Int. J. Nano Dimens., 8(1): 18-30, Winter 2017

ORIGINAL ARTICLE

Effect of nonionic surfactant additives on the performance of nanofluid in the heat exchanger

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Received 21 September 2016; revised 12 December 2016; accepted 16 January 2017; available online 16 February 2017

Abstract

A nanofluid is mixture of nano sized particles and a base fluid. This paper investigates by using laboratory based double pipe heat exchanger model, the performance of nanofluid containing about 48.46nm particle size nanoparticles (ZnO) without or with addition of nonionic surfactant Rokanol K7 (500ppm) into the base fluid double distilled water to prepared three different concentrations 1.0%, 2% and 3% (v/v) of ZnO-water or ZnO-RK7. Effects of temperature and concentration of nanoparticles on viscosity and heat transfer coefficient in heat exchanger are investigated. The experimental results shows that the viscosity of nanofluids increased with increasing concentration of fluid whereas decreased with increasing temperature from 20 to 60^{o}C. However, it has been also observed that heat transfer coefficient increases with the operating temperature and concentration of nanoparticles. The conclusion derived for the study is that overall heat transfer coefficient enhanced with increasing concentration upto 3% of ZnO-RK7 as compared to without surfactant nanofluids.

Keywords: *Heat exchanger; Heat transfer coefficient; Nanofluid; Nonionic surfactant; Viscosity.*

How to cite this article
P Lakhawat G, P Ugwekar R, G Suke S. Effect of nonionic surfactant additives on the performance of nanofluid in the heat exchanger. Int. J. Nano Dimens., 2017; 8(1): 18-30, DOI: 10.22034/ijnd.2017.24373

INTRODUCTION

In the recent years, there has been a necessity of requirement for energy conservation and thermal management due to increasing demand for power and the rising energy cost. Heating and cooling processes play important role in most of the energy systems; therefore, there is a need to increase the heat transfer and energy efficiency of these thermal management systems. New strategies for industrial world have to be developed to improve the thermal behavior of fluids in the heat exchangers. It is well established that the thermal performances of conventional working fluids in heat exchangers, such as water, ethylene glycol, propylene glycol, engine oil, mineral oil, kerosene oil and silicon oil are commonly used in heat transfer equipment [1]. The thermal effectiveness of such type of equipment can be greatly enhanced by improving the thermal conductivity of working fluids and this can be achieved by dispersing a small quantity of solid particles such as Cu, Al_2O_3, Ag, TiO_2 in water and ethylene glycol as base fluids [2].

The augmentation of thermal conductivity of conventional fluids through the suspension of solid particles in mm or µm sized has not been interest for practical applications, due to the problems associated with sedimentation, erosion, fouling, and increased pressure drop through the flow passages. However, the effective thermal conductivity and viscosity of nanofluids introduced nanoparticles (NPs) in low volume fraction within base fluids, leading to the concept of “nanofluids” [3, 4].

In the previous report, Cu as NPs had larger velocity and temperature values than Ag as NPs [5]. The study showed that the effect of NPs on nanofluids viscosity under wide ranges of temperatures experimentally indicated that viscosity drops sharply with temperature especially

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for high concentration of NPs [6]. Moreover, the effect of temperature, nanomaterial size, and nanomaterial volume fraction on thermal conductivity was experimentally indicated as increasing the volume of fraction of NPs, temperature profile has been increased a lot which means the heat transfer properties can be enhanced by selecting appropriate NPs sizes [7]. Thus, such phenomenon cannot be ignored and dependence of nanofluid properties on temperature, volume fraction of NPs must be taken into account in order to predict the correct role of NPs on heat transfer enhancement.

Furthermore, agglomeration of NPs results is not only settlement and clogging of microchannels but also decreasing thermal conductivity of nanofluids. The problem may be solved by chemical treatment addition of surfactant into working fluid. Earlier reports shows that effect of surfactant additives on nucleate pool boiling heat transfer of refrigerant-based nanofluid and three types of surfactants including Sodium Dodecyl Sulfate, Cetyltrimethyl Ammonium Bromide and Sorbitan Monooleate (Span-80) were used in the experiments. The experimental outcomes indicated that the presence of surfactant enhances the nucleate pool boiling heat transfer of refrigerant-based nanofluid on most conditions, but deteriorates the nucleate pool boiling heat transfer at high surfactant concentrations [8]. Surfactants used in nanofluids also called dispersants. Adding dispersants in two-phase systems is an easy and economic method to enhance the stability of nanofluids. Dispersants can markedly affect the surface characteristics of a system in small quantity. Dispersants consists of a hydrophobic tail portion, usually a long-chain hydrocarbon, and a hydrophilic polar head group. Dispersants was employed to increase the contact of two materials, sometimes known as wettability. Nanofluids have been found to possess enhanced thermophysical properties such as thermal conductivity, thermal diffusivity, viscosity, and convective heat transfer coefficients compared to those of base fluids like oil or water and that was demonstrated great potential applications in many fields [9].

However, the convective heat transfer coefficient of nanofluids with or without surfactant at different concentrations, there are no previous studies are reported in any literature. In the present work, Zink oxide (ZnO) containing nanofluids were prepared with or without using any surfactant. Hence, the purpose of this paper is to experimentally investigate the effect of surfactant in a double pipe heat exchanger using nanofluids, and models have been developed to predict the thermal properties of nanofluids and experimentally to investigate the viscosity of nanofluids. These nanofluids have been tested for their cooling performance under transient conditions.

EXPERIMENTAL

Chemicals

Highly pure zinc nitrate [$Zn(NO_3)_2.6H_2O$] and sodium hydroxide [NaOH] were purchased from Sigma-Aldrich, Bangalore. Ethanol and starch were procured from SD Fine Chemical, Mumbai. Nonionic surfactant Rokanol K7 (PCC Rokita SA, Poland) supplied by Central Scientific Company Nagpur, India. Double distilled water (18.2 MΩ, Barnstead EASYPure ROdi) was used as solvent.

Synthesis of ZnO nanoparticles

The ZnO NPs were prepared by wet chemical method using zinc nitrate and sodium hydroxides precursors and soluble starch as stabilizing agent. Soluble starch (0.5%) was dissolved in 500 ml of double distilled water and kept in microwave oven for complete solubilization. Then 0.1 M of Zinc nitrate was added in the above solution and the solution was kept under constant stirring at room temperature using magnetic stirrer for one hour. After complete dissolution of zinc nitrate and 300 ml 0.2 M of sodium hydroxide solution was added under constant stirring, drop by drop touching the walls of the vessel. The reaction was allowed to proceed for 2 h after complete addition of NaOH and kept the solution to settle for overnight then supernatant solution discarded carefully. The remaining solution was centrifuged at 10,000 rpm for 10 min and again supernatant was discarded. The precipitated of NPs were washed three times with distilled water and ethanol. Washing was carried out to remove the byproducts and excessive starch that were bound with the NPs. After washing, the NPs were dried at 80°C for overnight. During drying, $Zn(OH)_2$ is completely converted into ZnO takes place [10].

Characterization of ZnO nanoparticles

The synthesized ZnO NPs were characterized for their optical and nanostructural properties. X-ray diffraction (XRD) pattern for ZnO NPs was recorded using an X-ray diffractometer (PANLYTICAL) using Cu Kα radiation of wavelength λ = 0.1539 nm in the scan range 2θ = 10-99°. Morphology of the sample was investigated using scanning electron microscope (SEM, WEGA II TESCAN) which also has been used for compositional analysis of the prepared ZnO NPs. These instruments facility were used for characterization of ZnO NPs at Department of Chemical Engineering, VNIT Nagpur, India.

Preparation of nanofluid with or without surfactant

Three different concentrations of nanofluid 1%, 2% and 3% were prepared by mixing ZnO NPs with double distilled water under vigorous stirring at 4000 rpm for about 3 to 4 h. However, ZnO nanocomposite based nanofluids mixed with 500 ppm nonionic surfactant Rokanol K7 to produce as nanofluids with surfactants (ZnO-RK7). Then vibrating the ZnO-RK7 nanofluids by an ultrasonic processor for 1 h to disperse the NPs evenly in the ZnO-RK7 nanofluids and kept for more than 24 h to stabilize the nanofluids.

Nanofluid viscosity measurement

The viscosity of ZnO-RK7 nanofluids and water were measured by using a rotational rheometer (Physica, MCR-301, Anton Paar, and Graz, Austria). The instrument consists of two parallel cylindrical surfaces with a gap of 0.5 mm; the mobile cylinder has a diameter of 50 mm. The viscosity of the suspensions was determined by varying shear rate in the range of 10 to 140/s. Measurements were taken five times at temperatures of 20°C, 40°C and 60°C for each experiment.

Measurement of heat transfer coefficient

Laboratory scale double pipe heat exchanger model was prepared. The Schematic view of the experimental setup is shown in Fig. 1. The heat exchanger model made up of stainless steel pipes. Inside and outside inner pipe diameter are 15.05 mm and 19.95 mm respectively whereas; inside and outside outer pipe diameter are 46.8 mm and 50.8 mm respectively. The length (L) 1.5m long horizontal double pipe heat exchanger was used only for the counter current operation due to small length of heat exchanger. The apparatus consists of a test section were two reservoir tanks and two centrifugal pumps used to circulate the fluid such as hot fluid (distilled water) pump and cold fluid (distilled water with or without surfactant nanofluids) pump. Before performance of the system, the hot fluid was kept constant maintained inlet temperature 60°C by control system consisting of thermocouple with the help of heating tank consisting of heater and stirrer. There hot fluid flow through inner tube where as cold fluid (with or without surfactant) flow through annular space of the experimental model. The test section thermally isolated from the surroundings by asbestos rope insulation in order to reduce the heat loss into the atmosphere.

Thermocouples of type-J were mounted at both the ends of the test section to measure the bulk temperature of the cold fluid under consideration. The inlet and exit temperature of hot fluid was also measured by using J-type thermocouples which are inserted into the flow directly. The receiver tanks were used for collecting cold fluid and hot fluid leaving the test section. During the test run, the inlet and exit temperatures of hot and cold fluid were measured. The mass flow rates of both hot and cold fluids measured using an inline fluid flow measuring device. The experiment was performed and recorded seven measurements in one hour for each (1%, 2% and 3%) concentration of both nanofluids (with or without surfactant) sample.

Data processing

The experimental data were used to calculate convective heat transfer coefficient and overall heat transfer coefficient. For fluid flows in a double tube heat exchanger expressed by following equations [11].

The effective thermophysical properties of hot fluid (hot distilled water) and cold fluid (distilled water and with or without surfactant nanofluids) were determined first.

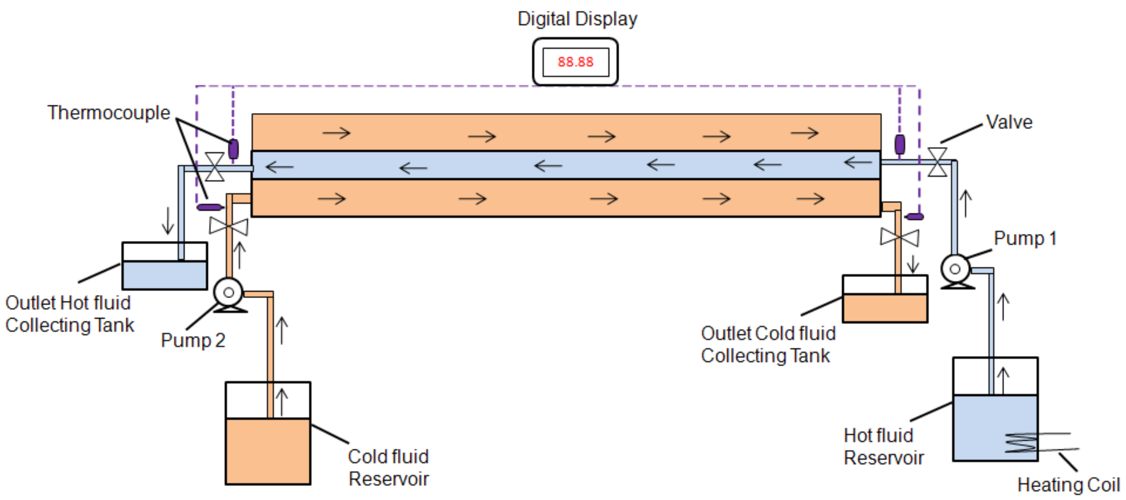

Fig. 1: Schematic diagram of the laboratory setup of double pipe heat exchanger model.

The heat transfer rate of the hot distilled water (hot fluid) in the inner tube is

$$Q_{(hot\,fluid)} = m^{o}_{(hot\,fluid)}\, Cp_{(hot\,fluid)} (T_{in} - T_{out}) \quad (1)$$

where m^{o} is the mass flow rate in kg/s of the hot distilled water (hot fluid), Cp = Specific heat in J/kg K of hot fluid and T_{out} and T_{in} are the outlet and inlet temperatures of the hot fluid, respectively.

The heat transfer of the cold fluid (double distilled water or with or without surfactant nanofluids) for the outer tube is

$$Q_{(cold\,fluid)} = m^{o}_{(cold\,fluid)}\, Cp_{(cold\,fluid)} (T_{out} - T_{in}) \quad (2)$$

where m^{o} is the mass flow rate in kg/s of the distilled water or nanofluid (cold fluid), Cp = Specific heat in J/kg K of cold fluid and T_{in} and T_{out} are the inlet and outlet temperatures of the cold fluid, respectively.

The mass flow rate of hot fluid or cold fluid is

$$m^{o}_{(hot\,fluid)} = (Re\ \pi\ d_i\ \mu) / 4 \text{ , or}$$
$$m^{o}_{(cold\,fluid)} = (Re\ \pi\ d_o\ \mu) / 4 \quad (3)$$

where Re is the Reynolds number, d_i and d_o diameter of inner and outer tube respectively and μ is the viscosity of hot fluid or cold fluid.

The average heat transfer (Q) of the system was calculated by the equation is

$$Q = Q_{(hot\,fluid)} + Q_{(cold\,fluid)} / 2 \quad (4)$$

If assume that the NPs and/or surfactant are well dispersed inside the base-fluid (distilled water), the effective physical properties of the nanofluids mixture like density, specific heat, viscosity and thermal conductivity can be evaluated.

The effective densities of nanofluids are calculated by using of the [12] correlations, which are defined as follows:

$$\rho_{nf} = (1 - \varphi_V)\, \rho_{bf} + \varphi_V\, \rho_{np}, \quad (5)$$

Where ρ_{bf} is density of base fluid (distilled water) and ρ_{np} is the density of NPs (ZnO). φ_V is the volume concentration of the solid NPs (1%, 2% and 3%).

The effective specific heat of nanofluids which can be calculated from Xuan and Roetzel relation [13]:

$$(\rho Cp)_{nf} = (1 - \varphi_V)\, (\rho Cp)_{bf} + \varphi_V (\rho Cp)_{np} \quad (6)$$

The effective viscosity of the nanofluids estimated by using Einstein model [14] which is predicted viscosity for particle suspension in base fluid when the volume concentration is lower than 5% is

$$\mu_{nf} = (1{+}2.5\, \varphi_V)\, \mu_{bf} \quad (7)$$

The effective thermal conductivity of the nanofluids evaluated by using Maxwell's model as follows [15]:

$$k_{nf} = k_{bf}\, [(k_p + 2k_{bf}) - 2\, \varphi_V (k_{bf} - k_p) / (k_p + 2k_{bf}) + \varphi_V (k_{bf} - k_p)] \quad (8)$$

where k_{nf} is the effective thermal conductivity of nanofluids ($k$nf), k_p is the thermal conductivity of NPs, k_{bf} is the thermal conductivity of base fluid. The convection heat transfer coefficient from the hot fluid section can be written as [16]

$$Q_{(hot\,fluid)} = h_i A_i (T_{wi}^{\sim} - T_i), \quad (9)$$

$$T_i = T_{in\,(hot\,fluid)} + T_{out\,(hot\,fluid)} / 2, \quad (10)$$

$$T_{wi}^{\sim} = \Sigma\, (T_{wi}/6) \quad (11)$$

where T_{wi} is the local surface temperature at the inner wall of the inner tube. The average surface temperature $T_{wi}^{\sim}$ is calculated from 6 points of T_{wi} lined between the inlet and outlet of the inner pipe.

The convective heat transfer coefficients of the inner tube fluid is

$$h_i = Q_{(hot\,fluid)} / A_i (T_{wi}^{\sim} - T_i) \quad (12)$$

The convection heat transfer coefficient from the cold fluid section can be written as

$$Q_{(cold\,fluid)} = h_o A_i (T_{wo}^{\sim} - T_o) \quad (13)$$

$$T_o = T_{out\,(cold\,fluid)} + T_{in\,(cold\,fluid)} / 2, \quad (14)$$

$$T_{wo}^{\sim} = \Sigma\, (T_{wo}/6), \quad (15)$$

where T_{wo} is the local surface temperature at the inner wall of the outer tube. The average surface temperature $T_{wo}^{\sim}$ is calculated from 6 points of T_{wo} lined between the inlet and outlet of the outer pipe.

The convective heat transfer coefficients of the outer tube fluids is

$$h_o = Q_{(cold\,fluid)} (T_{out} - T_{in}) / A_i (T_{wo}^{\sim} - T_o) \quad (16)$$

The amount of heat gained by fluid estimated from Newton's law of cooling is

$$Q = U A\, (\Delta T)_{LMTD}, \quad (17)$$

where U is the overall heat transfer coefficient, *A is the* surface area in m^2 of the inner tube, $(\Delta T)_{LMTD}$ is the logarithmic mean temperature difference for counter flow.

$$(\Delta T)_{LMTD} = \Delta T_1 - \Delta T_2 / \ln (\Delta T_1 / \Delta T_2) \quad (18)$$

where ΔT_1 is $(T_{in} - T_{out})$ and ΔT_2 is $(T_{out} - T_{in})$
The overall heat transfer coefficient based on the inner and outer tubes areas are

$$U_i = Q / A_i (\Delta T)_{LMT} \text{ and } U_o = Q / A_o (\Delta T)_{LMTD} \quad (19)$$

where A_i is the surface area of the inner tube = $\pi d_i L$ and A_o is the surface area of the outer tube = $\pi d_o L$

Statistical analysis

The convective heat transfer coefficients of the inner pipe fluids (h_i) and outer pipe fluids (h_o) in heat exchanger calculated and data were expressed as arithmetic mean ± SD. Different concentrations of nanofluids (with or without surfactant) were compared with base fluid (a), whereas 1% (nf) with ZnO-RK7 was compared with ZnO-bf (b), 2% (nf) with ZnO-RK7 was compared with ZnO-bf (c), and 3% (nf) with ZnO-RK7 was compared with ZnO-bf (d) and compared with 2% and 3% (with or without surfactant) nanofluids (e). Statistical difference between two means was determined by one-way ANOVA and mean values showing statistical difference $P < 0.01$ or $P < 0.05$ were considered as statistically significant.

RESULTS AND DISCUSSION

XRD and SEM analysis

Several synthesis methods stated the ZnO-NPs produced was white to off-white colored powder [17]. Our synthesized ZnO-NPs were white in color, odorless powder. Previously reported ZnO-NPs size and morphology depends on the method of synthesis and the ZnO-NPs synthesized was granular and spherical in shape and having an average size of 22-33 nm [18]. In the present study prepared ZnO-NPs were characterized by XRD and SEM. The XRD pattern of ZnO nanopowder represents in Fig. 2. A definite line broadening of the XRD peaks indicates that the prepared material consist of particles in nanoscale range. This XRD patterns analysis, determined peak intensity, position and width, full-width at half-maximum (FWHM) data. Here 24 peaks are noticed in accordance with zincite phase of ZnO. The diffraction peaks located from 28.63° to 98.45° have been keenly indexed as hexagonal wurtzite phase of ZnO [19-21]. It also confirmed that the synthesized nanopowder was free of impurities as it does not contained any characteristics XRD peaks other than ZnO peaks. The average crystallite size of the synthesized ZnO-NPs diameter D was calculated using Debye-Scherrer formula [22] as follows:

$$D = (K \lambda) / (\beta \cos \theta) \quad (20)$$

where K is the scherrer constant (0.9), λ is the wavelength of incident X-rays, θ is the centre of the peak in radians, β is the peak full width at half-maximum (FWHM) intensity of the diffraction peak corresponding to plane. The average particle size of the sample was found to be 48.46nm which is derived from the FWHM of more intense peak corresponding to 101 plane located at 36.26° using Scherrer's formula.

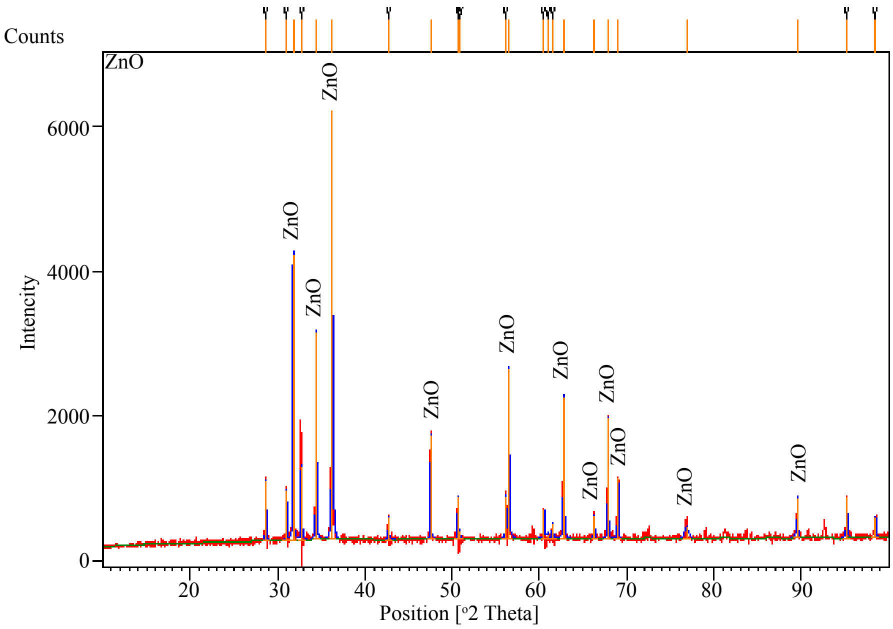

Fig. 2: X-ray diffraction pattern of ZnO nanoparticles.

However, the SEM was used to decide size, location and shape of NPs. Fig. 3a and 3b shows that the SEM images of ZnO-NPs and confirm the formation of ZnO NPs are spherical in shape and their particle sizes about 48.46 nm calculated from the Debye-Scherrer formula. As evident from the SEM, synthesized ZnO NPs prevail in slightly agglomerated state. Macroscopically speaking, previous report indicated that, the properties of a homogenous nanofluid that affect its thermal behaviour include heat capacity, thermal conductivity, density and viscosity [23]. For non-homogenous nanofluids, instability due to sedimentation is expected to affect the heat transfer behaviour in a negative way. As mentioned previously, surfactants and/or dispersants are often used to stabilize NPs suspensions, which could exert a significant influence on both the rheological behaviour of the fluids and the heat transfer [24-26].

Viscosity of nanofluids

The prepared nanofluids, with no contamination to medium, good fluidity, low viscosity, high stability, and high thermal conductivity, would have potential applications as coolants in advanced thermal systems [27]. In the present study viscosity of nanofluids (with or without surfactant) were measured for different particle concentrations (1%, 2% and 3%) between 20 °C to 60 °C. The viscosity of the pure double distilled water was also measured prior to measurement, and the results are compared with those from the literature in order to verify the accuracy of the measurement system. The results are shown in Fig. 4 for nanofluids (without surfactant) and in Fig. 5 for nanofluids (with surfactant). Previous study reports shows that interactions between metal oxide (MO) NPs and propylene glycol (PG) molecules led to lower viscosity of MO–PG nanofluids and shows as excellent prospects for cooling applications [28]. In the present study effective viscosity of these nanofluids, shows a similar behavior as water with the increase in temperature. The viscosity of ZnO-RK7 nanofluids stabilized by Rokanol K7 dispersant for different particle concentrations (1%, 2% and 3%), with varying temperature between 20°C to 60°C. As there was expected that the addition of surfactants raised dynamic viscosity coefficient of ZnO nanofluids and reduced the viscosity with increased the temperature. Results shows that effective viscosities at 20 °C and 60 °C of 3% ZnO–water nanofluids are 4.2mPAs and 3.25mPAs respectively, where as 3% ZnO-RK7 nanofluids are 2.52 mPAs and 1.5 mPAs at 20°C and 60 °C respectively.

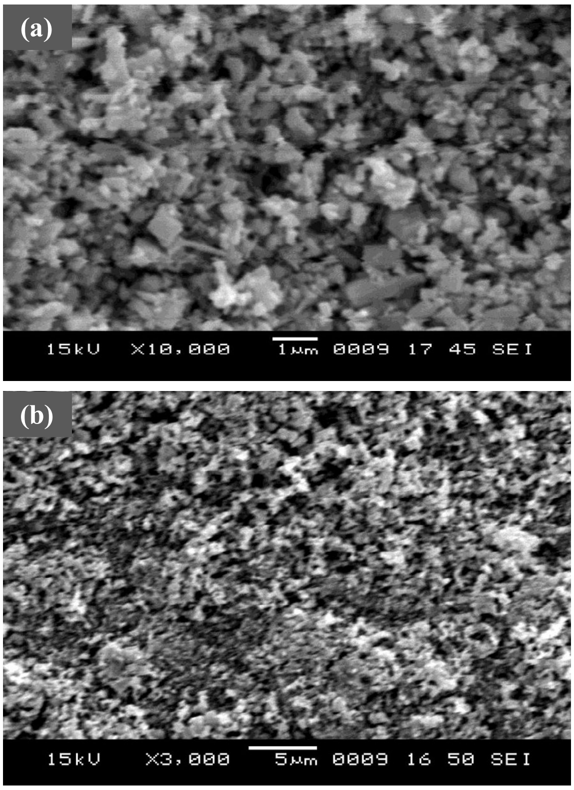

Fig. 3: Scanning electron micrograph of synthesized ZnO nanoparticles

Furthermore, the relative viscosity is the ratio of effective viscosity of nanofluid and the pure base fluid, as a function of volumetric particle concentration shown in Fig. 6. Measured viscosity of nanofluids is much higher than that predicted by the Einstein eq. (7), which shows strong effect of interactions of the NPs. Viscosity of nanofluids increases dramatically, with increase in particle concentration which may be related with not using any surfactant while producing the

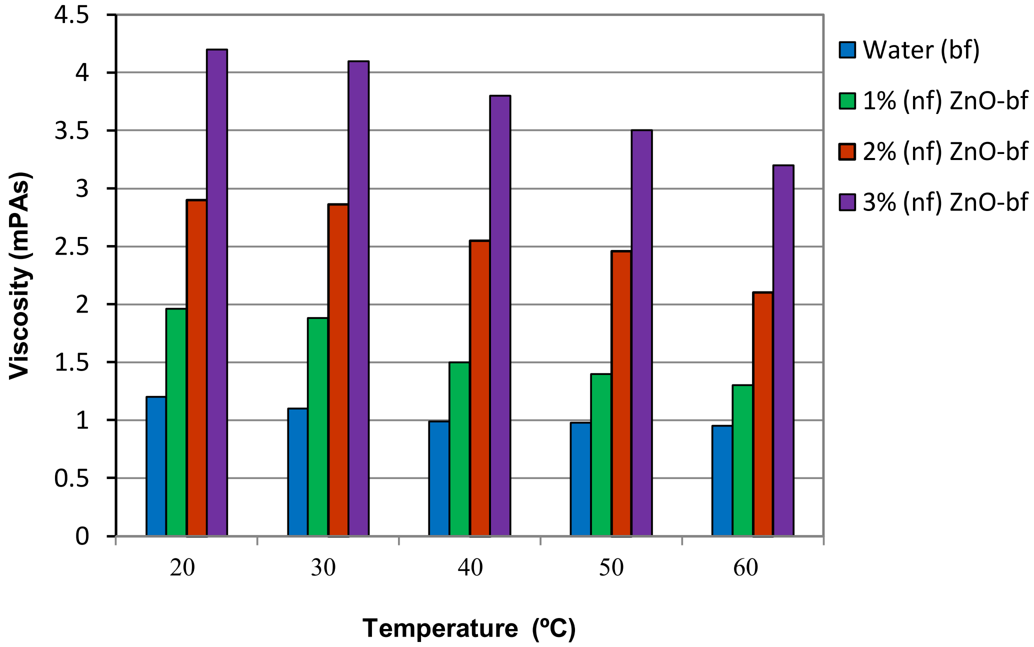

Fig. 4: Effective viscosities of ZnO–water nanofluids for 1%, 2% and 3% concentrations as a function of temperature.

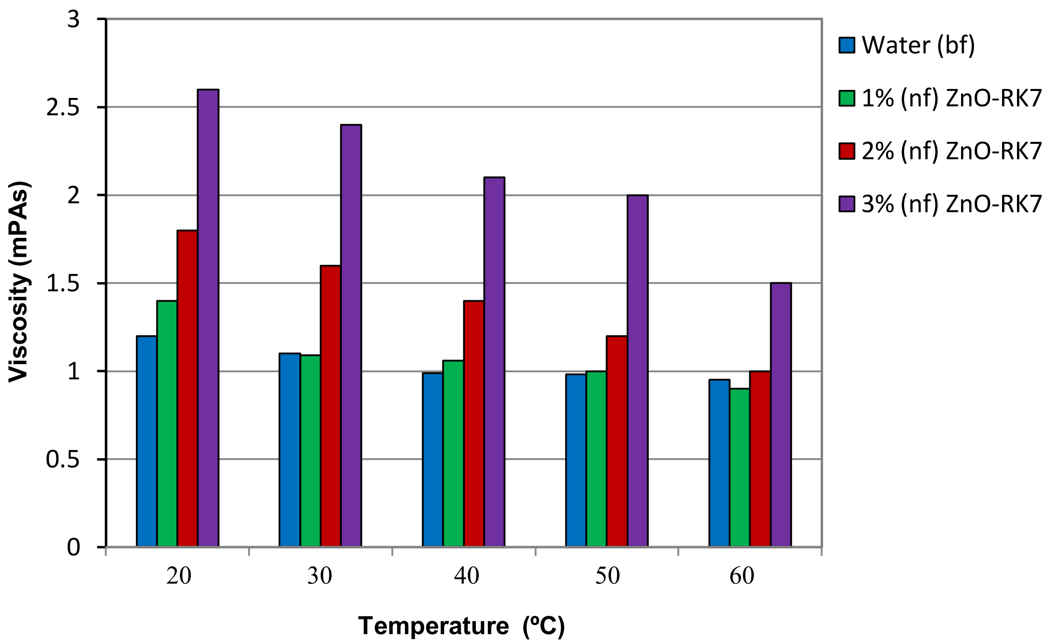

Fig. 5: Effective viscosities of ZnO–RK7 nanofluids for 1%, 2% and 3% concentrations as a function of temperature.

nanofluids. There was observed that by increasing the *Re*, the drop pressure increased. Nanofluid indicated higher pressure drop compared with the base fluid. Moreover, friction factor increases with increasing in concentration of NPs due to the rise of working fluid viscosity. The pressure drop gets more enhanced at the higher *Re*. Addition of surfactant in nanofluids that results reduce the viscosity. Relative viscosity of ZnO-bf and ZnO-RK7 nanofluids as a function of NPs volume concentration shows that the viscosity of base fluids increases with addition of different concentration of ZnO nanoparticles. But with addition of RK7 the viscosity was drastically decreased in ZnO-RK7 nanofluids shown as green colour which touches to the Einstine model black dotted lines.

Moreover, previously reported disturbance of hydrogen bonding network of ethylene glycol by ZnO nanoparticles resulted in reduced dispersion viscosity [29]. The advantages of well dispersed nanofluids to be used as coolants are (i) higher surface area for heat transfer, (ii) lower viscosity and lesser pumping power, and (iii) good colloidal stability due to the smaller size of aggregates [30].

Heat transfer coefficient in heat exchanger

Additions of NPs in the base fluid results are changes in nanofluids density, specific heat, thermal conductivity, and viscosity. Therefore, before the study on the convective heat transfer performance of the nanofluid, the properties of nanofluid must be known accurately. By assuming that the NPs are well dispersed in the distilled water as base fluid, the concentration of NPs may be considered uniformly throughout the tube. Although this assumption may not be true in reality because of some physical phenomena such as particle migration, it can be a useful tool to evaluate the physical properties of a nanofluid. In the present paper, NPs small diameter 48.46 nm and volume fraction 1%, 2% and 3% are assumed to be uniform and constant. The greater Brownian diffusion coefficient (less nanoparticle diameter) and less thermophoresis force (lower volumetric concentration) may lead to ignore nanoparticle migration [31]. Therefore, nanoparticle migration can be ignored in this study. Hence, uniform volumetric concentration of nanofluid can be assumed through the heat exchanger.

Heat transfer improvements can be achieved by increasing the heat transfer coefficient either by using more efficient heat transfer model, or by improving the transport properties of the heat transfer material. However, the heat transfer coefficient can also be increased by enhancing the properties of the coolant for a given method of heat transfer. If we predict that the NPs are well dispersed inside the base-fluid, the effective physical properties of the nanofluids mixture like effective density, specific heat, viscosity and thermal conductivity are shown in the Table 1. Additives are often added to liquid coolants to improve specific properties [13]. An optimum value for heat transfer coefficient was found by experimental investigation on pool boiling heat transfer of ZnO, and CuO water-based nanofluids with increasing surfactant concentration within nanofluid [32].

In the present study used double pipe heat exchanger model, where initially experiments are conducted with plane double distilled water to establish the validity of the experimental results as a part of calibration process. The deviation between the energy gained by the nanofluid from the energy lost by the hot fluid is in the range of less than 5%. After validating the results obtained from the test setup using water as heat transfer fluid, nanofluid at different concentration (1%, 2% and 3%) are introduced into the test section for the estimation of heat transfer coefficient. However, in the previous study found that one of the reasons is the use of thermophysical properties particularly viscosity and effective thermal conductivity of nanofluids which is an important factors in calculating Reynolds, Prandtl, and Nusselt numbers. Reynolds number (*Re*) is a function of thermo-physical properties like density and dynamic viscosity. The nanofluids with different volume concentrations have different thermophysical properties than base fluid. The substantial increases in the *Re* can be observed with the increase in concentration of nanoparticles. The heat transfer coefficient of the nanofluid increases with an increase in the *Re*, also the heat transfer coefficient increases with the increase of the volume concentration of the nanofluid. Moreover, increasing the volume concentration cause increases in the viscosity of the nanofluid leading to increase in friction factor and the boundary layer thickness [33]. The Nusselt numbers of the nanofluid are higher than the base fluid, and the numbers are increasing with the increase in *Re* as well as the particle volume concentration. In the present work observed that the heat transfer characteristics of the nanofluid increased.

Experimental convective heat transfer coefficient of inner tube fluid and outer tube fluids are shown in Fig. 7 (A and B). There was observed that the convective heat transfer coefficient increases with increase the concentration of nanofluids (ZnO-bf) and also improvement in the thermophysical properties of nanofluids with addition of nonionic surfactant (ZnO-Rk7). The addition of surfactant Rokanol K7 which helps to binds the particles together in the fluid medium and prevents the sedimentation which can be indicated that surfactant helps the nanofluids to homogeneously distribute in the heat exchanger. Presence of surfactant increases the heat transfer coefficient as compared to without surfactant because NPs binds in the medium themselves and there was reduction of sedimentation. Hence, more conduction and convection take place that results in both the inner (*hi*) and outer (*ho*) tube fluid increased heat transfer coefficient with nonionic surfactant (ZnO-Rk7) nanofluid as compared to nanofluids ZnO-bf.

However, in the double pipe heat exchanger, local convection coefficients are larger at outer pipe as compared to inner pipe. The overall heat transfer coefficient of inner tube and outer tube fluids are shown in Fig. 8. Overall heat transfer coefficient (*U*) showing more in the outer pipe as compared inner pipe. Results indicate same trend of the heat rate for the overall heat transfer rate using distilled water as working fluid. This is because heat rate is directly proportional to the overall heat transfer coefficient. The overall heat transfer coefficient for distilled water at inner pipe (*Ui*) found that less than 200 W m^{-2} K^{-1}. For the nanofluid, the overall heat transfer coefficient increases with the increase in volume concentration of the nanofluid, the value of the overall heat transfer coefficient (*Uo*) indicated at 3% volume concentration of the nanoparticles with an enhancement more than 350 W m^{-2} K^{-1}, the reason is that the NPs increase the thermal conductivity and a large energy exchange process resulting from the chaotic movement of the nanoparticles. This enhancement in heat transfer indicated that nanofluids could be a promising replacement for pure water in microchannel where need to more efficient heat transfer. Effectiveness of heat exchangers nanofluid increases with increase of particle concentration with surfactant in nanofluid.

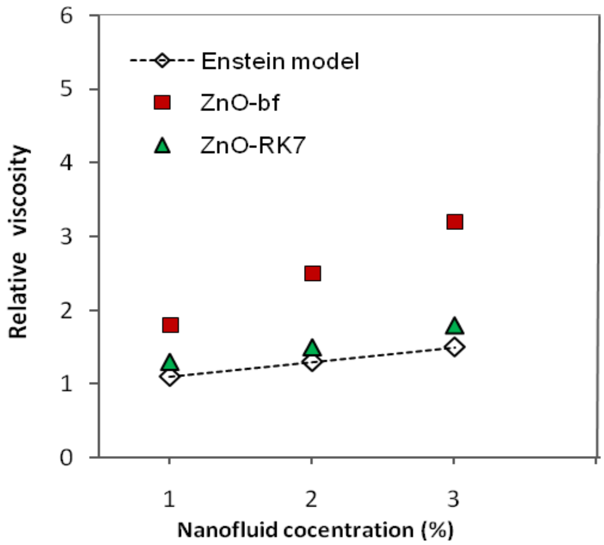

Fig. 6: Relative viscosity of ZnO-bf and ZnO-RK7 nanofluids as a function of nanoparticle volume concentration.

Table 1: Effective thermal properties of nanofluids.

Parameters	1% (nf)	2% (nf)	3% (nf)
Density (ρ_{nf}), kg/m^3	992.850	994.700	996.550
Specific heat (Cp), J/ kg K	4253.065	4226.132	4099.197
Viscosity ($\mu_{nf)}$, kg/m^2 s	0.001487	0.002254	0.002897
Thermal conductivity (k_{nf}), W/mK	0.64482	0.68964	0.73446

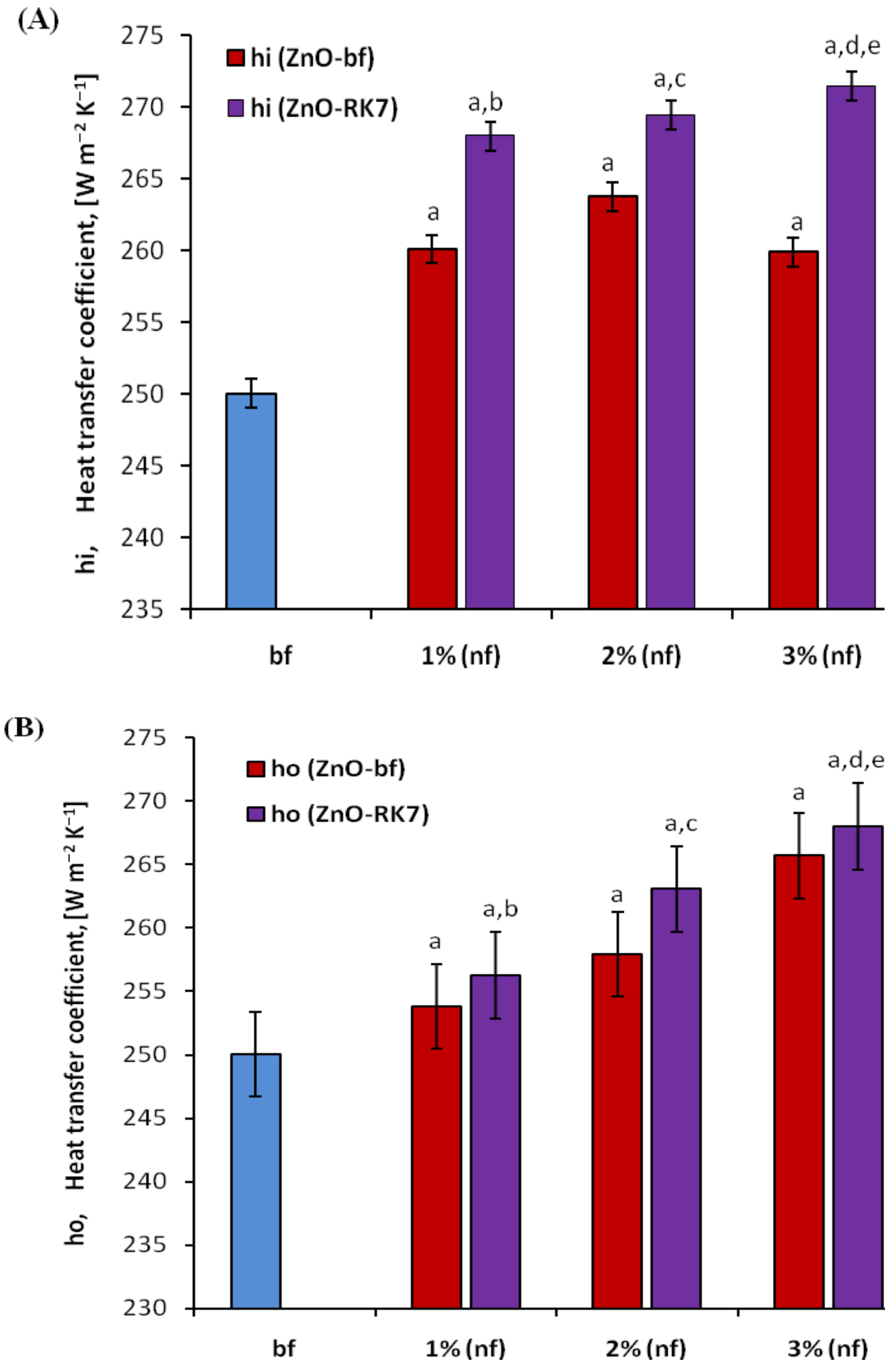

Fig. 7: Convective heat transfer coefficient inner tube fluid (hi) and outer tube fluid (ho) of heat exchanger. Convective heat transfer coefficient expressed in Wm-2K-1 of heat exchanger (A) inner tube fluids (hi) and (B) outer tube fluids (ho). Results were expressed as mean ± standard deviation (n=6). Symbols a, b, c, d and e represent significantly different compared; P < 0.01-0.05.

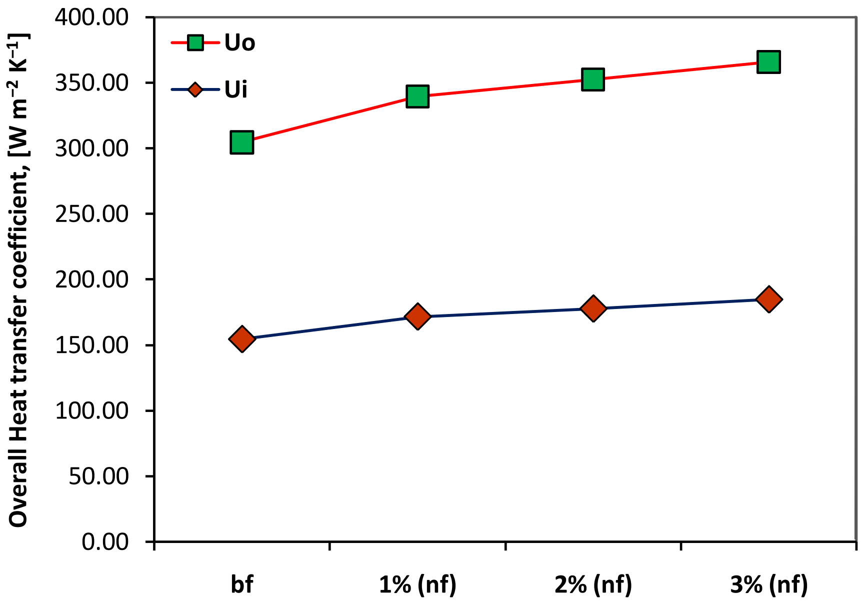

Fig. 8: Overall heat transfer coefficient inner tube fluid (Ui) and outer tube fluid (Uo) of heat exchanger.

CONCLUSIONS

With respect to utilizing NPs in many processes, attention has been focused on improvement of heat exchanger efficiency by adding solid NPs particles to heat transfer fluids. In the present study, heat transfer study of ZnO/water nanofluid in a double-tube heat exchanger has been experimentally investigated. The volume fraction, shape, dimensions and properties of the NPs affect the thermal conductivity of nanofluids. Results were provided as heat transfer coefficient in the heat exchanger. The following conclusions have been drawn from the present study:

Dispersion of the NPs 48.46 nm ZnO with 1%, 2% and 3 % concentrations into the distilled water as base fluid, heat transfer coefficient of nanofluids increases the thermal conductivity and viscosity of the nanofluid, this augmentation increases with the increase in particle concentrations.

Local convective heat transfer coefficient of inner tube and outer tube in the double pipe heat exchanger has been measured experimentally. Results showed that increasing the NPs concentration moderately enhances the local convective heat transfer coefficient in the heat exchanger model. Maximum enhancement of the heat transfer coefficient found at 3% nanofluid in comparison with base fluid.

This study showed that low viscosity and high heat transfer coefficient nanofluids in double pipe heat exchanger model obtained by subjecting the ZnO-RK7 nanofluids to an extended temperature as compared to the water as base fluid.

At the particle volume concentration of 3% the overall heat transfer coefficient is 350 W m^{-2} $K^{-1}$and for the base fluid it is 200 W m^{-2} K^{-1} this means the amount of the overall heat transfer coefficient of the nanofluid is 57% greater than that of distilled water.

Addition of NPs increased average Nusselt number, which indicated higher heat transfer into the fluids. Thus nanofluids could be a promising replacement for pure water in heat exchanger tubes where need to more efficient heat transfer.

The increase in *Re* caused increase in the heat transfer rate as well as pressure drop and decrease in the thermal resistance. Using nanofluids at high *Re* compared with low *Re* have higher average Nusselt number.

In almost all cases, the rate of heat transfer coefficient enhancement of nanofluids to that of distilled water decreased with increasing the *Re*. Hence, increase in the heat transfer coefficient may be due to the high density of NPs on the wall pipe and the migration of the particles. The extensive research is needed to understand the heat transfer characteristics of the nanofluid and to obtain the other relations.

ACKNOWLEDGEMENTS

The authors are thankful to the LTJSS management and LIT Nagpur for their support and encouragement for this research work. The authors also would like to thank Department of Chemical Engineering, Vishvashariya National

Institute of Technology Nagpur for giving the opportunity to use the instruments facility for completion of this work.

AUTHORS' CONTRIBUTIONS

GPL conducted the experiments and participated in the discussion of the results. RPU and VMN conceived of the study and participated in the design and coordination of the study. SGS carried out the literature review, drafted the manuscript and prepared all Figures and participated in the discussion of the results. All three authors read and approved the final manuscript.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

Nomenclature

A	:	Cross section Heat transfer area, [m^2]
Cp	:	Spesific heat, [$J\ kg^{-1}\ K^{-1}$]
d	:	Diameter of tube, [m]
h	:	Heat transfer coefficient, [$W\ m^{-2}\ K^{-1}$]
k	:	Thermal conductivity, [$W\ m^{-1}\ K^{-1}$]
L	:	Length of the tube, [m]
mm	:	Millimeter
µm	:	Micrometer
m^o	:	Mass flow rate ($kg\ s^{-1}$)
Q	:	Heat transfer rate, [W]
Re	:	Reynolds number
T	:	Operating temperature, [°C]
U	:	Overall heat transfer coefficient, [$W\ m^{-2}\ K^{-1}$]

Greek Letters

$(\Delta T)_{LMTD}$	:	Logarithmic mean temperature difference (°C)
μ	:	Dynamic viscosity (kg/m s)
ρ	:	Density (kg/m^3)
φ_V	:	Nanoparticle volume concentration (%)

Subscripts

hot fluid	:	Hot distilled water
cold fluid	:	Nanofluids
bf	:	Base fluid (water)
nf	:	Nanofluids
i	:	Inner tube
o	:	Outer tube
p	:	Nanoparticle
v	:	Volume concentration
w	:	Inner wall of the tube
in	:	Inlet of pipe
out	:	Outlet of pipe

REFERENCES

[1] Sundar L. S., Singh M. K., Venkata Ramana E., Singh B., Grácio J. M., Sousa A. C., (2014), Enhanced thermal conductivity and viscosity of nanodiamond-nickel nanocomposite nanofluids. *Sci. Rep.* 4: 4039-4044.

[2] Rahimi-Gorji M., Pourmehran O., Hatami M., Ganji D. D., (2015), Statistical optimization of microchannel heat sink (MCHS) geometry cooled by different nanofluids using RSM analysis. *Eur. Phys. J. Plus.* 130: 22-26.

[3] Domairry G., Hatami M., (2014), Squeezing Cu–water nanofluid flow analysis between parallel plates by DTM-Padé Method. *J. Mol. Liq.* 193: 37-44.

[4] Mohammad M., Sadeghinezhad E., Tahan Latibari S., Kazi S. N., Mehrali M., Zubir M. N., Metselaar H. S., (2014), Investigation of thermal conductivity and rheological properties of nanofluids containing graphene nanoplatelets. *Nanoscale Res. Lett*. 9: 1-12.

[5] Hatami M., Ganji D. D., (2014), Natural convection of sodium alginate (SA) non-Newtonian nanofluid flow between two vertical flat plates by analytical and numerical methods numerical methods. *Case Stud. Therm. Eng*. 2: 14-22.

[6] Angue Minsta H., Roy G., Nguyen C. T., Doucet D., (2009), New temperature and conductivity data for water-based nanofluids. *Int. J. Therm. Sci.* 48: 363-371.

[7] Ahmadi A. R., Zahmatkesh A., Hatami M., Ganji D. D., (2014), A comprehensive analysis of the flow and heat transfer for a nanofluid over an unsteady stretching flat plate. *Powder Tech.* 258: 125-133.

[8] Peng H., Ding G., Hua H., (2011), Effect of surfactant additives on nucleate pool boiling heat transfer of refrigerant-based nanofluid. *Exp. Therm. Fluid Sci*. 35: 960-970.

[9] Yu W., Xie H., (2012), A Review on nanofluids: Preparation, stability mechanisms, and applications. *J. Nanomater.* 17: 35873-35878.

[10] Talam S., Karumuri S. R., Gunnam N., (2012), Synthesis, characterization, and spectroscopic properties of ZnO Nanoparticles. *ISRN Nanotechnol.* 6: 372505-372509.

[11] Aghayari R, Maddah H., Zarei M., Dehghani M., Kaskari Mahalle S. G., (2014), Heat Transfer of Nanofluid in a Double Pipe Heat Exchanger. *Int. Scholarly Res. Notices.* Article ID 736424: 7.

[12] Pak B. C., Cho Y. I., (1998), Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles. *Exp. Heat Transfer.* 11: 151-170.

[13] Xuan Y., Roetzel W., (2000), Conceptions for heat transfer correlation of nanofluids. *Int. J. Heat Mass Transf.* 43: 3701–3707.

[14] Einstein A., (1906), A new determination of molecular dimensions. *Ann. Der. Phy*. 19: 289-306.

[15] Yu W., Choi S. U. S., (2003), The role of interfacial in the enhancemened thermal conductivity of nanofluid: A renovated Maxwell model. *J. Nanopart. Res*. 5: 167-171.

[16] Lotfi R., Rashidi A. M., Amrollahi A., (2012), Experimental study on the heat transfer enhancement of MWNT-water nanofluid in a shell and tube heat exchanger. *Int. Commun. Heat Mass Transf.* 39: 108-111.

[17] Siva Kumar S., Venkateswarlu P., Rao V. R., Rao G. N., (2013), Synthesis, characterization and optical properties of Zinc Oxide nanoparticles. *Int. Nano Let.* 3: 30-36.

[18] Chang H., Tsai M. H., (2008), Synthesis and characterization of ZnO nanoparticles having prism shape by a novel gas condensation process. *Rev. Adv. Mater. Sci*. 18: 734-743.

[19] Zhou J., Zhao F., Wang Y., Zhang Y., Yang L., (2007), Size controlled synthesis of ZnO nanoparticles and their photoluminescence properties. *J. Luminescence*. 122-123: 195-197.

[20] Khoshhesab Z. M, Sarfaraz M., Asadabad M. A., (2011), Preparation of ZnO nanostructures by chemical precipitation method, Synthesis and Reactivity in Inorganic.

Metal-Organic and Nano-Metal Chem. 41: 814-819.

[21] JCPDS, (1977), Powder diffraction file, alphabetical index, inorganic compounds, international centre for diffraction data, Newtown Square, Pa, USA.

[22] Cullity B. D., (1967), Elements of X-Ray diffraction, addison-wesley, reading, Mass, USA, 3rd edition.

[23] Wen D., Ding Y., (2005), Experimental investigation into the pool boiling heat transfer of aqueous based c-alumina nanofluids. *J. Nanopart. Res*. 7: 265-274.

[24] Yang Y. M., Maa J. R., (2001), On the criteria of nucleate pool boiling enhancement by surfactant addition to water. *Trans. Inst. Chem. Eng*. 79 (Part A): 409-415.

[25] Wen D. S., Wang B. X., (2002), Effects of surface wettability on nucleate pool boiling heat transfer for surfactant solutions. *Int. J. Heat Mass Transf*. 45: 1739-1747.

[26] Hetsroni G., Gurevich M., Mosyak A., Rozenblit R., Segal Z., (2004), Boiling enhancement with environmentally acceptable surfactants. *Int. J. Heat Fluid Flow.* 25: 841-848.

[27] Kole M., Dey T. K., (2010), Thermal conductivity and viscosity of Al_2O_3 nanofluid based on car engine coolant. *J. Phys. D: Appl. Phys.* 43: 315501-315505.

[28] Suganthi K. S., Anusha N., Rajan K. S., (2013), Low viscous ZnO–propylene glycol nanofluid: A potential coolant candidate. *J. Nanopart. Res.* 15: 1986-1989.

[29] Suganthi K. S., Vinodhan V. L., Rajan K. S., (2014), Heat transfer performance and transport properties of ZnO–ethylene glycol and ZnO–ethylene glycol–water nanofluid coolants. *Appl. Energy.* 135: 548-559.

[30] Wang X., Mujumdar A. S., (2007), Heat transfer characteristics of nanofluids: A review. *Int. J. Therm. Sci.* 46: 1-19.

[31] Malvandi A, Ganji D. D., (2014), Brownian motion and thermophoresis effects on slip flow of alumina/water nanofluid inside a circular microchannel in the presence of a magnetic field. *Int. J. Therm. Sci*. 84: 196-206.

[32] Shoghl S. N., Bahrami M., (2013), Experimental investigation on pool boiling heat transfer of ZnO, and CuO water-based nanofluids and effect of surfactant on heat transfer coefficient. *Int. Commun. Heat Mass Transf.* 45: 122-129.

[33] Albadr J., Tayal S., Alasadi M., (2013), Heat transfer through heat exchanger using Al_2O_3 nanofluid at different concentrations. *Case Studies Therm. Eng*. 1: 38-44.