IMPLEMENTATION OF NANOFLUIDS IN PLATE HEAT EXCHANGER: A REVIEW

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ABSTRACT

Nanofluids are colloidal suspensions of nano- sized particles in the conventional base fluid such as water, engine oil and ethylene glycol. The nanoparticles include the chemically stable metals, metal oxides and non-metallic. In the present study, the literature available on the applications of nanofluids in plate heat exchanger have been compiled and reviewed. However, this paper elaborates the thermal performance of nanofluids in plate heat exchangers (PHEs) based on experimental studies. The aim of this review to focus on experimental investigation on variety of nanofluids as a cooling media in plate heat exchanger based on available literature.

Keywords: Chevron-Type, Exergy Loss, Heat Transfer Coefficient, Nanofluids, Plate Heat Exchanger (PHE).

I INTRODUCTION

Heat exchangers are those appliances that serve for controlling the temperature of a substance by adding or removing the thermal energy. The heat transfer among the media caused by temperature difference only, without the use of any external energy. A heat exchanger may be classified as: I. a direct contact type heat exchanger and ii. An indirect contact type heat exchanger. In direct contact type heat exchangers, the two media, between heats is to be exchanged, are in direct contact, e.g. cooling towers. In an indirect contact type heat exchanger, the two media, between heat is exchanged, are separated by a wall [1, 2]. A plate heat exchanger is an indirect contact type heat exchanger.

The plate heat exchangers (PHEs) habitually a set of thin corrugated metal plates with port holes at their corners providing the means of flow for the two fluids media, between heat transfers shall take place. These plates are assembled into a fix frame plate and a movable pressure plate and compressed by tightening bolts. Plate heat exchangers may be fabricated in gasketed or welded design characterized by the model in that the flow channels for the two heat exchanging media are sealed. The plates are provided with a bordering gasket that seals the inter plate channel .When these plate packs are compressed, the fluids flow into alternate channels. The number of plates is determined by the flow rate, physical properties of the fluids, pressure drop and temperature. The hot and cold fluids flow in alternate channels and the heat transfer takes place between adjacent channels. The corrugation of the plates promotes turbulence inside the channels and improves the mechanical strength of the plate pack[3, 4].

In the beginning, the enhanced convective heat transfer coefficient and thermal conductivity of liquids was achieved by mixing micron sized particles with a base fluid[5]. However, rapid sedimentation, clogging, erosion and high-pressure drop caused by these particles hindered its application practically. An addition of nanoparticles in a base fluid results an impressive augmentation in the thermo physical properties of base fluids. Nanofluids, that are a colloidal mixture of nanoparticles (1–100 nm) and a base liquid (nanoparticle fluid suspensions) is the term first coined by Choi in the year 1995 [6] at the Argonne National Laboratory. The nanofluids exhibited superior thermal properties over conventional fluids.

II RELEVANCE OF NANOFLUIDS

Convective heat transfer coefficient is utmost important parameter that attracts many researchers to investigate the heat transfer augmentation in nanofluids, relevant to numerous engineering applications such as- nuclear systems cooling, chemical process and microelectronics. Owing to improved heat transport properties, nanofluids are believed to be relatively potential fluids that attribute to enhance heat transfer coefficients. However, the additions of nanoparticles merely in the base fluids not impinge on the thermal conductivity but also the viscosity and the specific heat capacity.

A few review papers have been discussed on the application of nanofluids in heat exchangers by G. Huminic and A. Huminic [7] . In present study, we try to particularly review the application of various nanofluids in plate heat exchanger, in more details. However, probably no comprehensive literature available on application of nanofluids particularly in plate heat exchanger much. Moreover, the purpose of this paper is to explain the application of nanofluids in plate heat exchangers based on experimental investigations.

2.1 Experimental investigations on plate heat exchanger

Tiwari et al. [8] has compared the ratio of heat transfer coefficient and ratio of pressure drop of various nanofluids experimentally for different concentrations and different rates of flow in PHE. Various nanofluids, in this present study, are CeO_2, Al_2O_3, TiO_2 and SiO_2 at the concentrations ranging from 0.5- 3.0 vol. % with different flow rates, ranging from 1.0 - 4.0 lpm for hot water flow rate of 3 lpm. For the investigation of heat transfer and pressure drop characteristics, an experimental apparatus has been fabricated incorporating the commercial PHE manufactured by Alfa Laval India Limited (model M3 FG). The experimental apparatus consists of cold fluids (nanofluids) and hot fluids (distilled water) flow loops. The hot water flow loops incorporated an insulated hot water tank in conjunction with immersion heaters. The required inlet hot water temperature was achieved by temperature controller. The flow rate was controlled by rotameter. For measuring the pressure difference between entrance and exit ports of PHE for hot distilled water and aforementioned nanofluids the differential pressure manometers were employed. The variations of flow rates range from (1-4) lpm for nanofluids and hot distilled water both. The range of inlet temperature was from 25° C to 30° C for cold fluid keeping inlet temperature of hot distilled water constant (i.e. 70° C) throughout experiment.

The experimental results showed that the convective heat transfer coefficient ratio varied from 1.14 to 1.36 for aforementioned nanofluids at particular coolant flow rate for its respective optimum volumetric fraction. The predicted value of optimum volume concentrations by the authors was 0.75%, 1.0%, 0.75% and 1.25% for CeO_2-water, Al_2O_3-water, TiO_2-water and SiO_2-water nanofluids respectively. The maximum augmentation observed was about 35.9%, 26.3%, 24.1% and 13.9% respectively at optimum volume concentration, the cold fluid flow rate and hot distilled water flow rate was 3 lpm for both fluid streams. The experimental results illustrated in the Fig: 1.

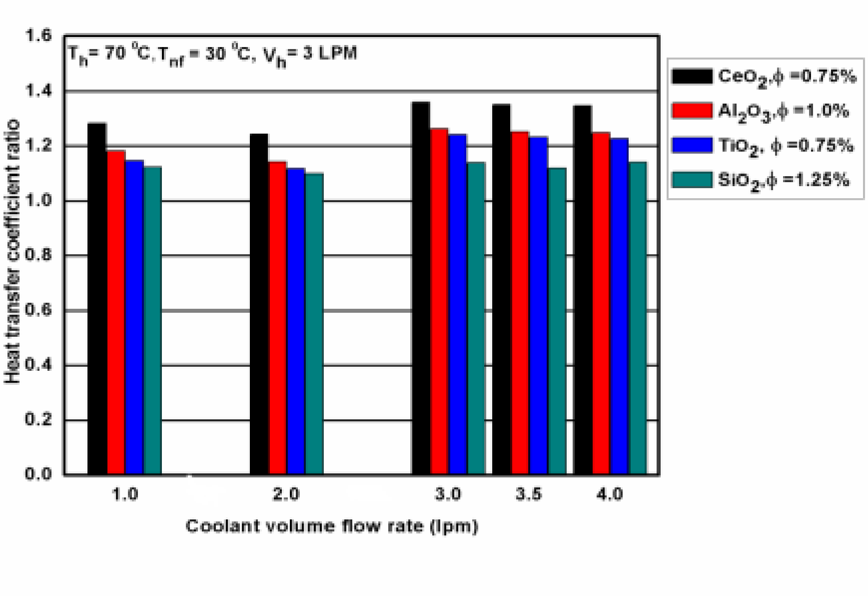

Fig.1 Heat Transfer coefficient of different nanofluids at optimum volume concentration in PHE (Tiwari et al. [8]).

Further the authors were also outlined the pressure drop ratio of above mentioned nanofluids at different volume rate with their optimum volume concentration. It was observed that the pressure plunged sharply as the rate of volume flow of coolant increased. The pressure drop ratio was highest for SiO_2-water nanofluid and lowest with TiO_2-water nanofluid as shown in fig: 2.

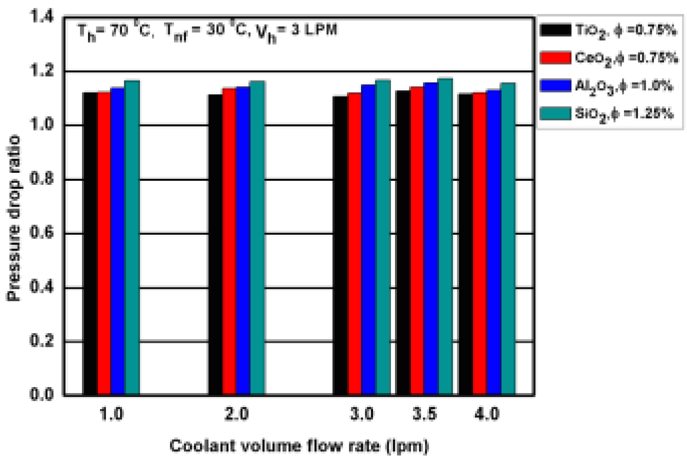

Fig: 2. Pressure Drop Ratio of different nanofluids at optimum volume concentration (Tiwari et al. [8]).

Also Tiwari et al. [9] conducted an experiment for the analysis of the heat transfer characteristics of different nanofluids in corrugated PHE.They employed CeO_2-water nanofluids ranging from 0-3.0% volume concentrations. The experimental apparatus of this study was similar to described by Tiwari et al. [8] .The plates have the corrugation angle of 30° with 0.5 mm plate thickness. The water was employed as a hot fluid stream and water or the nanofluids as a coolant in the PHE. The aim of present study was to compare with their performance with water. The cold water/nanofluid was stored in a tank with capacity 25 litre. The inlet temperatures were 30°C and 70°C for cold and hot water respectively and were recirculated with the help of centrifugal pump. The volume flow rate was controlled by float-type rotameter.

The results showed that the maximum total heat transfer coefficient occurred at 0.75% volume concentration (optimum) and this augmentation was approximately 28% at 3 lpm volume flow rate of coolant. The overall (total) heat transfer coefficient decreases beyond optimum concentration. The augmentation of overall heat transfer coefficient were found about 18.2%, 27.9%, 22.0%, 20.3%, 18.9%, 17.2% and 13.0% for 0.5,0.75,1.0,1.25,1.5,2.0 and 3.0 vol. % respectively as shown in fig 3.

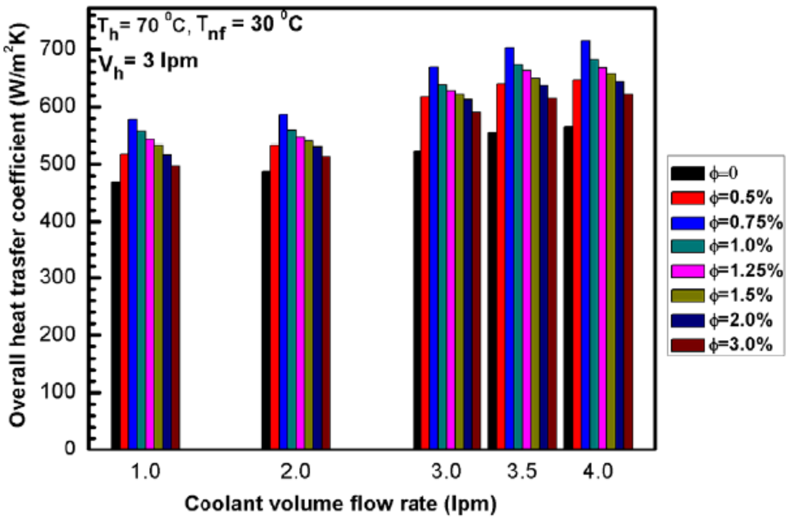

Fig: 3. Overall heat transfer coefficient of CeO_2/water nanofluid with rate of flow of coolant (Tiwari et al. [9]).

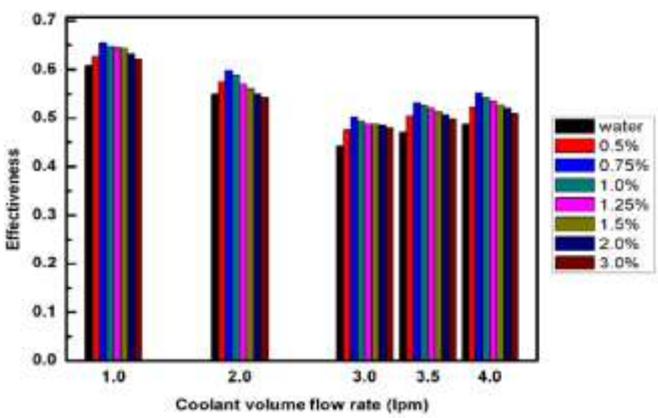

Fig: 4. Variation of effectiveness of CeO_2/water nanofluid with coolant volume flow rate(Tiwari et al. [9]).

Moreover, the authors had also outlined the variation of effectiveness of CeO_2/water nanofluid with different volumetric flow rate of the coolant. The outcomes showed that the effectiveness of the nanofluid strongly depends upon the overall heat transfer coefficient and the value of the effectiveness increases up to 0.75 volume concentration i.e. upto optimum value as shown in fig. 4.

Pantzali et al.[10] studied the effects of nanofluid (CuO-water, 4% v/v) on the performance of a miniature plate heat exchanger with modulated surface experimentally. The authors ascertained that the augmentation of overall heat transfer coefficient was highest at lower coolant volume flow rate for a particular volume flow rate of hot water, as depicted in fig.5.

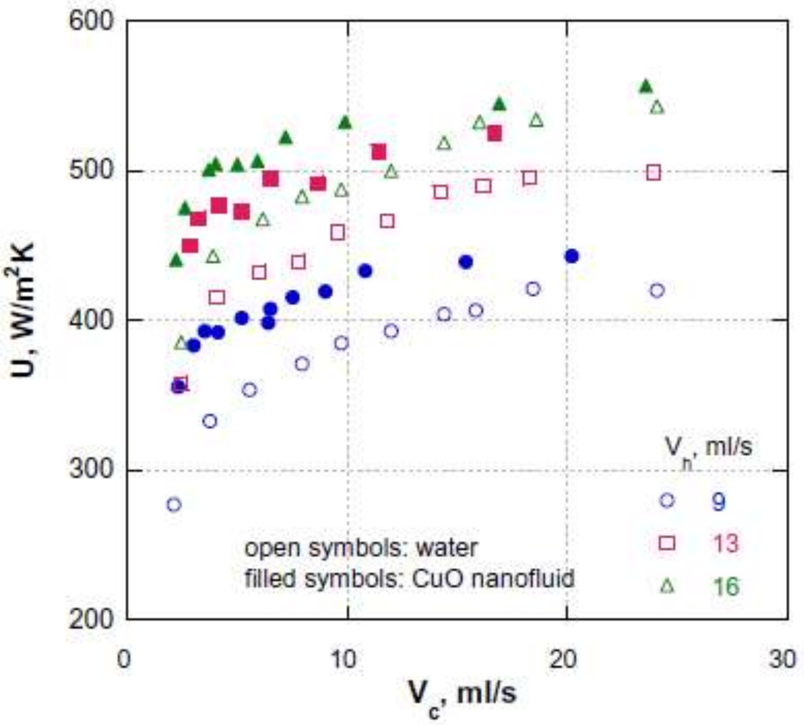

Fig.5. Total heat transfer coefficient of CuO-water nanofluid with volume flow rate of coolant for different hot water flow rates (Pantzali et al. [10]).

Khairul et al. [11] studied the effects of water and CuO/water nanofluids as coolants on heat transfer coefficient, heat transfer rate, frictional loss, pressure drop, pumping power and exergy loss in the corrugated plate heat exchanger. They had focused on the heat transfer analysis by using CuO/water nanofluids with 0.5%, 1.0% and 1.5% particle volume concentration and compared with water. In their analysis, it was assumed that the flow of nanofluids through the PHE are fully developed both thermally and hydrodynamically. However, it was also assumed that the flow of nanofluids through the plates were incompressible and turbulent flow regime. The thermophysical properties of nanofluids were measured at 300 K constant temperatures. The experimental set up of their work was depicted in Fig.13. The volume flow rate of hot fluid was measured as 2 L/min.

The outcomes of their analysis revealed that, the enhancement in heat transfer coefficient were about 17.70%, 21.80% and 24.7% for 0.5%, 1.0% and 1.5 vol. % of CuO/water nanofluids respectively with compare to water. The results showed a significant heat transfer rate for nanofluids. In the present study it was also remarked that the increment of particle volume fraction and volume flow rate of nanofluids could enhance the friction factor that should result in an increased pressure drop and pumping power. The analytical results showed a reduction in exergy loss by 24%, 16.25% and 8% for 1.5 vol. %, 1.0 vol. % and 0.5 vol. % of CuO/water nanofluids respectively compare to water also. The average value of enhanced effectiveness was found as 34%, 22% and 12% for 1.5 vol. %, 1.0 vol. % and 0.5 vol. % of nanoparticles in contrast with water.

An investigation on heat transfer performances of Al_2O_3-water nanofluid as coolants in a counter flow corrugated PHE have been done experimentally by Pandey and Nema [12]. Their methodology included the preparation of Al_2O_3/water nanofluids of required fractions i.e., 2.0, 3.0, and 4.0 vol. % and measurements of thermophysical properties of aforementioned nanofluid.

The results showed that the heat transfer performances improved with decrease in the concentrations of nanofluid and increase in Reynolds and Peclet-number. At a given coolant flow rate, the heat transfer rates and convective heat transfer coefficient enhancement were maximum for 2 vol. % Al_2O_3/ water nanofluid. However, the authors reported that the use of aforementioned nanofluid more than 2% volume fraction should be avoided because it will not be economical and will result in more pressure drop, owing to their higher viscosity, without any considerable benefit in heat transfer performance. For a given coolant, the friction factor decreased with increase in Peclet number. Moreover, among the four coolants (i.e.0%,2%,3% & 4% vol.), the non-dimensional exergy loss was minimum with 2% nanofluid for a coolant flow rate of up to 3.7 lpm, beyond that water gave the least value as depicted in Fig.7.

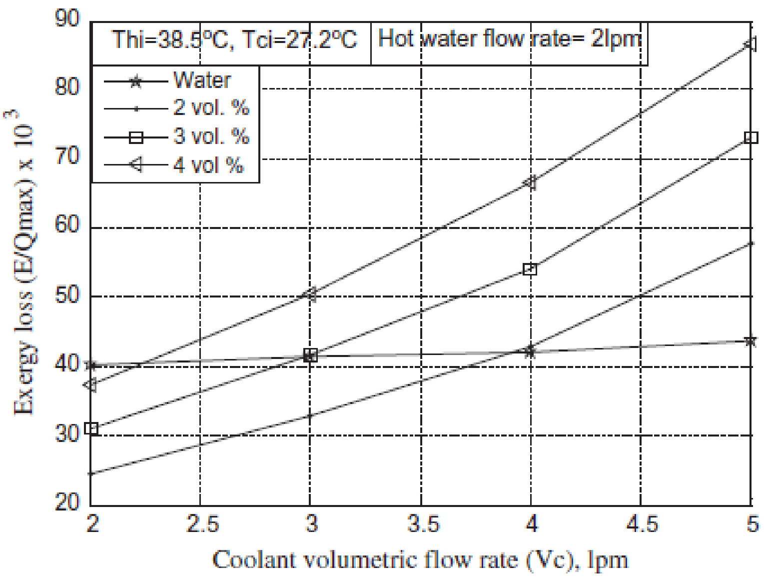

Fig.7. variation of non-dimensional exergy loss v/s coolant volumetric flow rate (Pandey and Nema [12]).

K. Anoop et al. [13] studied, heat transfer performances of nanofluids in industrial type PHE experimentally. Their experimental procedures were in two steps. In the first step, SiO_2/water nanofluid was prepared of desired concentration (2%, 4%, and 6% by weight) for the experimentation. In the next step, two flow loops (i.e. hot flow loop and cold flow loop) were design to run in a counter flow configuration through an industrial-type PHE to analyse heat transfer characteristics of the aforementioned nanofluid. The experimental set up incorporated both, plate heat exchanger and shell-and-tube heat exchanger. But, the apparatus was designed in such a way that experiments might be done in either PHE or shell-and-tube heat exchanger by switching the control valves.

Their experimental set up composed of two flow loop i.e. hot flow loop and the cold flow loop. The hot water was stored in a large heating tank controlled by proportional-integral-derivative (PID) in hot flow loop while water or desired concentrations of SiO_2 nanofluids stored in a small tank in cold flow loop. In their experimentation, the cold fluid along with chilled water was being pumped through a heat exchanger in counter flow manner first and further it supplied to the PHE for conducting the experiment and then pumped back to cold tank again. The chilled water was stored in an industrial chillier with capacity of 11-ton to maintain a steady low temperature of the fluid. K-type thermocouples were employed for measuring the temperatures and that were placed at the entrance and exit of the heat exchanger in hot and cold loops. Pressure transducers, placed at the inlet and outlet of the cold loop, were employed to measure the pressure drop across the PHE. Coriolis flow meters were used to measure mass flow rates in hot and cold loops both.

The results revealed that addition of nanoparticles had a significant influence on the total heat transfer coefficient. However, the effect was insignificant at lower fraction of 2.0 and 4.0 wt%. Lower particle concentrations showed better heat transfer enhancement than higher concentrations at lower mass flow rates as depicted in Fig.8. The inset figure showed the cross-sectional view of the PHE. Moreover, the Maximum enhancement of approximately 5% in overall heat transfer coefficient was experienced for 2.0 wt% at the lowest mass flow rate in the present experiment.

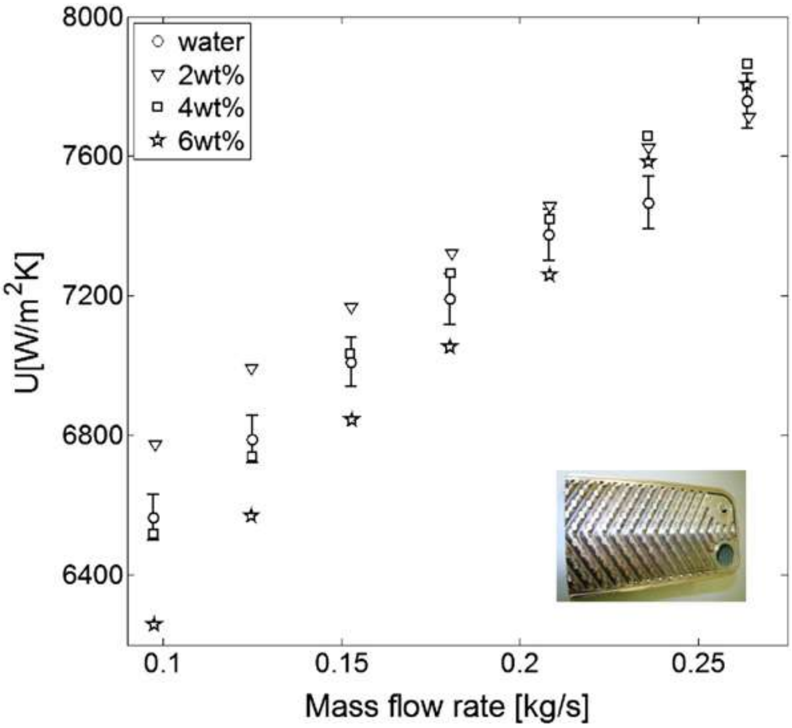

Fig.8. variation of total heat transfer coefficient of SiO_2-water nanofluid in a PHE (K. Anoop et al. [13]).

III CONCLUSION

The applications of the nanofluids in plate heat exchanger experimentally reviewed here exclusively. The review reveals that the nanofluid shows the outstanding performance in terms of heat transfer characteristics and pressure drop improvement in plate heat exchanger. The heat transfer coefficients increased with increasing the nanoparticle volume fractions owing to the improvement in thermophysical properties. However, the heat transfer performances improved with decrease in the concentrations of nanofluid and increase in Reynolds and Peclet-number conferred by some experimental investigations which reveals the noteworthy chaos.

The effectiveness of the nanofluids depends upon not only the thermophysical properties but also depend on flow behaviour (i.e. laminar or turbulent) in some experimental studies. However, the effectiveness decreased with increasing the Reynolds number reported by research group.

Thus it is concluded that more attention is needed towards the heat transfer characteristics of nanofluids and uniformity of their results.

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