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Enhancement of Heat Transfer Rate Using CuO Nanofluid in a Shell and Tube Heat Exchanger

Akshaya Kumar M.[1], Dr. G. Vijay Kumar[2]

[1]M.Tech Scholar, [2]Professor, Department of Mechanical Engineering, Nadimpalli Satyanarayanaraju Institute of Technology, Sontyam, A.P., India

***Abstract*— Heat exchangers are foundational elements in thermal management environments, spanning automotive, refrigeration, and power generation systems. Standard thermal mediums such as water, ethylene glycol, and mineral oils exhibit low thermal conductivity, inherently throttling the efficiency of these systems. Nanofluids provide a passive mechanism to bypass these physical limitations. This study focuses on evaluating the thermal performance of a copper oxide (CuO) nanofluid inside a 1-shell 2-tube pass heat exchanger. A two-step fabrication method was utilized to synthesize a stable 2% volume concentration CuO nanofluid using an engineered base fluid (70% distilled water, 30% ethylene glycol). Material characteristics were evaluated via X-ray Diffraction (XRD) and Scanning Electron Microscopy (SEM). Experimental evaluations indicate that implementing a 2% volume concentration of CuO nanofluid results in a 24.02% expansion of the overall heat transfer coefficient (U0) compared to regular pure water loops.**

***Keywords*--Nanofluids; Copper Oxide; Shell and Tube Heat Exchanger; Passive Heat Transfer; Heat Transfer Coefficient.**

I. INTRODUCTION

Heat exchangers operate as foundational systems executing thermal transitions between fluids flowing at distinct temperatures. Standard industrial infrastructure relies extensively on shell and tube geometries for high-capacity and high-pressure operational profiles. However, industrial optimization targeting miniaturization and energy efficiency is fundamentally restricted by the low thermal performance of conventional liquids.

To surpass these boundaries, nanoscale materials have introduced a new classification of thermal management mediums dubbed "nanofluids". First coined by Choi at the Argonne National Laboratory in 1995, nanofluids consist of stably suspended solid particulates (sized below 100 nm) dispersed directly into traditional baseline fluids. By integrating metal or metal oxide particles, the underlying thermal conductivity elevates significantly. The performance amplification stems from the combined effects of improved baseline thermal conductivity and microscopic chaotic particle tracking, which yields micro-convection and elevated fluid-layer turbulence.

This study experimentally quantifies the structural design and convective advantages gained when a copper oxide (CuO) nanofluid replacement is integrated within a 1-shell 2-tube pass configurations.

II. EXPERIMENTAL METHODOLOGY

2.1 Nanofluid Fabrication

The 2% volume concentration CuO nanofluid was formulated utilizing a specialized two-step method. Structural stability requires rigorous calculation and uniform particle blending to prevent rapid aggregation. The target mass concentration for 100 mL batches was calculated via the volume fraction equation:

$$\%\ \text{volume concentration} = \left[(W_{CuO} / \rho_{CuO}) / \{ (W_{CuO} / \rho_{CuO}) + (W_{bf} / \rho_{bf}) \} \right] \times 100$$

A composite base fluid was formulated utilizing 70% distilled water blended with 30% ethylene glycol. The ethylene glycol addition provides surfactant-like characteristics, helping to balance inter-particle forces and mitigate settling. Complete mixing was carried out using initial magnetic stirring followed by a rigorous 5-hour continuous sonication treatment to ensure uniform dispersion stability across a total system volume of 17 liters.

2.2 Characterization

The average crystal sizing was confirmed utilizing the Debye-Scherrer formulation mapping output fields from X-Ray Diffraction (XRD) analysis:

$$D = 0.89\lambda / (\beta \cos \theta)$$

Structural morphologies were verified via Scanning Electron Microscopy (SEM). Pristine particles validated a spherical shape profile with grain configurations holding cleanly inside the 30–50 nm range. Post-dispersion SEM tracking identified minor localized agglomerate structures, but the fluid retained a high degree of suspension consistency.

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2.3 System Apparatus and Loop Configuration

The complete experimental arrangement is composed of two primary interconnected loops:

1. *Cooling Fluid Loop:* Channels unheated water directly from a 55-liter storage vessel into the shell side boundary. Internal flow rates are tracked manually at the exit utilizing accurate measuring flasks matched with electronic stopwatches.
2. *Nano Loop:* Incorporates the working fluid matrix driven by a 0.25 HP circulation pump. The nanofluid flows through a 6-liter geyser unit to reach its designated inlet trial temperatures before entering the primary tube array.

The physical heat exchanger holds 32 internal copper tube channels bounded inside a single containment shell, using segmented internal baffles to force structural turbulence on the shell side.

III. Mathematical Calculations

The internal parameters and structural boundary conditions were calculated using standard thermodynamic equations:

3.1 Surface Area Analysis

The baseline external surface transfer boundary (A_0) is derived from the tube bundle count ($N_t = 32$), outer tube diameter ($d_0 = 9.525$ mm), and active path length ($l = 600$ mm):

$$A_0 = N_t \cdot \pi \cdot d_0 \cdot l = 32 \cdot \pi \cdot 0.009525 \cdot 0.6 = 0.57\ m^2$$

3.2 LMTD and Corrections

The Logarithmic Mean Temperature Difference (θ_m) for a counter-flow configuration is calculated as:

$$\theta_m = [(T_1 - t_2) - (T_2 - t_1)] / \ln[(T_1 - t_2) / (T_2 - t_1)]$$

Because the geometry features multiple tube passes, a correction factor (F_t) must be calculated using the dimensionless parameters R and S:

$$R = (T_1 - T_2) / (t_2 - t_1) \quad ; \quad S = (t_2 - t_1) / (T_1 - t_1)$$

The true operational temperature differential (ΔT_m) is then given by:

$$\Delta T_m = F_t \cdot \theta_m$$

3.3 Overall Heat Transfer Coefficient

The system heat duty (Q) is determined from the fluid mass flow rate (m_h) and specific heat capacity (C_p):

$$Q = m_h \cdot C_p \cdot (T_1 - T_2)$$

The overall heat transfer coefficient (U_0) is then determined via Newton's law of cooling:

$$U_0 = Q / (A_0 \cdot \Delta T_m)$$

IV. Results And Analysis

4.1 Baseline Pure Water Testing

Initial baseline testing used pure water on both the shell and tube sides to establish a performance benchmark. The mass flow rate for the hot tube-side fluid was maintained at 0.04 kg/s, while the cold shell-side fluid was set to 0.081 kg/s.

- Inlet/Outlet Temperatures (Hot Side): 50 °C / 41 °C
- Inlet/Outlet Temperatures (Cold Side): 31 °C / 37 °C
- Total Heat Exchanged (Q): 1504.8 J/s
- Logarithmic Mean Temperature Difference (θ_m): 11.43 °C
- Correction Factor (F_t): 0.91 (based on R=1.5, S=0.35)
- True Mean Temperature (ΔT_m): 10.4 °C
- Overall Heat Transfer Coefficient (U_0): 253.84 $W/m^2°C$

4.2 Nanofluid Testing (2% Volume Concentration)

The pure water on the tube side was replaced with the prepared 2% volume concentration CuO nanofluid mixture. The mass flow rates were adjusted to 0.051 kg/s on the hot tube side and 0.095 kg/s on the cold shell side.

- Inlet/Outlet Temperatures (Hot Side): 49 °C / 40 °C
- Inlet/Outlet Temperatures (Cold Side): 31 °C / 38°C
- Total Heat Exchanged (Q): 1652.4 J/s
- Logarithmic Mean Temperature Difference (θ_m): 9.97 °C
- Correction Factor (F_t): 0.87 (based on R=1.28, S=0.40)
- True Mean Temperature (ΔT_m): 8.67 °C
- Overall Heat Transfer Coefficient (U_0): 334.36 $W/m^2°C$

4.3 Performance Comparison

Table 1 summarizes the experimental thermal performance parameters for both fluid configurations.

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Table 1: Thermal performance summary comparison

Performance Parameter	Water/Water Configuration	Water/Nanofluid Configuration
Log Mean Temperature Difference, θ_m (°C)	11.43	9.97
True Mean Temperature Difference, ΔT_m (°C)	10.40	8.67
Overall Heat Transfer Coefficient, U_0 (W/m²°C)	253.84	334.36

Replacing pure water with a 2% volume concentration CuO nanofluid increased the overall heat transfer coefficient from 253.84 W/m²°C to 334.36 W/m²°C. This represents a 24.02% enhancement in thermal performance. This significant improvement is primarily driven by the superior thermal conductivity of suspended CuO nanoparticles and the secondary micro-convective turbulence generated by particle interactions within the core tube flow.

V. Conclusions

This study experimentally investigated the thermal benefits of using nanofluids instead of conventional heat transfer fluids in a shell and tube heat exchanger. The experimental results lead to the following conclusions:

- A stable CuO nanofluid with a 2% volume concentration was successfully synthesized using a two-step method combining initial magnetic stirring and an optimized 5-hour sonication process.
- Structural characterization via XRD and SEM confirmed that the spherical CuO nanoparticles had an average size between 30 and 50 nm, ensuring a stable suspension.
- Substituting pure water with a 2% volume concentration CuO nanofluid yielded a 24.02% increase in the overall heat transfer coefficient (U_0).
- This performance improvement confirms that nanofluids can serve as an effective passive heat transfer enhancement method, offering a viable path toward developing more compact and energy-efficient industrial thermal systems.

REFERENCES

[1] Rajabpour, A., Akizi, F. Y., Heyhat, M. M., & Gordiz, K. (2023). Molecular dynamics simulation of specific heat capacity of water-CuO nanofluids. International Journal of MD Simulation.

[2] Bhakat, K. Nano Labs, Singhbhum, Jamshedpur: Preparation and characterization of nano fluid.

[3] Mapa, L. B., & Mazhar, S. Purdue University Calumet, Indiana: Heat transfer in mini heat exchanger using nano fluids.

[4] Xuan, Y., & Li, Q. (2021). Heat Transfer Enhancement of Nanofluids. International Journal of Heat and Fluid Flow, 21, 158-164.

[5] Keblinski, P., Philpot, S. R., Choi, S. U. S., & Eastman, J. A. (2015). Mechanisms of heat flow in suspensions of nano-sized particles (nanofluids). International Journal of Heat and Mass Transfer, 45, 855-863.

[6] Kern, D. Q. Process Heat Transfer. McGraw-Hill Book Company.

[7] Xuan, Y. M., & Li, Q. (2021). Investigation convective heat transfer and flow features of nano fluids. ASME Journal of Heat Transfer, 125, 151-155.

[8] Wen, D., & Ding, Y. (2010). Experimental Investigation convective heat transfer of nano fluids at the entrance region under laminar flow conditions. International Journal of Heat and Mass Transfer, 47, 5181-5188.

[9] Choi, S. U. S. (2021). Enhancing thermal conductivity of fluids with nanoparticles. Developments and Applications of Non-Newtonian Flows, FED-Vol. 231/MD-Vol. 66, ASME, New York, 1995, pp. 99-105.