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PERFORMANCE EVALUATION OF INNOVATIVE TYPE HEAT EXCHANGER USING Al_2O_3 NANOFLUID

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Abstract – The experimental Performance investigation is carried out for innovative type heat exchanger such as spiral tube heat exchanger (STHE) using Al_2O_3 nanofluid. The objective of this study is to determine the effects of the variation of mass flow rate of cold fluid and inlet temperature of hot and cold fluid on the performance of heat exchanger in terms of effectiveness, overall heat transfer coefficient, performance index and pressure drop. Working fluids used for experimental investigation are hot water as hot fluid, cold water as cold fluid and Al_2O_3 nanofluid.

***Key Words*:** Al_2O_3 Nanofluid, Spiral tube heat exchanger (STHE), , Heat Exchanger, Effectiveness.

1. INTRODUCTION

Heat exchanger is a device which is important and expensive equipment which is used in almost all fields of process such as food and dairy process, waste heat recovery process, air conditioning and refrigeration systems also used across industries such as power generation, pharmaceutical, petrochemicals and chemical reactors to transfer heat efficiently between two fluids without mixing them. The most commonly used heat exchangers are shell and tube heat exchangers which face drawbacks like large space requirements, lower heat transfer efficiency and high fouling tendencies.

To overcome these challenges, compact heat exchangers with innovative geometries, such as spiral tube heat exchangers, have been developed. Their unique geometry enhances heat transfer while reducing size and cost. Research on spiral tube heat exchangers remains limited.

Simultaneously, the use of nanofluids suspensions of nanoparticles in conventional fluids has emerged as a promising method for improving thermal performance due to their enhanced thermal conductivity. Combining spiral tube designs with nanofluids offers significant potential for developing high-efficiency, compact heat exchangers.

In parallel, the use of nanofluids- fluids containing nanoparticles like Aluminium Oxide (Al_2O_3) dispersed in water has gained attention because of their higher thermal conductivity and potential to improve heat transfer rates. By combining spiral tube geometry with nanofluids, it becomes possible to design compact, efficient and cost effective heat exchangers for industrial applications.

As the geometry of Spiral tube heat exchanger is compact as compared to the conventional shell and tube heat exchanger and also less research work is carried out to investigate the performance of this type of heat exchanger. The research work carried out is mostly on the air and water as working fluid. Keeping these aspects in the mind, the following main objectives are confirmed to carry out the present experimental work.

1. Experimentally study the effect of of spiral coil on the performance of spiral tube heat exchanger.

2. Experimentally study the effect of various composition of Al_2O_3 nanofluid on the performance of spiral tube heat exchanger.
3. Compare the results of heat exchanger performance with nanofluid and without nanofluid.
4. Study the feasibility of nanofluid, in the spiral tube heat exchanger for enhancing the heat transfer rate.

2. LITERATURE REVIEW

Kundan L. et al. (2021) conducted experimental work by manufacturing a horizontal double-tube counter-flow heat exchanger with and without twisted tape inserts (twist ratio of 3.2, 4, and 6) using $TiO_2 - H_2O$ nanofluid. They found that the convective heat transfer coefficient for $TiO_2 - H_2O$ nanofluid (0.05% by vol.) was 4–6% higher than the base fluid. Additionally, they observed increases in heat transfer coefficients of 6%, 10.9%, 17.4%, and 23.4% for volume concentrations of 0.05%, 1%, 2%, and 3% of TiO_2 nanoparticles, respectively. When employing twisted tape inserts with a twist ratio of 3.2, the heat transfer coefficient increased by 45%. They also studied the heat transfer coefficient for different types of nanofluids such as; $TiO_2 - H_2O$, $Al_2O_3 - H_2O$, and CuO- H_2O with 1% concentration of nanoparticles (by vol.) at different Reynolds' numbers. The results obtained by using the two-phase model approach (ANSYS Fluent 14.5) are significantly close to the experimental results than the single-phase approach. The simulated results show no significant effect of the size (30 nm and 50nm) of nanoparticles (TiO_2) on the heat transfer coefficient values of $TiO_2 - H_2O$ nanofluid at 0.05% volume concentration. Notably, the use of twisted tape inserts with plain water as the working fluid increased the heat transfer coefficient by 34–36% (maximum) and the friction factor by 2.1 times.

Zheng M. et al. carried out their experimental study to investigate the effects of $Al_2O_3 - H_2O$ nanofluid with a mean diameter of 50 nm on heat transfer performance in a counter flow double-pipe heat exchanger. During their experimentation they pass the nanofluid through inner pipe of the double-pipe heat exchanger as a cold side fluid considering fully developed turbulent flow regime with different Reynolds numbers ranging from 20,000 to 60,000. They conducted experiments by varying the flow rates of nanofluid within the range from 1.1 to 3.9 m^3/h along with inlet temperature of 400C and 500C the volume concentration of nanofluid is varying from 0.25% and 0.5%. Results indicate that the Nusselt number increases with increasing nanoparticles volume concentration and Reynolds number but decreases with the inlet temperature at cold side of double-pipe heat exchanger. The maximum increase of Nu is respectively 23.2% and 32.23% for inlet temperature of 40 °C and 50 °C. Numerical analysis is done by using the single-phase model in Computational Fluid Dynamics adopted to simulate the heat transfer performance by ANSYS Fluent commercial software. They found that the simulated results show a good agreement with the experimental results and results derived from Gnielinski's correlation. The maximum error between experimental Nusselt numbers and simulated results are found to be 12.8%. It is concluded that the CFD approach gives good prediction for heat transfer performance in a double-pipe heat exchanger using $Al_2O_3 - H_2O$ nanofluid.

Mohammad Hazbehian et al. [3] investigated experimentally that enhancement in heat transfer coefficients of base fluid in combination with structural modifications of tape inserts. Polyvinyl Alcohol and TiO_2 with mean diameter of 15 nm were chosen as base fluid and nanoparticles, respectively. The experiments are carried out in plain tube with four longitudinal internal fins and reduced width twisted tape (RWTT) inserts of twist ratio varying form 2–5 and width of 12–16. Experiments are undertaken to determine heat transfer coefficients and friction factor of TiO_2/PVA nanofluid up to 2.0 % volume concentration at an average temperature of 30 °C. The investigations are undertaken in the Reynolds number range of 800–30,000 for flow in tubes and with tapes of different width length ratios. The experiments was verified with well-known correlations. The average Nusselt number and friction factor in the tube fitted with the full-length twisted tapes at y/w = 3.0, and 5.0, are respectively 50–130, and 30–95 % higher than those in the plain tube; 90–220 and 100–270 % when the working fluid is nanofluid, respectively. For the reduced width twisted tapes, the heat transfer rate is decreased with decreasing tapes width. The average Nusselt numbers in the tube fitted with the RWTT of 16, 14 and 12 are respectively, 210–390, 190– 320 and 170–290 % of that in the plain tube. With the similar trend mentioned above, RWTT with higher width length yield higher thermal enhancement factor in comparison with smaller width. The use of RWTT led to the highest thermal performance factor up to 1.75. Maximum thermal performance factor which was obtained belonged to twists with twist ratio of 2 and width of 16 with φ = 0.5 % and Reynolds number range of 800–30,000. The heat transfer coefficient is further enhances for nanofluid in a tube with RWTT insert. The enhancement is also depends on the twisted tape width. Higher heat transfer rates are obtained with increase in twist width. However, the increase in twists width rises friction factor which deteriorates thermal performance factor in heat exchangers.

Abbaspour M. et al. studied numerically two various passive methods for heat transfer enhancement, including conical ring and wire coil are placed in a tube as turbulators. Four conical rings with four side holes are utilized with the same distance. The wire coil is employed at the center of the tube. The considered Reynolds numbers are between 4000 and 10,000. The studied geometrical parameters contain the pitch and diameter of a wire coil. Four different pitches of wire coil, including 10, 12, 14, and 16 mm, are evaluated. Furthermore, four values of wire coil diameter such as 2, 4, 6, and 8mm are certain. The obtained numerical results displayed that by declining the pitch of a wire coil (37.5%), the average Nusselt number increases by about 143%. Also, augmentation in wire coil diameter by 300% leads to a growth in average Nusselt number by about 131%. Moreover, owing to utilizing two various turbulators, the pressure drop is significantly high in comparison with the bare tube. At Re = 10,000, growth in the inner diameter of the wire coil by 300% leads to an increase in thermal performance by about 36.12%. Moreover, as the pitch of the wire coil rises by 60%, the thermal performance declines by about 35.71%. Because of using two various turbulator in the tube, the pressure drop is more significant in comparison with the plain tube. So, the thermal performance of the tube with the proposed turbulator is lower than unity or lower than plain tube.

Rajan Kumar et al. investigated experimentally the effect of coiled spring inserts on heat transfer, pressure drop, and performance parameters of a triple tube heat exchanger (TTHX). Three different spring inserts having a pitch of 5, 10, and 15mm are used and the diameter of the spring wire is taken as 1 mm. The experiments were carried out under a turbulent flow regime, with water as a working medium in parallel and counter flow configurations. The variation in different performance characteristics like heat transfer coefficient, Nusselt number, and effectiveness have been compared at various Reynolds numbers ranging between 4000 and 16,000 in the considered flow patterns. The Nusselt number of TTHX with the lowest pitch spring is found to be higher than that of the plain TTHX by 57.27% at Re = 4000 for the counter flow configuration. Both the thermal performance factor and effectiveness increased as the pitch of the spring insert was decreased. The effectiveness of TTHX with the lowest pitch spring insert is found higher than that of the plain TTHX by 43.84% in the counter flow pattern. Increment in Nusselt number is observed with a decrease in spring pitch. Nusselt number of TTHX with the lowest-pitched spring is higher than that of the plain TTHX by 57.27% at Re = 4000 for the counter flow pattern. Friction factor decreases with an increase in Reynolds number. For the S3 turbulator, the friction factor achieves the maximum value of 486.43% enhancement in comparison with plain TTHX at Re = 4000. The rate of heat transfer per unit pumping power for plain TTHX is higher compared with the TTHX with spring inserts. The TPF is greater than unity only in the case of TTHX with the lowest-pitched spring inserts. For the same Reynolds number, the TPF of TTHX with spring inserts is more effective than plain TTHX. Also, TPF increases as spring insert pitches decrease. The same pattern is followed in the case of effectiveness.

Sahin B. et al. experimentally studied the performance of CuO nanofluid with water as a base fluid inside a horizontal tube regarding the heat transfer and pressure drop characteristics. The CuO nanofluid is prepared by adding the CuO nanoparticles of average diameter of 33nm into the deionized water. The CuO nanofluid is prepared with the volume fraction of 0.5%, 1%, 2%, and 4% and sonicated about 20 hours by using Hielscher UP200S ultrasonic homogenizer then no sedimentation in the nanofluid is observed and are found stable up to 28 days under static conditions. They performed the experiments under the steady-state, constant heat flux and turbulent flow regime conditions after achieving proper stability of nanofluid. Their results shows that the particle volume concentrations greater than 1% volume is not suitable for the heat transfer augmentation purpose. Primarily up to Re = 4000 no heat transfer augmentation is seen; the highest heat transfer augmentation is achieved at a value Re = 16.000. The effective thermal conductivity (kn) of the nanofluid was measured using a KD2 Pro thermal property meter. This device using the transient hot wire method works by evaluating the time and temperature response of the sudden electric signals. The local Nusselt number increases with the increase of the particle volume fraction up to 1%vol. At higher values than 1% vol., the local Nusselt number decreased with increasing particle volume fraction.

3. EXPERIMENTAL METHOD AND NANOFLUID PREPARATION

The experimental study was conducted on Spiral Tube Heat Exchangers (STHE) to evaluate thermal performance using Al_2O_3 nanofluid. A custom experimental setup was fabricated, comprising a hot fluid tank (HFT) and cold fluid tank (CFT) made of stainless steel, with heaters, pumps and an air cooled heat exchanger to maintain constant fluid temperatures. Hot and cold fluids were circulated using two 0.25 hp pumps, while submersible pump ensured continuous cold fluid flow through the air cooled exchanger. The setup included rotameters, differential manometers, K-type thermocouples, digital temperature indicators and an on/off temperature controller for precise monitoring and control.

Hot fluid flow through the shell, and cold fluid through the tube side in a counterflow arrangement. Experiments were performed by keeping the volume flow rate of hot fluid constant at 5 lpm and varying the cold fluid volume flow rate from 5 lpm, to 1 lpm in the range of 1 lpm. At the same time the inlet temperature of hot and cold fluid is also varied. Inlet temperature of hot fluid is varied in the range of 70 to 78ºC and inlet temperature of cold fluid is varied in the range of 32 to 36ºC. Before noting any reading system is allowed to reach steady state. The flow rates were controlled by adjusting the valve and measured by the two calibrated rotameter having range 0 - 5 lpm. The operating parameter and their range are given in the table shown below.

Variables	Range
Hot fluid inlet temperature, ºC	70-78
Cold fluid inlet temperature, ºC	32-36
Shell side water flow rate [LPH]	5
Coil-side water flow rate [LPH]	1-5

Al_2O_3 Nanofluid was prepared using a surfactant assisted method with Sodium Lauryl Sulfate (SLS), followed by magnetic stirring (1500 rpm, 1 hour) and ultrasonic (20 kHz, 1 hour) to achieve uniform dispersion and stability. Sedimentation photograph analysis confirmed stability for at least nine hours. Thermophysical properties like density, specific heat, viscosity and thermal conductivity were calculated using standard correlations, showing increased density and thermal conductivity, decreased specific heat and slightly increased viscosity with higher nanoparticle concentration. The amount of Al_2O_3 nanoparticles required to prepare nanofluids of different (%) volume concentration in a 10 litres of water is summarized in the table shown below.

Sr. No.	%Volume Concentration (ø)	Mass of Al_2O_3 in (Grams)
1	0.05	5
2	0.25	25
3	0.5	50

This methodology provides controlled and repeatable conditions to analyze the heat transfer enhancement of STHE using Al_2O_3 nanofluid. The experimental setup (HFT, CFT, STHE, pumps, air cooled exchanger and instrumentation) can be included to visually summarize the arrangement.

4. RESULTS AND DISCUSSIONS

Experiments on spiral tube heat exchanger (STHE) using water and Al_2O_3 nanofluids show the following trends. 1] Effectiveness (ε): Decreases with increasing cold fluid mass flow rate, nanofluids give higher ε than water. From figure it is observed that as the mass flow rate of cold fluid increases the effectiveness of heat exchanger decreases. The highest value of effectiveness obtained is 0.92 for 0.5% of Al_2O_3 nanofluid and the lowest effectiveness value is obtained for cold water is 0.16.

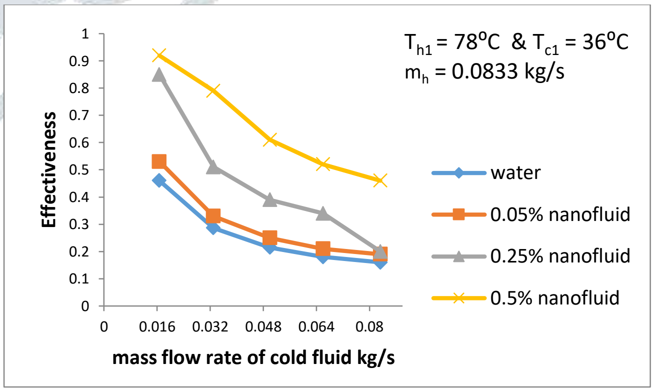

Figure 1: Effectiveness versus mass flow rate

2] Overall Heat Transfer Coefficient (U): Increases with mass flow rate, nanofluids improve U. From figure it is observed that as the mass flow rate of cold fluid increases the Overall Heat Transfer Coefficient increases. The highest Overall Heat Transfer Coefficient value is obtained for 0.5% Al_2O_3 is 319.12 W/m^2K and the lowest overall Heat Transfer Coefficient value is obtained for the cold is 178.12 W/m^2K.

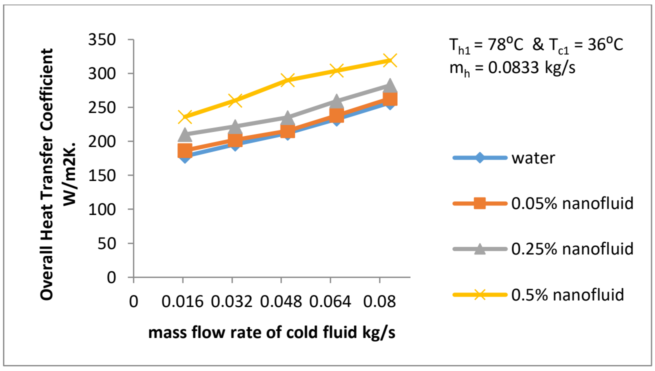

Figure 2: Overall HT Coefficient versus mass flow rate

3] Pressure Drop (ΔP): Rises with mass flow rate, nanofluids show slightly higher ΔP because of increased viscosity. From figure it is observed that as the mass flow rate of cold fluid increases the pressure drop of heat exchanger increases. Highest value of pressure drop is obtained for the 0.5% Al_2O_3 nanofluid is 14 mm of Hg and the lowest value is obtained for the cold water is 3 mm of Hg.

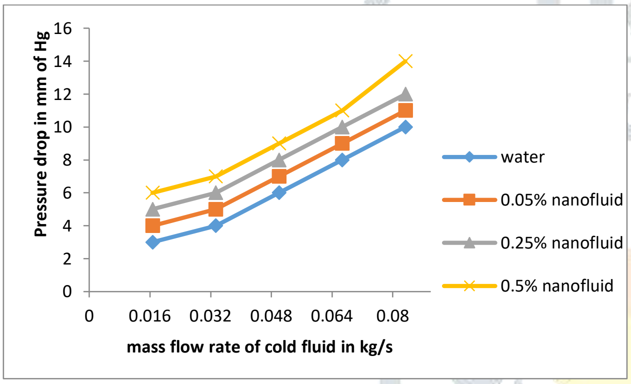

Figure 3: Pressure drop versus mass flow rate

4] Performance Index (PI): >1 for 0.5% nanofluid. From figure it is observed that as the mass flow rate of cold fluid increases with increase in the concentration of nanofluid performance index also increases. P.I. is greater than 1 for only water - 0.5% Al_2O_3 nanofluid and for remaining two concentrations it is less than one which shows that for those two concentration pressure drop occurring in the STHE is more dominant than the heat transfer enhancement.

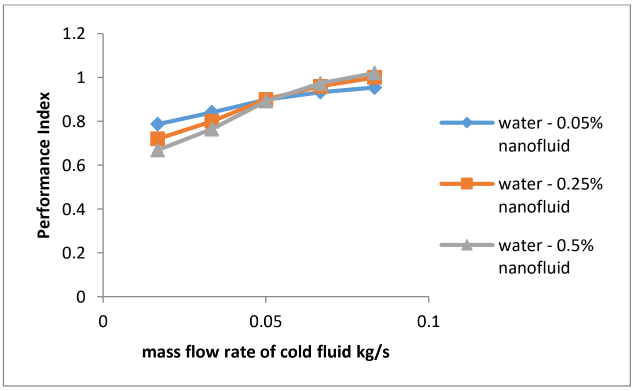

Figure 4: Performance Index versus mass flow rate

Al_2O_3 Nanofluid enhance STHE performance compared to water while maintaining acceptable pressure drop levels. The increase in heat transfer rate and performance index with nanofluids confirms their potential for improving heat exchanger efficiency and making them suitable for advanced thermal management applications.

5. CONCLUSIONS

- Effectiveness of STHE decreases with increase in mass flow rate of cold fluid. For 0.5% of Al_2O_3 nanofluid,
- Overall heat transfer coefficient increases with increase in mass flow rate of cold fluid.
- For water and 0.5% of Al_2O_3 nanofluid, Performance index is 1.02. For remaining two water and Al_2O_3 nanofluids, performance index is less than 1 for both types, which indicates that pressure drop is more dominant than heat transfer enhancement.
- With increase in mass flow rate of cold fluid pressure drop increases. Pressure drop is increased by 11.1%, 22.2% and 33.3% for 0.05%, 0.25% and 0.5% of Al_2O_3 nanofluid respectively.

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