Experimental Analysis of a Counter Flow Plate Heat Exchanger by Using Nanofluids at Different Concentrations

Anil Kumar and Amman Jakhar

Abstract Heat transfer characteristics of nanofluids are improved by increasing the mass flow and inlet temperature. This article is intended to study the rate of transfer heat of nanofluids by counter flow conditions using forced convection mode. A two-step method was used to finalise the alumina nanoparticles. In this experimental analysis as the size of the particle decreases, the rate of heat transfer increases. In this experimental analysis, nanoparticles with a diameter size of 30 nm were used. Distilled water was used as the base fluid to prepare the nanofluids of alumina with different volume concentrations (0.14, 0.28, 0.4 and 0.52%). The experimental results show better thermophysical properties of nanofluid, and also Reynolds number and Prandtl number have been calculated.

Keywords Plate heat exchanger · Nanofluids · Base fluid

1 Introduction

The heat exchanger is a component that uses thermal energy to control the temperature of a substance or system. It can be classified as either a direct contact or indirect contact device. Pandey et al. [1] have studied that the Reynolds number for a hydraulic diameter of 750–3200 is varied by the flow rates of air and water. The data are presented in an experimental analysis. Singh and Ghosh et al. [2]. In experimental analysis numerical and experimentation results were analysed and got that the two results are in good agreement. And the results showed an improvement of approximately 13% in thermal conductivity and 14% in heat transfer rate, and 9% in efficiency in total heat transfer coefficient at the expense of heat loss and pump power when using nanofluids. "The exergy rate were also reduced by using a nanofluid with an optimal concentration of 1 vol%" Khanlari et al. [3]. The experiments were performed under different positions to establish the influence of the use of nanofluid. Mansoury [4] has studied the double HE tube that showed the best

A. Kumar (✉) · A. Jakhar
Department of Mechanical Engineering, OM Sterling Global University, Hisar 125001, India
e-mail: anilmec191@osgu.ac.in

V. Krishna et al. (eds.), *Recent Advances in Hybrid and Electric Automotive Technologies*, Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-981-19-2091-2_9

rate of heat transfer coefficient result with a maximum improvement of 60%. The use of the nanofluid denoted the lowest penalty at pressure losses with a maximum improvement of 27% for the HE plate, while the highest penalty was observed at pressure losses with a maximum improvement of 85% in HE with double tube and calendar. Barzegarian et al. [5]. The heat transfer assessment revealed that the addition of nanofluids to the mix increases the Nusselt numbers by almost 30%. It also showed a significant increase in heat transfer coefficient due to the volume fraction. The heat transfer result demonstrates the application of nanofluids as compared to base fluids which leads to an increase in Nusselt numbers up to "9.7, 20.9 and 29.8% at 0.03, respectively, 14 and 0.3% by volume, respectively". Since it was found that the volume fraction of said nanoparticles, the total heat transfer coefficient of the heat exchanger increased by about "5.4, 10.3 and 19.1%, respectively". Choi et al. [6] have found a new class of fluid that can be designed using the principle of suspending metal nanoparticles in a conventional heat transfer fluid. Pak et al. [7]. In this experiment, a circular tube has been studied. Measurements of viscosity were also carried out by using a viscometer of Brookfield rotary. The viscosity of liquids dispersed with particles of Al_2O_3 and TiO_2 at a concentration of 10% by volume is about 200 and 3 times that of water. Xuan et al. [8]. It is observed that the heat transfer rate enhance by nanoparticles which increases nanofluid increases the thermal conductivity and induces heat dispersion of the flow, it is an new way to improve heat transfer. Passman et al. [9]. "In this study, an attempt was made for a nanofluid consisting of water and a volume concentration of 1% Al_2O_3/water. Al_2O_3 nanoparticle with a diameter size of 50 nm was used, and it was found that the rate of heat transfer coefficient and the heat transfer coefficient of the nanofluid were slightly higher than that of the base liquid at the same mass velocity and at the same inner temperature".

2 Word Methodology

The experimental study proposes nanofluid's heat transfer rate in plate-type heat exchanger (PHE). A sequence of steps for this work is shown below (Fig. 1).

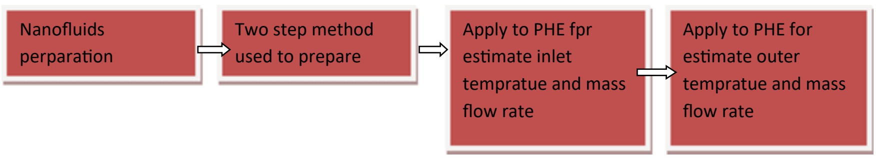

Fig. 1 .

Fig. 2 Ultrasonic cleaner

Table 1 Properties of basic liquids and nanoparticles at atmospheric temperature 27 °C

	(ρ) (kg/m^3)	C_p (J/kg K)	K (W/m K)	Viscosity μ (kg/m s)	A (m^2/s)	Prandtl no. (Pr)
Water	1000	4200	0.65	838.2×10^{-6}	0.147×10^{-6}	5.8
Al_2O_3	2925	745	45			

2.1 Preparation of Nanofluids

Alumina is a mixture of aluminium and oxygen. Preparation of nanofluid plays a very important role. Nanofluids were prepared by using commercially available alumina of approximate 30 nm diameter with the base fluid being distilled water. The Nano alumina powder is dispersed in 1,000 common basic liquids such as water at different volume concentrations of 2, 3, 4 and 5% using an ultrasonicator that is available in the nanotechnology lab (Fig. 2 and Table 1).

2.2 Experimental Setup

The counter flow heat exchangers are made up of mild steel. In this work is included a photograph of the experimental setup fabricated to find out the characteristics of different flow rates at different fluid volume concentrations. It includes a hot water and coolant loop and measuring system. The main components of the setup are

Fig. 3 Setup

numbered in schematics. It includes a water tank containing a heater, pump and the flow rate and temperature measuring instruments. Pump flow rate is 0.4 kg/s and surface area (A) of the heat exchanger is 0.3 m^2 (Fig. 3).

Nanofluids thermophysical properties

Experimentally, thermophysical properties of nanofluids were measured. The viscosity of nanofluid is measured by viscometer at room temperature and thermal conductivity by K-type thermocouple, and specific heat by measuring thermal instruments.

3 Heat Transfer Rate and Nanofluid Properties' Evaluation

3.1 Heat Transfer Rate

Nanofluid density by Pak and Cho [9] relations is

$$\rho_{\mathrm{nf}} = (1 - \varphi)\rho_{\mathrm{bf}} + \varphi\rho_{\mathrm{p}} \tag{1}$$

where Nanofluid density is ρ_{nf}, φ is the nanoparticle volume concentration, and base liquid ρ_{p} is nanoparticles density.

Specific heat of nanofluid from Xuan [10] is

$$\left(\rho C_{\mathrm{p}}\right)_{\mathrm{nf}} = (1 - \varphi)\left(\rho C_{\mathrm{p}}\right)_{\mathrm{f}} + \varphi\left(\rho C_{\mathrm{p}}\right)_{\mathrm{p}} \tag{2}$$

where Nanofluid specific heat is $(C_p)_{nf}$ and $(C_p)_p$ is Nanoparticle specific heat and (C_{pf}) is heat capacity of the base fluid.

The heat transfer rate is

$$Q = m(C_p)_{nf}\Delta T \tag{3}$$

where heat transfer rate is Q and m is the mass flow rate of nanofluid flow, temperature difference of cooling fluid is ΔT.

The logarithmic mean temperature difference (LMTD) is determined according to the following relationship:

$$\Delta T_{lm} = [(T_{bi} - T_{no}) - (T_{bo} - T_{ni})/\ln(T_{bi} - T_{no}/T_{bo} - T_{ni})] \tag{4}$$

When the logarithmic mean temperature difference (LMTD) is ΔT_{lm}, T_{bi} and T_{bo} are inlet and outlet temperatures of the base liquid, where T_{ni}, T_{no} are nanofluid inlet temperature and outlet temperature.

The heat transfer coefficient is determined according to the relation given below.

$$Q = UA_s\Delta T_{lm} \tag{5}$$

In this relationship, the total heat transfer coefficient is U and the surface area of the heat exchanger is A_s.

Nanofluids thermal conductivity from Choi and Yu [8] relation is

$$K_{nf} = K_{bf} * (K_p + 2K_{bf}) - 2\varphi(K_{bf} - K_p)/K_p + 2K_{bf} + \varphi(K_{bf} + K_p) \tag{6}$$

where the thermal conductivity of the nanofluid is K_{nf}, and thermal conductivity of the nanoparticle is K_p and thermal conductivity of the base fluid is K_{bf}.

Drew and Passman [11] proposed an equation to calculate nanofluid viscosity as follows:

$$\mu_{nf} = (1 + 2.5)\mu_{bf} \tag{7}$$

where μ_{nf} is the viscosity of the nanofluid and μ_{bf} is for base fluid.

To assess the accuracy of the measurement, the test was performed on distilled water, before checking the characteristics of heat transfer of different volume concentrations of Al_2O_3/water. From the experimental system, the measured values are the inner and outer temperatures of the inlet of distilled water and the different concentrations of the nanofluid as well as for hot water at different flow rates.

"Friction factor (f) calculated by using the Gnielinski equation for base fluid and Duangthongsuk and Wongwises relation for nanofluid is as follows":

$$f = [1.58 \ln \mathrm{Re} - 3.82]^{-2} \tag{8}$$

Table 2 The result for base fluid and nanofluids in counter flow conditions

Counter flow condition			
	LMTD	U	Q
Water	52.5	247.23	3761.12
0.14%	45	423.12	6104
0.28%	47	468.24	6427.98
0.4%	42	678.18	8121
0.52%	38	895.00	8665.89

This equation indicates to find out the friction factor, where f denotes the friction factor and Re denotes the Reynolds number.

Find the Reynolds number and Prandtl number by using the relation

$$\mathrm{Re} = \rho V D/\mu \tag{9}$$

$$\mathrm{Pr} = \mu/\rho\alpha \tag{10}$$

In this relation, velocity is V, diameter is D and viscosity is μ of the nanofluid and α denotes thermal diffusivity of fluid.

And we calculated thermal diffusivity and the Peclet number by using the equation

$$\alpha = \left[K/\rho C_\mathrm{p}\right] \tag{11}$$

and

$$\text{Peclet number (Pe)} = [V D/\alpha] \tag{12}$$

For finding the Nusselt number (Table 2),

$$\mathrm{Nu} = [(0.125 f)(\mathrm{Re} - 1000)\mathrm{Pr}/1 + 12.7(0.125 f)^{0.5}\left(\mathrm{Pr}^{2/3} - 1\right) \text{ for base fluid} \tag{13}$$

$$\mathrm{Nu} = \left[0.074\mathrm{Re}^{0.707}\mathrm{Pr}^{0.385}\varphi^{0.074}\right] \text{ for nanofluid.} \tag{14}$$

4 Result and Discussion

Heat was measured from the experimental analysis. In this experiment, first we calculated the values of heat transfer characteristics for pure water and then calculated the values of Al_2O_3/water at the same mass flow rate and inlet and outlet temperatures at the same values. In this experiment, the nanofluid concentrations are 0.14, 0.28, 0.4

and 0.52% and then applied for the heat exchanger and calculated the heat transfer characteristics for counter flow conditions. In the counter flow conditions, the highest rate observed for 0.52% volume percentage is 8665.89 W. And as the Nusselt number increases, the Prandtl number also increases (Figs. 4 and 5).

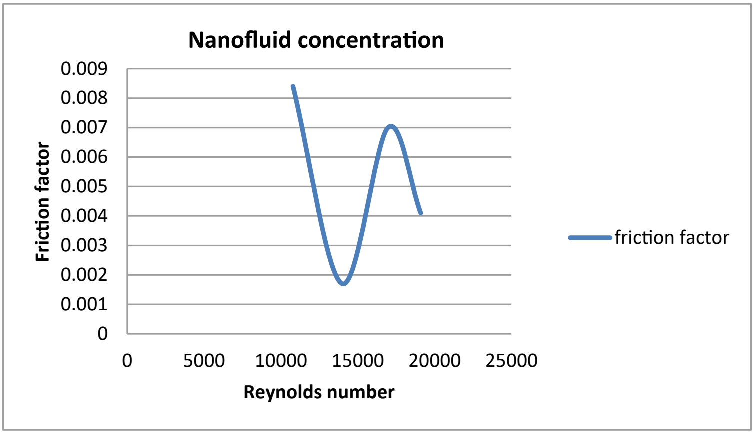

Fig. 4 The relation between friction factor and Reynolds number

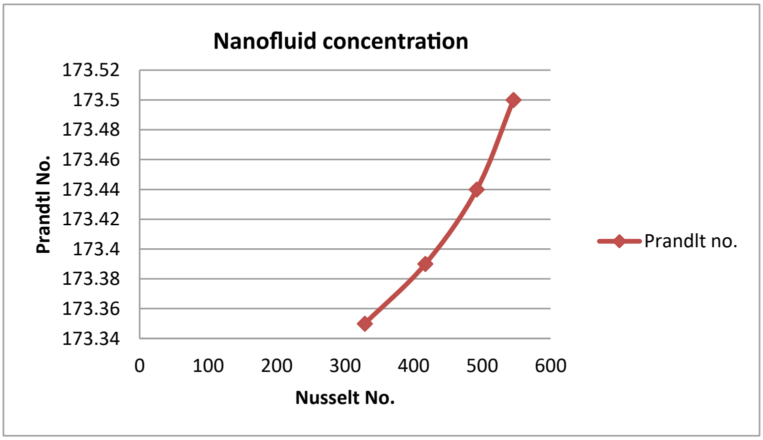

Fig. 5 Relation between Prandtl and Nusselt numbers

5 Conclusion

The rate of heat transfer on counter flow plate-type heat exchanger by using Al_2O_3 nanofluid has been investigated experimentally. And heat transfer rate, Reynolds number, Prandtl number, friction factor and overall heat transfer coefficient were measured for counter flow conditions. Important results were measured in this experiment as follows:

1. The heat transfer rate of the nanofluid increases as the volumetric concentration of the nanofluid increases.
2. Reynolds number increases with decreasing friction factor for nanofluid.
3. In counter flow conditions, the rate of heat transfer is more for 0.52%, and volume concentrations of nanofluids is 8665.89 W. The total heat transfer rate of nanofluids is more than 2 times that of the base liquid.
4. The stability of nanofluid for 30 nm size is incipient.

References

1. Pandey SD, Nema VK (2011) Investigation of the performance parameters of an experimental plate heat exchanger in single phase flow. Energy Eng 1(1):19–24
2. Singh S, Verma P, Ghosh SK (2021) Numerical and experimental analysis of performance in a compact plate heat exchanger using graphene oxide/water nanofluid. Int J Numer Methods Heat Fluid Flow
3. Khanlari A, et al (2020) Investigation of the influences of kaolin-deionized water nanofluid on the thermal behavior of concentric type heat exchanger. Heat and Mass Transf 56(5):1453–1462
4. Mansoury D, et al (2019) Heat transfer and flow characteristics of Al_2O_3/water nanofluid in various heat exchangers: experiments on counter flow. Heat Transf Eng
5. Barzegarian R, Aloueyan A, Yousefi T (2017) Thermal performance augmentation using water based Al_2O_3-gamma nanofluid in a horizontal shell and tube heat exchanger under forced circulation. Int Commun Heat Mass Transf 86:52–59
6. Choi SU, Eastman JA (1995) Enhancing thermal conductivity of fluids with nanoparticles (No. ANL/MSD/CP-84938; CONF-951135-29). Argonne National Lab., IL
7. Pak BC, Cho YI (1998) Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles. Exp Heat Transf Int J 11(2):151–170
8. Xuan Y, Roetzel W (1998) Conceptions for heat transfer correlation of nanofluids. Int J Heat Mass Transf 43(19):3701–3707
9. Drew DA, Passman SL (1998) Theory of multicomponent fluids. Appl Math Sci 135:105–120. 185 https://doi.org/10.1007/0-387-22637-0_11