure 1). The working fluid or refrigerant (R134a) takes the heat of the substance which is to be cooled and changes its phase in the evaporator coils into vapour, these evaporator coils are dipped in the suspension of Al$_2$O$_3$ and distilled water. The refrigerant vapour at low pressure and low temperature then enter the compressor where it is compressed isentropically and consequently its temperature and pressure increases significantly. From the compressor, the refrigerant at high-temperature and pressure goes to the condenser where it rejects heat to the atmosphere and once again changes its phase to liquid. After the condenser, the liquid refrigerant moves through the capillary tube where it is isentropically throttled and its temperature and pressure is reduced. The setup consists of the following components:

![Figure 1. Schematic diagram of setup](image_url)
4. Formulae used

The following formulae are used for the calculation:

A. Compressor Work, \( W_c = (h_2 - h_1) \) \( \quad (1) \)
B. Cooling effect produced, \( Q_r = (h_1 - h_4) \) \( \quad (2) \)
C. COP = \( Q_r / W_c \) \( \quad (3) \)

Where,
\( h_1 \) = enthalpy of refrigerant at inlet of compressor in kJ/kg
\( h_2 \) = enthalpy of refrigerant at exit of compressor in kJ/kg
\( h_3 \) = enthalpy of refrigerant at exit of the condenser kJ/kg
\( h_4 \) = enthalpy of refrigerant at inlet of evaporator in kJ/kg

5. Experimental data

The following data are recorded after steady state condition is achieved at three ambient temperatures.

| Components         | Specification                                      |
|--------------------|---------------------------------------------------|
| 1. COMPRESSOR      | HERMATICALLY SEALED GAS COMPRESSOR WITH ELECTRICAL ACCESSORIES MODEL: KCJ44HAG-B220H RATED POWER CONSUMPTION: 450W |
| 2. CONDENSER       | DIAMETER OF PIPE: 3/8” LENGTH OF PIPE: 13” NUMBER OF ROWS: 3 NUMBER OF PIPES IN EACH ROW: 12 MATERIAL OF PIPES: COPPER |
| 3. CAPILLARY TUBE  | DIAMETER: 0.5mm TO 2.5mm LENGTH: 0.5m TO 5m CAPILLARY TUBE USED: 40 NO. CAPILLARY |
| 4. EVAPORATOR      | OUTER COIL DIAMETER: 9” INNER COIL DIAMETER: 6” NUMBER OF COILS: 11 EACH |

| SYMBOL | UNITS | 28°C | 32°C | 36°C |
|--------|-------|------|------|------|
| \( p_{ev} \) | bar   | 3.9  | 3.5  | 4.9  |
| \( p_{cond} \) | bar   | 18   | 14   | 21   |
| \( T_1 \) | °C    | 15   | 18   | 21   |
| \( T_2 \) | °C    | 71   | 67   | 76   |
| \( T_3 \) | °C    | 61   | 56   | 76   |
| \( T_4 \) | °C    | 6    | 4    | 8    |
6. Result table

Performance results for varying concentrations of Al₂O₃ nanofluid at different ambient temperature

| Symbols | Units | 28°C | 32°C | 36°C |
|---------|-------|------|------|------|
|         | Conventional system |       |       |      |
| Qᵣ      | kJ/kg | 111.45 | 129.8 | 123.9 | 119.77 | 102.92 | 123.1 | 111.24 | 103.87 | 89.5 | 111.59 | 103.48 | 96.46 |
| Wᵣ      | kJ/kg | 33.54 | 31.1 | 31.7 | 32.22 | 33.8 | 31.47 | 32.04 | 32.8 | 34.25 | 32.09 | 32.36 | 33.19 |
| CO₂     |       | 3.32 | 4.17 | 3.90 | 3.71 | 3.04 | 3.91 | 3.47 | 3.16 | 2.61 | 3.47 | 3.19 | 2.91 |

Qᵣ = Refrigerating effect

Wᵣ = Compressor work

7. Performance results and discussions

7.1 Effect of ambient temperature on refrigerating effect

![Figure 2. Variation of refrigerating with ambient temperature](image)

The above graph between refrigerating effect and ambient temperature shows a downward trend with an increase in ambient temperature for all the cases. At 28°C ambient temperature, the concentration having 0.01% of nano-particles by weight shows the highest refrigerating effect, as the concentration of nano-particles is reduced from 0.01% to 0.001% refrigerating effect is also decreased significantly. At 32°C, the refrigerating effect of 0.01% concentration is 123.1 kJ/kg, while that of the 0.005% and
0.001% is 111.24 kJ/kg and 103.87 kJ/kg respectively and at 36°C, the values for (0.01%, 0.005%, 0.001%) is 111.59 kJ/kg, 103.48 kJ/kg, 96.46 kJ/kg respectively.

7.2 Effect of ambient temperature on compressor work

![Compressor work vs Ambient temperature](image)

Figure 3. Variation of compressor work with ambient temperature

The variation of compressor work with ambient temperature is shown above. The compressor has to do more work as the ambient temperature increases. The lowest compressor work was obtained at 28°C in case of 0.01% concentration, i.e., 31.1 kJ/kg. At 32°C compressor work of different concentration (0.01%, 0.005%, 0.001%) is 31.47 kJ/kg, 32.04 kJ/kg, 32.8 kJ/kg. Similarly, at 36°C the compressor work for 0.001% is 33.19 kJ/kg and for the 0.01% is 32.09 kJ/kg.

7.3 Effect of ambient temperature on COP

![COP vs Ambient temperature](image)

Figure 4. Variation of COP with ambient temperature

The variation of COP versus ambient temperature is shown in the graph above. As the highest refrigerating effect was shown by the 0.01% concentration of nan-particles, COP is also highest in this case at all temperatures. At 28°C, 32°C & 36°C ambient temperature, the COP for the three cases is as follows; 4.17, 3.91, 3.47 for 0.01% concentration, 3.9, 3.47, 3.19 for 0.005% concentration and 3.71, 3.16, 2.91 respectively.
8. Conclusion

In this experimental analysis, our prime focus was to increase the COP of the vapour compression refrigeration system by incorporating different concentrations of nano-particles. The experiments were performed at three ambient temperatures viz., 28°C, 32°C, 36°C which yielded the results as follows:

- At 28°C, the COP of the VCRS using Al₂O₃ nanofluid was enhanced by 25.7%, 17.4% and 11.7% for 0.01%, 0.005% and 0.001% by wt. of Al₂O₃ respectively as compared to the conventional system.
- At 32°C, the percentage enhancement of COP using Al₂O₃ nanofluid was 28.6%, 14.1% and 3.9% for 0.01%, 0.005% and 0.001% by wt. of Al₂O₃ respectively as compared to the conventional system.
- At 36°C, COP of the VCRS using Al₂O₃ nanofluid was increased by 32.9%, 22.2% and 11.5% for 0.01%, 0.005% and 0.001% by wt. of Al₂O₃ respectively as compared to the conventional system.

9. References

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