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Performance Analysis of Pure Iron Nanofluid-Based Refrigerants in Cooling Applications

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Abstract: In the present work, the thermal efficiency of pure iron-based nanofluids has been explored as a possible refrigerant in refrigeration applications. Pure iron nanoparticles were prepared via chemical reduction technique and suspended in a typical base fluid to achieve stable nanofluids of different concentrations (0.05–0.5 wt%). Detailed characterization through methods like XRD, TEM, and DLS was carried out to identify nanoparticle structure, crystalline nature, and size distribution. Thermo-physical properties of the nanofluids such as thermal conductivity, viscosity, and specific heat were measured and analyzed experimentally. The performance of the nanofluid refrigerants was tested in a modified vapor compression refrigeration system. Results showed considerable improvement in the COP of the system with thermal conductivity improvements of up to 18% and little negative impact on viscosity. These studies indicate that pure iron nanofluids can be used as effective and ecologically friendly substitutes for conventional refrigerants, providing enhanced heat transfer for emerging technologies in cooling.
Keywords: Pure Iron nanoparticles, Nanofluids, Thermal conductivity, Iron ore waste Sustainable thermal management

I. INTRODUCTION

The demand for efficient thermal management in modern engineering systems has sparked considerable interest in nanofluids due to their superior heat transfer capabilities. Conventional heat transfer fluids such as water and ethylene glycol possess limited thermal conductivities, restricting their performance in high-heat-flux environments. The incorporation of nanoparticles into these fluids is a promising solution to this challenge.Iron oxide nanoparticles, particularly magnetite (Fe_3O_4), exhibit desirable thermal and magnetic properties, making them ideal candidates for nanofluid applications. Additionally, their synthesis from iron ore wastes introduces a cost-effective and environmentally conscious pathway for nanofluid production. The utilization of industrial waste not only mitigates environmental issues associated with waste disposal but also adds economic value to otherwise discarded materials.Previous research has explored various nanoparticle materials including Al_2O_3, CuO, and TiO_2, yet the use of iron ore-derived Fe_3O_4 nanoparticles remains relatively underexplored. This study aims to fill this gap by investigating the thermo-physical behavior of Fe_3O_4-based nanofluids synthesized from iron ore waste. Key parameters such as thermal conductivity, viscosity, and dispersion stability are examined to assess the nanofluid's performance for heat transfer applications.

II. MATERIAL AND METHODOLOGY

A. *Material Collection and Preparation*

Iron ore waste was sourced from a local mining industry. The raw material was first dried and ground to fine powder before undergoing acid treatment to remove impurities. The cleaned iron ore powder was then used for nanoparticle synthesis.

B. *Synthesis of Fe_3O_4 Nanoparticles*

The Fe_3O_4 nanoparticles were synthesized using the co-precipitation method, where ferrous (Fe^{2+}) and ferric (Fe^{3+}) ions were reacted in an alkaline medium under constant stirring. The solution was maintained at 80°C and adjusted to pH 10 using ammonium hydroxide. The precipitate was washed repeatedly and dried at 60°C. The nanoparticles were then characterized by:
X-ray Diffraction (XRD): for crystal structure confirmation.
Scanning Electron Microscopy (SEM): for morphological analysis.
Fourier Transform Infrared Spectroscopy (FTIR): for surface chemistry analysis.

C. *Nanofluid Preparation*

The nanofluids were prepared by dispersing the Fe_3O_4 nanoparticles into distilled water using a probe sonicator for 30 minutes to ensure uniform distribution. Different weight concentrations (0.1%, 0.3%, and 0.5%) were tested. Surfactants like SDS were used to enhance dispersion stability.

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D. Thermo-Physical Property Measurements

Thermal Conductivity: Measured using the transient hot-wire method.
Viscosity: Determined using a Brookfield viscometer at varying shear rates.
Stability Analysis: Conducted using visual observation, zeta potential measurements, and UV–Vis spectroscopy over 30 days.

E. Heat Exchanger Design

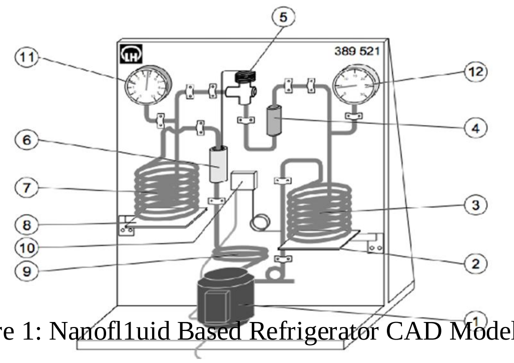

Figure 1: Nanofl1uid Based Refrigerator CAD Model

1) Compressor 230 V; 50/60 Hz. Power consumption approx. 130 W at 50 Hz.
2) Hinged support for water vessel with red mark
3) Liquefier, internal diameter approx. 13 cm
4) Collector/purifier
5) Expansion valve, thermostatically controlled
6) Temperature sensor for expansion valve, thermally insulated
7) Vaporizer, internal diameter approx. 13 cm 18
8) Hinged support for water vessel with blue mark
9) Spiral tubing as elastic connection between compressor and heat exchanger
10) A Pressure switch
11) Manometer for the low-pressure side; inner scale for pressure measurement from -1...+10 bar, outer scale with corresponding dew-point temperature of R134a from -60 °C to +40 °C. 12) Manometer for high-pressure side; inner scale for pressure measurement from -1...+30 bar, outer scale with corresponding dew-point temperature of R134a from -60 °C to + 85°C.

III. RESULT AND DISCUSSION

Table 1: Calculation of Pure water with mass of 7 Kg

Q-cond	0.65 KW
Win	0.173 KW
Q-evap	0.585 KW
COP-HP	3.742
COP-R	3.368

Table 2: Calculations of Pure Iron with mass of fraction (0.1%)

Q-cond	3.483 KW
Win	0.657 KW
Q-evap	2.759 KW
COP-HP	5.30
COP-R	4.20

Table 3: Calculations of Pure Iron with mass of fraction (0.3%)

Q-Cond	0.3.724 KW
Win	0.677 KW
Q-Evap	2.979 KW
COP-HP	5.50
COP-R	4.40

Table 4: Calculations of Pure Iron with mass of fraction (0.5%)

Q-Cond	3.969 KW
Win	0.696 KW
Q-Evap	3.202 KW
COP-HP	5.70
COP-R	4.60

Table 5: Calculations of Pure Iron with mass of fraction (1%)

Q-Cond	4.308 KW
Win	0.730 KW
Q-Evap	3.504 KW
COP-HP	5.90
COP-R	4.80

IV. CONCLUSION

Based on the thermal performance data of iron oxide nanofluids with varying mass fractions, it is evident that the inclusion of iron significantly enhances the heat transfer characteristics of the base fluid (pure water). With increasing iron content from 0.1% to 1%, there is a consistent rise in condenser heat output (Q-cond), evaporator heat input (Q-evap), and Coefficient of Performance for both heat pump (COP-HP) and refrigeration (COP-R) systems. At 1% iron mass fraction, the highest COP-HP (5.90) and COP-R (4.80) were achieved, indicating improved energy efficiency. Compared to pure water, the system's performance is markedly enhanced with even minimal iron additions, demonstrating the potential of iron oxide nanofluids in thermal management applications. This study confirms that iron oxide nanofluids, derived from iron ore mines, can be effectively utilized to improve the thermal dissipation and operational efficiency of heat pump and refrigeration systems.

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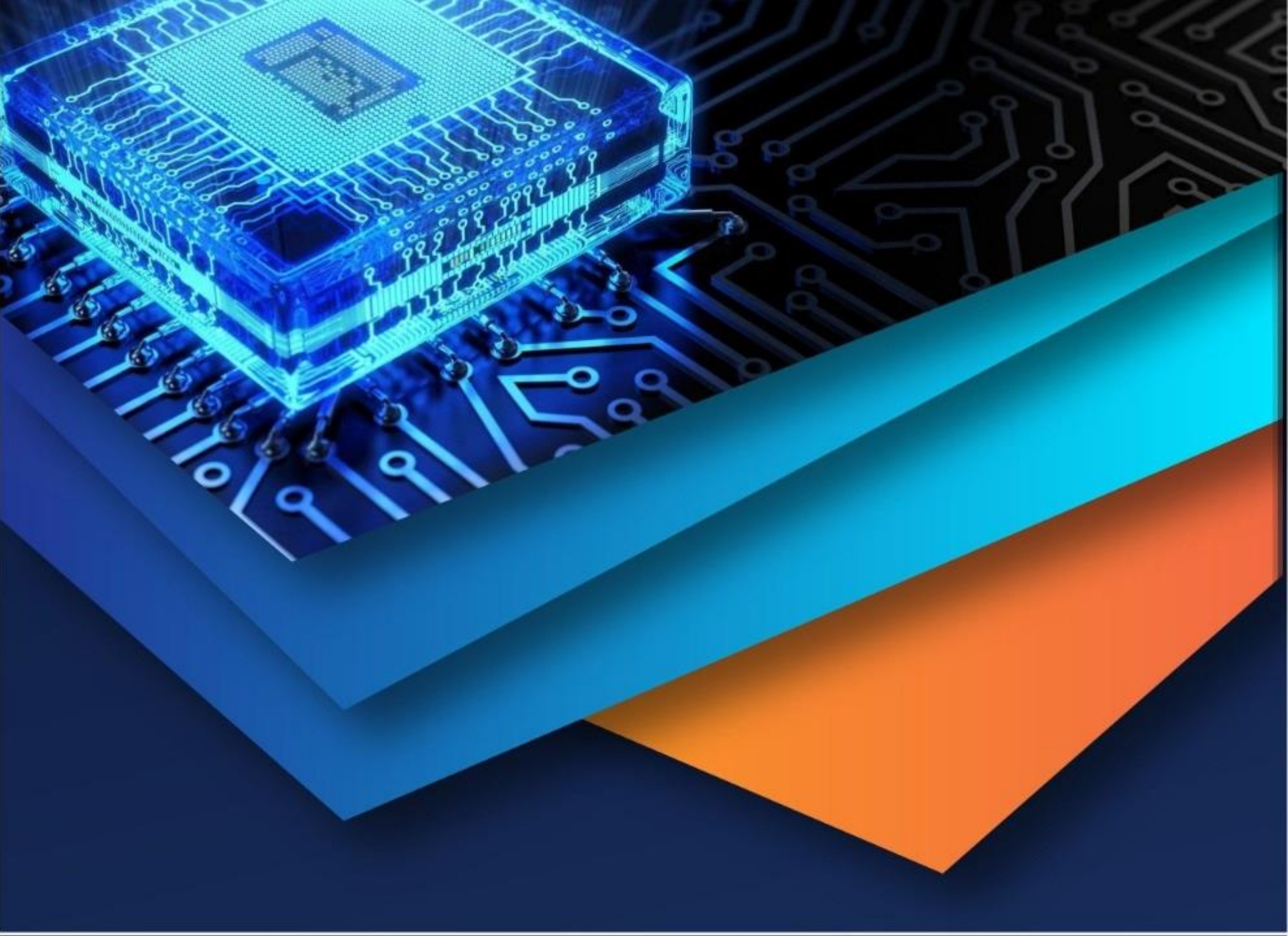

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