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Original Article

Experimental Study on Forced Convective Heat Transfer Enhancement Using Water-based ZnO Nanofluid

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Abstract - *The development of energy-efficient heat transfer fluids, which are required in many industrial applications, is hampered by low thermal conductivity. In this paper, metal oxide nanoparticles are suspended in traditional heat transfer fluids to create a novel new class of heat transfer fluids, and their effectiveness in enhancing heat transfer rate is presented. When compared to currently employed heat transfer fluids, the resulting nanofluids are projected to have superior heat transfer performance and offer the best hope for improving heat transmission. An experimental examination of the forced convective heat transfer characteristics of a nanofluid containing water and zinc oxide nanoparticles is presented in this paper. Experiments are carried out to see how the volume fraction of nanoparticles and the pH of the solution affect the outcome. The experiment is carried out in a parallel and counterflow flow heat exchanger with the cold fluid. Two types of fluid are prepared: The first type of fluid is Zinc Oxide nanoparticles dispersed in water, and the second type is Zinc Oxide nanoparticles distributed in KOH water solution. The overall heat transfer coefficient variation with increasing cold water flow rate is investigated and compared to the results obtained with increasing nanofluid flow rate. A similar study and comparison of results are done for the variation of Nusselt number with respect to Reynold's number. A significant improvement in heat transfer coefficient is observed with ZnO in water as cold fluid (nanofluid)*

Keywords - *Concentric Pipe Heat Exchanger, Dispersion, Overall heat transfer coefficient, Nanofluid, Nusselt number, Reynolds Number*.

I. INTRODUCTION

Although a range of active and passive strategies are used to improve heat transfer, the low thermal conductivity of process fluid inhibits the compactness and effectiveness of heat exchangers. Enhancing heat transfer requires improving the thermal characteristics of energy transmission fluids. Suspending small solid particles in fluids is an innovative approach to improve the thermal conductivity of fluids. Fluids can contain a variety of powders, including metallic, non-metallic, and polymeric particles[1-2]. Fluids with suspended particles are expected to have higher thermal conductivities than ordinary fluids [3-4]. In most situations, the suspended particles have diameters of micrometres (μm) or even millimetres. Large particles might cause serious issues, including abrasion and blockage. As a result, fluids with large suspended particles have limited utility in heat transfer augmentation. Nanoparticles suspended in ordinary fluids such as water or ethylene glycol improve heat transfer characteristics of fluids effectively. Particles with a diameter of fewer than 100 nanometers (nm) have characteristics that differ from those of typical solids[5-6]. Nanophase powders offer substantially greater relative surface areas and a great potential for heat transfer enhancement when compared to micron-sized particles[7-8]. The heat transmission performance of a fluid can be considerably increased by suspending nanophase particles in it while heating or cooling it.

The following are some of the most important reasons [9-10]:

[1] Suspended nanoparticles increase the fluid's surface area and heat capacity.
[2] The nanoparticles suspended in the fluid improve the fluid's effective (or perceived) thermal conductivity
[3] There is more interaction and collision between particles, fluid, and the flow passage surface.
[4] The fluid's mixing fluctuation and turbulence are heightened.
[5] Nanoparticle dispersion flattens the fluid's transverse temperature gradient.

II. MATERIAL CHARACTERISTICS AND PREPARATION OF NANOFLUIDS

The initial step in using nanophase particles to change the heat transfer performance of conventional fluids is to prepare nanofluids. A liquid-solid mixture is not referred to as a nanofluid. Even suspension, stable suspension, durable suspension, low agglomeration of particles, and no chemical change in the fluid are all required[11]. Also, it is important to note that methods such as (1) Changing the pH value of the suspension, (2) using surface activators and/or dispersants (3) using ultrasonic vibration are utilized in the manufacture of nanofluids[12-13]. All of these methods are aimed at preventing particle cluster formation in order to achieve stable suspensions. In the present study, Zinc _oxide nanoparticles of 30-50 nm[14-15] were procured from Adnano technologies Shimoga, India. Technical data of ZnO nanoparticles are given in Table1.

Table 1. Technical specification of ZnO Nanoparticles

S.No	The descriptor of ZnO nanoparticles	Values
1	Molecular Formula	ZnO
2	Average Particle Size	30-50nm
3	Specific Surface area	80-110 m^2/g
4	Molecular Weight	81.408 g/mol
5	Melting point	1975^0c
6	Density	4.97 g/cm^3
7	Morphology	Spherical
8	Colour	Milky White

Zinc oxide has gained significant importance due to its high thermal and mechanical stability and versatile applications[16]. Three samples of nanofluids are prepared. In the first sample, 1gm of ZnO is dispersed in 10 litres of water, as shown in Figures 1 and 2. In the second sample, 10gms of Potassium Hydroxide pellets, as shown in Figure 3, are dissolved in 10 litres of water to which a further 1gm of Zinc oxide is added. The pH of sample 2 due to the addition of KOH, which is an alkali, has increased from 7 to 9. Sample 3 is prepared by dispersing 2gm of ZnO in10 liters of water. All three samples are centrifuged for 30 minutes, as shown in Figure 4, in order to obtain a uniform and stable suspension. Figure 5 shows the setup of parallel and counter flow heat exchangers used for conducting the experiments[17-18]. The prepared Sample 1 and Sample 2 images are shown in Figure 6 and Figure 7. The various cold fluid samples used in the experimentation, volume fractions, and the volume flow rates are shown in Table 2

Fig. 1 ZnO sample

Fig. 2 FESEM image of ZnO sample

Fig. 3 KOH pellets

Fig. 4 Centrifugation of sample

Fig. 5 Heat exchanger setup

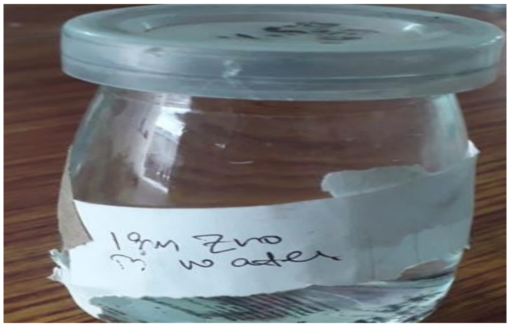


Fig. 6 ZnO dispersed in water

Fig. 7 ZnO and KOH dispersed in water

Table 2. Details of cold fluid samples and their flow rates [Litres Per Minute LPM]

Sample	Composition	Flow rates used in LPM
Pure water	100% pure water 10lts(H_2O)	0.5,0.8,1.0,1.2,1.5,1.8 and 2
Sample 1	Pure Water 10lts + ZnO(1gm)	0.5,0.8,1.0,1.2,1.5,1.8 and 2
Sample 2	PureWater10lts+ ZnO(1gm)+KOH(10gms)	0.5,0.8,1.0,1.2,1.5,1.8 and 2
Sample 3	Pure Water 10lts+ ZnO(2gm)	0.5,0.8,1.0,1.2,1.5,1.8 and 2

A. Estimation of nanofluid properties

The thermophysical properties of nanofluids that are used in this work are estimated using the following given correlations [19-20]. The property values obtained are shown in Table 3. These values are used in the estimation of heat transfer coefficients.

Φ (Volume fraction) = $(m_{np}/\rho_{np})/(m_{np}/\rho_{np}+m_f/\rho_f)$ --- (1)

ρ_{nf} (Density correlation) = $(1-\Phi)\rho_f + {}_{\Phi}\rho_{np}$ --- (2)

$(\rho c_p)_{nf} = (1-\Phi)(\rho c_p)_f + \Phi(\rho c_p)_{np}$ ---(3)

correlation for specific heat
μ (Dynamic Viscosity) = $\mu_0(1+ 2.5\Phi)$ --- (4) and

Thermal conductivity “K” of nanofluid is determined using Hamilton and crosser model as

$$\frac{K_{nf}}{K_{bf}} = \frac{K_{nP+(n-1)}K_{bf+(n-1)\phi(K_{np}-K_{bf})}}{Kn_{P+(n-1)K_{bf}}-\phi(Kn_p-K_{bf})} \text{ --------- } (5)$$

where subscript np denotes particle, f is base fluid, and nf is nanofluid. The value of n is equal to 3 for spherical particles.

Table 3. Thermophysical properties of water and prepared samples

Property	Water	Sample 1	Sample 2	Sample 3
Volume Fraction $^{(}\Phi)$	-	$2.0076 x10^{-4}$	$5.08x10^{-4}$	$4.014x10^{-4}$
pH	7	7	9	7
Density (ρ) kg/m^3	998	998.1	1001.1	999.6
Dynamic Viscosity (μ) N-s/m^2	$8.9x10^{-4}$	$8.9004x 10^{-4}$	$8.911x10^{-4}$	$8.909x10^{-4}$
Sp.Heat (C_p) J/kg^{0}c	4178	4178	4164.16	4187
Thermal Conductivity (K) W/mk	0.61	0.610036	0.610038	0.6107

III. EXPERIMENTATION

The heat exchanger used for the experiment is a concentric pipe heat exchanger [21-22]. The inner pipe is made of copper of size ID 21mm and OD 25mm and length 1100mm. The outer pipe is made of steel with ID 32mm and OD 38mm. The outer pipe is insulated completely from the outside using thermowell. Equipment is provided with four temperature sensors to monitor fluid temperatures, two rotameters to measure hot and cold water flow rates, and a heater to heat the fluid. Hot water is allowed to flow through the inner pipe, while the cold nanofluid is made to flow through the outer pipe. The flow rate of hot water is maintained constant at 1.2 LPM while the flow rate of cold

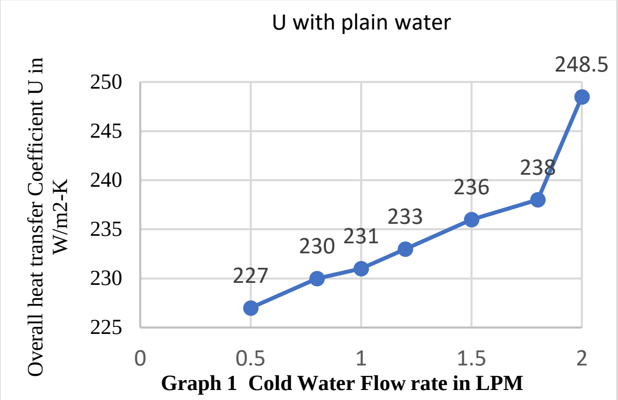
Nanofluid is varied from 0.5 liters per minute to 2.0 LPM. The experiment is carried out in counterflow mode, and temperature values, i.ehot, water inlet Th_i, Hot water outlet Th_o, cold water inlet $Tc_{i,}$ cold water outlet Tc_o is, recorded for each of the cold water flow rates, i.e. 0.5 LPM, 0.8 LPM,1 LPM,1.2 LPM,1.5 LPM 1.8 LPM and 2 LPM. The experiment is repeated using sample 1, sample 2 and sample 3. Overall heat transfer coefficient values and Nusselt number values are calculated for plain water, and results are compared with results obtained for sample 1, sample 2 and sample 3 and presented in the following section[23]

IV. RESULTS AND DISCUSSIONS

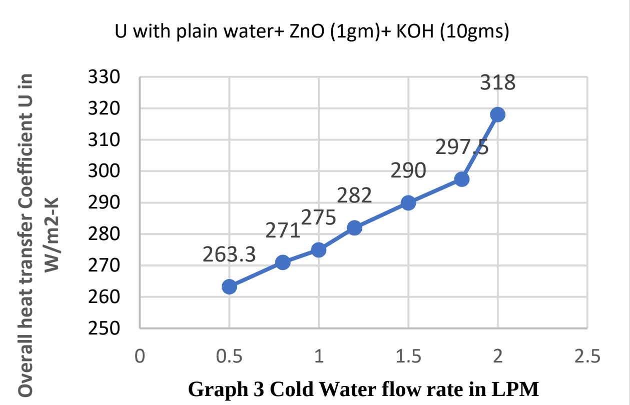
For the experimentation, prepared nanofluid samples are made to flow through the outer pipe as cold fluid at an inlet temperature of 30^0c. Plain water heated to $55^0c\pm5^0c$ is made to flow through the inner pipe at a constant flow rate of 1.2 LPM. To study the effect of flow rate on Nusselt Number and heat transfer coefficient, the flow rate of cold fluid in the outer pipe is varied, as shown in Table 2.

Table 4. Calculated values of overall heat transfer coefficient (W/m^2-K) at different flow rates

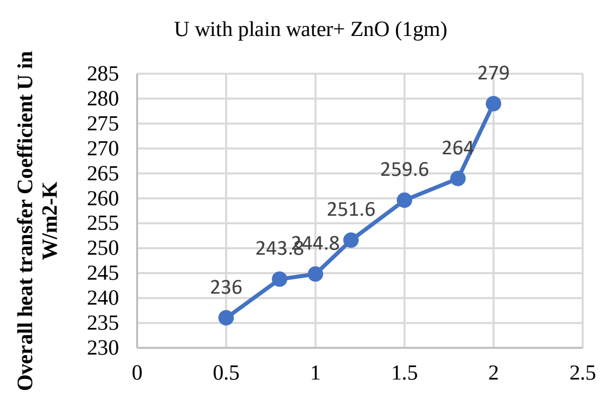
Samples	Flow Rate 1 (0.5 LPM)	Flow Rate 2 (0.8 LPM)	Flow Rate 3 (1.0 LPM)	Flow Rate 4 (1.2 LPM)	Flow Rate 5 (1.5 LPM)	Flow Rate 6 (1.8 LPM)	Flow Rate7 (2.0 LPM)
Pure Water	227	230	231	233	236	238	248.5
Sample 1	236	243.8	244.8	251.6	259.6	264.0	279.0
Sample 2	263.3	271.0	275.0	282.0	290.0	297.5	318.0
Sample 3	279.0	287.5	291.0	298.2	306.8	309.0	325.0



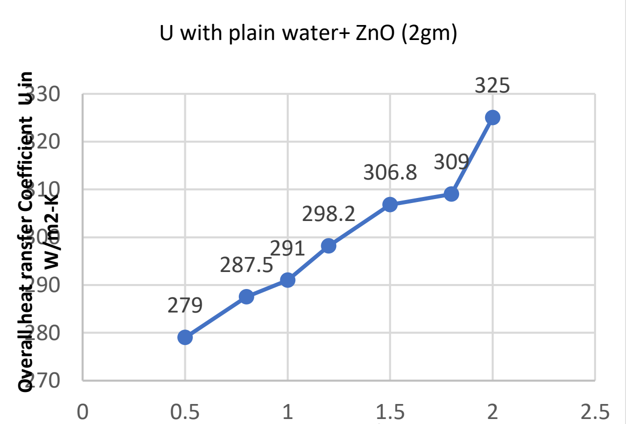
Graph 1 Cold Water Flow rate in LPM



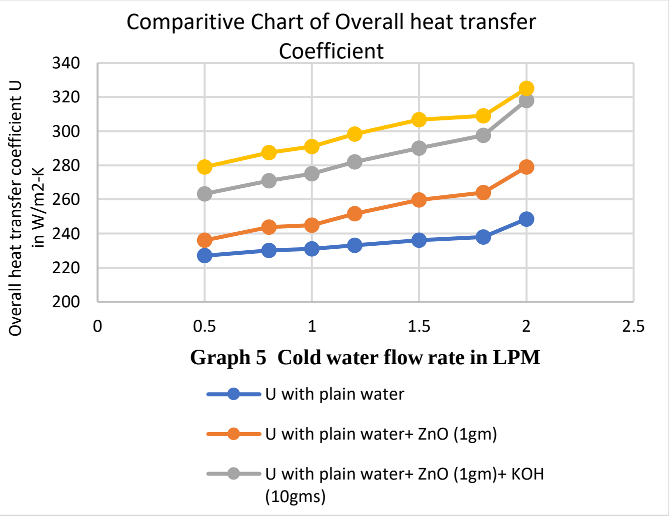
Graph 3 Cold Water flow rate in LPM



Graph 2 Cold water flow rate in LPM



Graph 4 Cold water flow rate in LPM



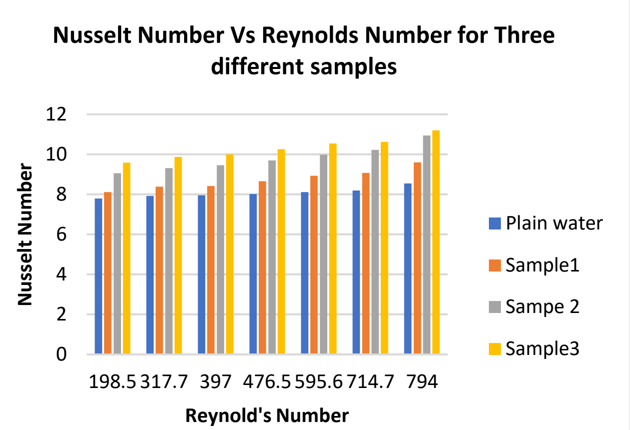
Graph 5 Cold water flow rate in LPM

1) As the cold fluid flow rate is increased from 0.5LPM to 2LPM in the outer pipe, the overall heat transfer coefficient is increased from 227 to 248.5 W/m^{2}·K for plain water, as shown in Table 4 and Graph 1, which is a 9.6% increase.
2) Similarly, for Plain water plus ZnO (1gm) (sample1) overall heat transfer coefficient increased from 236 to 279 W/m^{2}·K with a flow rate which is an 18% increase. For plain water plus ZnO (1gm) +KOH(10gm)(sample 2) overall heat transfer coefficient increased from 263.3 to 318 W/m^{2}·K, which is a 20.9 % increase. Overall heat transfer coefficient increased from 279.0 to 325 W/m^{2}·K for plain water plus ZnO (2gm) (sample3), which is 16.5 % as shown in Graph2-4. As the flow rate is increasing overall heat transfer coefficient is also increasing in each case which may be due to increased turbulence. The rate of increase in the overall heat transfer coefficient for all three samples is observed to be remarkably more when compared with results obtained for pure water at all flow rates. The shear-thinning phenomenon brought about by the addition of ZnO nanoparticles resulted in better fluid flow, thereby resulting in heat transfer coefficient enhancement. It is also observed that an increase in pH due to the addition of KOH has resulted in only a moderate increase in the overall heat transfer coefficient.
3) For a flow rate of 0.5 LPM, the percentage increase in overall heat transfer coefficient over plain water is 4%, 16%, and 23 % for sample1, sample2, and sample 3, respectively. Similarly, for a flow rate of 0.8 LPM, the percentage increase in overall heat transfer coefficient over plain water is 6%, 17.8%, and 25 % for sample1, sample2 and sample 3, respectively, as shown in Graph 5.
4) For a flow rate of 1.0LPM, the percentage increase in overall heat transfer coefficient over plain water are 6%, 19%, and 26 % for sample1, sample2 and sample 3. For a flow rate of 1.2 LPM, the percentage increase in the overall heat transfer coefficient over plain water is 8%, 21%, and 28 %. For a flow rate of 1.5 LPM, overall heat transfer coefficient enhancement over plain cold fluid is 10%,22.9%, and 30 %. At 1.8 LPM and 2 LPM corresponding enhancement values for sample 1,2 and 3 are 10.9% 25% , 29.9 % and 12.3% ,27.9% respectively, 30.8 % as shown in Graph 5.
5) Nanofluid's thermophysical properties and the chaotic movement of ultrafine particles are thought to be major factors in increasing heat transfer rates. The increase in thermal conductivity near the boundary layer caused by nanoparticle aggregation in the near-wall region undermines the development of the laminar boundary layer and makes heat transfer through the near-wall region simpler. One of the key factors that result in the enhancement of heat transfer utilizing nanofluids is the changed synergy between fluid velocity field and temperature gradient field [24].
6) Graph 6 shows the calculated Nusselt numbers for flows with different Reynolds numbers and various volume fractions of ZnO nanoparticles. As Reynold's number is increased from 198.5 to 794, Nusselt number is observed to increase from 7.8 to 8.55 for plain water, which is a 9.6% increase. Corresponding increased values for Samples 1,2 and 3 are 18.2%,20.8% and 16.8% respectively. At Reynold's number of 198.5 percentage increase in Nusselt number over plain water for samples 1,2, and 3 are 4.1%,16.13, and 23%, respectively, as evident from chart 6. Similarly, at Reynold's number of 794 percentage increase in Nusselt number over plain water for samples 1,2 and 3 are 12.3%,28%, and 31%, respectively. At 0.01vol % of ZnO, Nusselt number is observed to increase from 8.12 to 9.6 for Reynolds number increase from 198.5 to 794.

Table 5. Calculated values of Nusselt number of three samples at different Reynold's Number

Reynolds Number	Nusselt Number for plain water	Nusselt Number for Sample 1	Nusselt Number for Sample 2	Nusselt Number for Sample 3
198.5	7.8	8.12	9.058	9.59
317.7	7.92	8.39	9.32	9.88
397	7.95	8.42	9.46	10
476.5	8.02	8.66	9.7	10.25
595.6	8.12	8.93	9.98	10.55
714.7	8.19	9.08	10.23	10.62
794	8.55	9.6	10.94	11.2

Also, it increases from 9.59 to 11.2 for 0.02vol % of ZnO. The agglomeration effect of ZnO nanoparticles in nanofluid reduces as the Reynolds number increases, which amplifies the dispersion of the nanoparticles due to adequate mixing, resulting in a dramatic increase in the Nusselt number.



Graph 6

V. CONCLUSION

In the present study, an experimental investigation of forced convective heat transfer using ZnO nanofluid in a double pipe heat exchanger at constant heat flux was carried out. Overall heat transfer coefficient and Nusselt number was estimated for various volume fractions, pH values, and Reynolds numbers. The results show significant enhancement in overall heat transfer coefficient with increasing volume fraction of ZnO and Reynolds number. A moderate increase in overall heat transfer coefficient and Nusselt number was noticed with an increase in pH of the solution by the addition of KOH pellets which is evident from the results of sample 2 when compared to the results of sample 1. As a result, parameters such as thermophysical particle properties, the volume percent of nanoparticles, and pH of solution all work together to improve the overall heat transfer coefficient. At the highest Reynold’s number of 794 increase in Nusselt number was observed as 12.3% and 31% for 0.01% and 0.02% of volume fractions respectively and 28% for sample 2, which has pH of 9. Inter-particle collision, the ballistic nature of heat conduction, and nanoparticle clustering could all be factors in the remarkable increase in the overall heat transfer coefficient. Results reported by R.N.Radkar B.A.Bhanvase, D.P. Barai et al. are also in confirmation with the above results [25]. As a result of the improved heat transfer performance and compatibility of ZnO nanofluid, it may now be considered a viable choice for heat transfer applications.

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