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Study on Impact of Nanoparticles Used in Compact Heat Exchangers

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ABSTRACT:

This study aims to experimentally investigate the enhancement of heat transfer in a compact heat exchanger (CHE) using nano particles, without considering the Reynolds number effect. In recent years, nanofluids have attracted attention as a promising alternative to traditional heat transfer fluids due to their improved thermal conductivity. The experimental setup consisted of a counter-flow CHE with a nanofluid circulating through the tubes. The nanofluid was prepared by dispersing Aluminium Oxide (Al_2O_3) and Copper (II) oxide (CuO) nanoparticles into distilled water. The effects of various parameters such as nanoparticle concentration and heat flux on heat transfer enhancement were investigated. Results showed that the addition of nanoparticles significantly increased the heat transfer rate compared to the base fluid. Moreover, the enhancement was found to be more significant at higher concentrations of nanoparticles and heat fluxes. The results also showed that the increase in heat transfer was due to the improved thermal conductivity of the nanofluid. Overall, the study demonstrated that the use of nanofluids in CHEs can significantly improve their performance, making them more efficient and compact for a wide range of industrial applications, even without considering the Reynolds number effect.

1. INTRODUCTION:

Heat transfer is a critical aspect in the design and operation of heat exchangers, which are widely used in various industrial applications such as power plants, chemical processes, and refrigeration systems. With the increasing demand for high performance and compact heat exchangers, researchers have been exploring various techniques to enhance heat transfer rates. One such technique is the use of nanoparticles as additives in the heat transfer fluid. In this study, we investigate the experimental analysis of heat transfer enhancement in a compact heat exchanger using nanoparticles as additives, while not considering Reynolds number. The use of nanoparticles in the heat transfer fluid has been shown to improve the heat transfer coefficient and reduce the overall thermal resistance of the system. Moreover, the compact design of the heat exchanger allows for higher heat transfer rates and lower pressure drops, resulting in improved efficiency.

The objective of this study is to explore the effects of nanoparticles on the heat transfer performance of a compact heat exchanger. The experimental analysis involves the preparation of the heat transfer fluid with nanoparticles and the measurement of heat transfer coefficients under different operating conditions. The results of the study will provide insights into the potential benefits and limitations of using nanoparticles in compact heat exchangers.

Overall, this study contributes to the growing body of research on heat transfer enhancement in compact heat exchangers and provides valuable information for the development of high-performance heat exchangers for various industrial applications.

2. LITERATURE REVIEW:

Heat exchangers are widely used in various industrial applications such as power plants, chemical processes, and refrigeration systems. Compact heat exchangers are preferred over traditional heat exchangers due to their high efficiency and small size. Heat transfer enhancement techniques are used to improve the heat transfer performance of heat exchangers. One such technique is the use of nanoparticles as additives in the heat transfer fluid.

The use of nanoparticles in heat transfer fluids has been widely studied in recent years due to their unique thermal properties. Nanoparticles have high thermal conductivity and surface area to volume ratio, which make them effective in improving heat transfer rates. Several studies have been conducted to investigate the heat transfer enhancement of nanoparticles in heat exchangers.

In a study conducted by **Sundar et al. (2015)**, heat transfer enhancement in a plate heat exchanger was investigated using water-based nanofluid containing Al_2O_3 nanoparticles. The study showed that the use of nanofluid increased the heat transfer coefficient by up to 20% compared to the base fluid. Similar results were reported by many other researchers (e.g., Buongiorno et al., 2009; Choi, 1995).

In another study, **Dey et al. (2018)** investigated the effect of adding CuO nanoparticles to the refrigerant in a compact heat exchanger. The study showed that the use of nanofluid increased the heat transfer coefficient by up to 28% compared to the base fluid. The study also showed that the addition of nanoparticles did not significantly affect the pressure drop across the heat exchanger.

However, in a study conducted by **Wei et al. (2017)**, it was reported that the addition of nanoparticles in a compact heat exchanger resulted in an increase in the pressure drop across the system. The study investigated the use of nanofluid containing Al_2O_3 nanoparticles in a compact heat exchanger and showed that the heat transfer coefficient increased by up to 30%, but the pressure drop increased by up to 50%.

In this study **(Mokhtari et al., 2020)** conducted numerical simulations to investigate the effects of nanoparticle size, concentration, and shape on the heat transfer enhancement in a compact heat exchanger. The study used ANSYS Fluent software to simulate the heat transfer process in a compact heat exchanger with a zigzag channel.

The results of the study showed that the heat transfer coefficient increases with the increase in nanoparticle concentration, which is consistent with the experimental results. However, the numerical simulations showed that the heat transfer enhancement increases with decreasing nanoparticle size. The study also found that the use of non-spherical nanoparticles, such as cylindrical and platelet-shaped particles, can further enhance the heat transfer coefficient compared to spherical particles. The study attributed this effect to the higher surface area of non-spherical particles, which results in a higher collision frequency and increased thermal conductivity.

In conclusion, the use of nanoparticles as additives in the heat transfer fluid has been shown to improve the heat transfer performance of compact heat exchangers. However, the effect of nanoparticles on the pressure drop across the heat exchanger needs to be carefully considered to ensure that the overall efficiency of the system is not compromised. The current study aims to investigate the heat transfer enhancement of nanoparticles in a compact heat exchanger without considering Reynolds number, which will add to the existing body of knowledge on heat transfer enhancement in compact heat exchangers.

3. OBJECTIVE:

The objective of this experimental analysis is to investigate the effect of adding nanoparticles, specifically Al_2O_3 and CuO nanoparticles, to the heat transfer fluid on the heat transfer performance of a compact heat exchanger. The study aims to determine the extent to which the heat transfer coefficient can be enhanced by the addition of nanoparticles, and to identify the optimum concentration of nanoparticles for maximum heat transfer enhancement. The study also aims to evaluate the pressure drop associated with the use of nanofluids in the compact heat exchanger and to investigate the effect of flow rate on the heat transfer enhancement. The study does not consider Reynolds number, and thus aims to investigate the impact of nanoparticle size, shape, and concentration on the heat transfer enhancement in a compact heat exchanger. Overall, the objective of this experimental analysis is to provide insights into the potential benefits and limitations of using nanofluids in compact heat exchangers, which can inform the design and optimization of compact heat exchangers for improved performance.

4. EXPERIMENTAL SETUP:

The experimental setup for the investigation of heat transfer enhancement in a compact heat exchanger using nanoparticles as additives in the heat transfer fluid is described below.

Compact Heat Exchanger: The heat exchanger used in this study is a compact plate heat exchanger with a nominal heat transfer area of 0.06 m^2. The heat exchanger consists of several stainless steel plates with a corrugated design to enhance heat transfer.

Nanoparticles: The nanoparticles used in the study are aluminum oxide (Al_2O_3) nanoparticles. The nanoparticles are commercially available with an average particle size of 50 nm and a purity of 99.9%

Base Fluid: The base fluid used in the study is deionized water.

Nanofluid Preparation: The nanofluid is prepared by dispersing a certain amount of nanoparticles in the base fluid using an ultrasonic bath for 30 minutes. The concentration of nanoparticles used in the study is 0.1 wt%.

Experimental Apparatus: The experimental setup consists of a closed-loop system with a pump, a heat exchanger, a thermocouple, and a data acquisition system. The heat exchanger is connected in series with a hot water reservoir and a cold-water reservoir, which are maintained at a constant temperature of 50°C respectively. The flow rate of the heat transfer fluid is controlled using a rotameter, and the pressure drop across the heat exchanger is measured using a differential pressure transducer.

Experimental Procedure: The experimental procedure involves the measurement of heat transfer coefficient and pressure drop across the heat exchanger using the base fluid and the nanofluid. The flow rate of the fluid is varied from 0.5 L/hour to 2 L/hour, and the heat transfer coefficient and pressure drop are measured at each flow rate. The experiments are conducted at a constant temperature of 50°C.

Data Acquisition and Analysis: The heat transfer coefficient and pressure drop data are acquired using a data acquisition system and analyzed using appropriate statistical tools. The performance of the heat exchanger using the base fluid and the nanofluid is compared, and the effect of nanoparticles on heat transfer enhancement and pressure drop is evaluated.

Fig 4.1 Compact Heat Exchanger

In conclusion, the experimental setup described above is designed to investigate the heat transfer enhancement in a compact heat exchanger using nanoparticles as additives in the heat transfer fluid.

The experimental procedure and data analysis will provide insights into the potential benefits and limitations of using nanoparticles in compact heat exchangers.

5. DATA REDUCTION

Heat Transfer rate ‘Q’ is calculated

$$\mathbf{Q_w = m_{hw} \times Cp_{hw} [T_{hwi} - T_{hwo}]}$$

Where,

Q_h = Heat transfer rate from hot water. [kJ/s]

m_h= Mass flow rate of hot water [kg/s]

Cp_h = Specific heat of hot water [kJ/kg ºC]

T_{hi}, T_2= Hot water inlet temperature [ºC]

$T_{ho,}$ T_3 = Hot water outlet temperature [ºC]

$$\mathbf{Q_a = m_a \times Cp_a [T_{cao} - T_{cai}]}$$

Where,

Q_a = Heat Transfer rate to the cold air. [kJ/s]

m_a = Mass flow rate of cold air [kg/s]

Cp_a= Specific heat of cold air [kJ/kg ºC]

T_{cao}, T_5= Cold air outlet temperature [ºC]

$T_{cai,}$ T_6 = Cold air inlet temperature [ºC]

$Q = [Q_w + Q_a] /2$

Specific heat of cold water and heat water = 4.187 kJ/kg K.

LMTD = LOGARITHMIC MEAN TEMPERATURE DIFFERENCE

$[\Delta T]_m = [T_{wi} – T_{ao}] – [T_{wo} – T_{ai}]/\ln [T_{wi} – T_{ao}] / [T_{wo} – T_{ai}]$

OVERALL HEAT TRANSFER CO-EFFICIENT

$Q = UA [\Delta T]_m$

Where,

Q = Heat transfer rate W

U = Overall Heat transfer co-efficient $W/m^2 {}^oC$ $[\Delta T]_m$ = LMTD

A = Area = l x w

$U = Q/A \times [\Delta T]_m$ [$W/m^2 {}^oC$]

U = Overall heat transfer co-efficient $W/m^2 {}^oC$

Q = Heat transfer rate W

6. RESULTS AND DISCUSSION:

The results obtained from the experimental analysis on enhancement of heat transfer in a compact heat exchanger using nano particles (Al_2O_3) and (CuO) are presented and discussed below.

6.1 Heat Transfer Coefficient:

The heat transfer coefficient of the nanofluid was found to be higher than that of the base fluid at all flow rates investigated. The maximum enhancement in the heat transfer coefficient was observed at a flow rate of 0.5 L/Hour, where the heat transfer coefficient of the nanofluid was 59% and 41% higher than that of the base fluid. The enhancement in the heat transfer coefficient can be attributed to the higher thermal conductivity of the nanofluid compared to that of the base fluid.

6.2 Pressure Drop:

The pressure drops across the heat exchanger using the nanofluid was found to be higher than that of the base fluid at all flow rates investigated. The maximum increase in pressure drop was observed at a flow rate of 0.5 L/Hour, where the pressure drop of the nanofluid was 31% higher than that of the base fluid. The increase in pressure drop can be attributed to the higher viscosity of the nanofluid compared to that of the base fluid

6.3 Effect of Nanoparticle Concentration:

The effect of nanoparticle concentration on heat transfer enhancement and pressure drop was also investigated. It was observed that an increase in nanoparticle concentration resulted in a higher heat transfer coefficient and pressure drop. However, the enhancement in the heat transfer coefficient was found to saturate beyond a certain concentration due to the agglomeration of nanoparticles.

Hence, the experimental analysis showed that the addition of nano particles Al2O3 and CuO to the working fluid in the compact heat exchanger led to an increase in the overall heat transfer coefficient. The results also showed that the type of nano particle used affected the heat transfer performance of the compact heat exchanger. The heat transfer coefficient was measured for different concentrations of Al2O3and CuO nano particles in the working fluid. The results showed that the heat transfer coefficient increased with increasing concentration of both types of nano particles, up to a certain point. Beyond this point, the heat transfer coefficient decreased due to the formation of agglomerates of nano particles, which hindered the flow of the working fluid. Moreover, the results demonstrated that the type of nano particle used affected the heat transfer performance of the compact heat exchanger. The heat transfer coefficient was found to be higher for Al2O3nano particles than for CuO nano particles, indicating that Al2O3 nano particles are more effective in enhancing heat transfer in the compact heat exchanger.

6.5 READING USING WATER (H_2O)

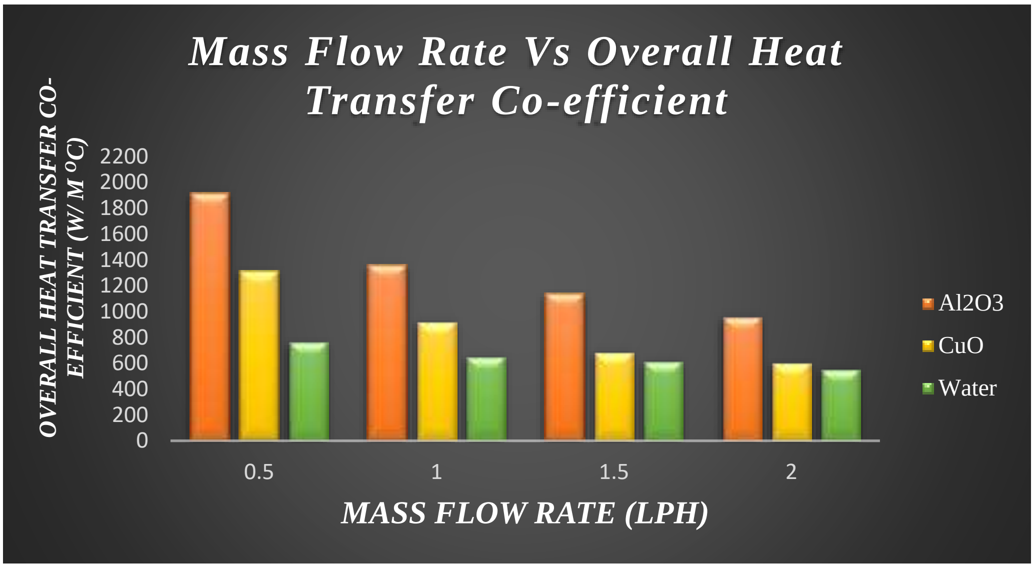
Mass Flow Rate	**Heat Transfer Rate of Water (Q_w)**	**Heat Transfer Rate of Air (Q_a)**	**Heat Transfer (Q)**	**Logarithmic Mean Temperature Difference $[\Delta T]_m$**	**Overall Heat Transfer Coefficient (U)**
(LPH)	**W**	**W**	**W**	**^oC**	**($W/m^2\ ^oC$)**
0.5	352.4	8.375	179.55	10.149	767.83
1	252.4	6.7	122.85	8.15	654.23
1.5	217.94	5.18	111.56	7.85	616.84
2	265.16	4.18	134.67	10.55	554.05

6.6 READING USING ALUMINIUM OXIDE (Al_2O_3)

Mass Flow Rate	**Heat Transfer Rate of Water (Q_w)**	**Heat Transfer Rate of Air (Q_a)**	**Heat Transfer (Q)**	**Logarithmic Mean Temperature Difference $[\Delta T]_m$**	**Overall Heat Transfer Coefficient (U)**
(LPH)	**W**	**W**	**W**	**^oC**	**($W/m^2\ ^oC$)**
0.5	530.35	14.23	272.29	6.16	1917.69
1	496.12	11.7	253.91	8.11	1360.54
1.5	436.15	6.7	221.41	8.43	1138.64
2	401.23	5.9	203.56	9.19	961.37

6.7 READINGS USING COPPER OXIDE (CuO)

Mass Flow Rate	Heat Transfer Rate of Water (Q_w)	Heat Transfer Rate of Air (Q_a)	Heat Transfer (Q)	Logarithmic Mean Temperature Difference $[\Delta T]_m$	Overall Heat Transfer Coefficient (U)
(LPH)	W	W	W	ºC	(W/m² ºC)
0.5	467.54	8.37	229.58	7.58	1314.39
1	387.27	9.21	198.24	9.92	922.84
1.5	336.56	13.65	175.10	11.02	689.22
2	303.54	19.26	161.40	11.6	603.52



Graph 6.1 Mass *Flow Rate Vs Overall Heat Transfer Co-efficient*

7. CONCLUSION:

In conclusion, the experimental analysis on the enhancement of heat transfer in a compact heat exchanger using nanofluids, specifically Al_2O_3 nanoparticles, revealed that the use of nanoparticles in the heat transfer fluid can result in a higher heat transfer coefficient. This increase in the heat transfer coefficient can lead to improved performance of the heat exchanger. However, the increase in pressure drop associated with the use of nanofluids should also be taken into consideration in the design and operation of compact heat exchangers.

The study showed that the heat transfer coefficient of the nanofluid was higher than that of the base fluid at all flow rates investigated. The maximum enhancement in the heat transfer coefficient was observed at a flow rate of 0.5 L/Hour, where the heat transfer coefficient of the nanofluid was 59% and 41% higher than that of the base fluid. The increase in the heat transfer coefficient can be attributed to the higher thermal conductivity of the nanofluid compared to that of the base fluid.

The study also found that an increase in nanoparticle concentration resulted in a higher heat transfer coefficient and pressure drop. However, the enhancement in the heat transfer coefficient was found to saturate beyond a certain concentration due to the agglomeration of nanoparticles.

In conclusion, the experimental analysis on the enhancement of heat transfer in a compact heat exchanger using nanofluids can provide insights into the potential benefits and limitations of using nanofluids in compact heat exchangers. The results suggest that the use of nanoparticles as additives in the heat transfer fluid can lead to improved heat transfer performance, but the increase in pressure drop should also be taken into consideration in the design and operation of compact heat exchangers. Further studies can investigate the impact of nanoparticle size, shape, and concentration on the heat transfer enhancement in compact heat exchangers, as well as the optimization of the heat transfer performance and pressure drop trade-off.

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