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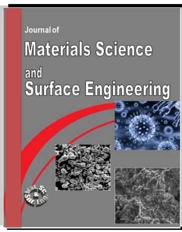

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Heat Transfer Behaviour of Nano-fluid at High Pressure

O.S. Prajapati[1], N. Rohatgi[2] and A.K. Rajvanshi[2]

[1]*Department of Mechanical Engineering, Rajasthan Technical University, Kota, India*
[2]*Department of Mechanical Engineering, Malaviya National Institute of Technology, Jaipur, India*

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Abstract

Recent investigations on nanofluids indicate that the suspended nanoparticles markedly change the heat transfer characteristics of the suspension. In this study, heat transfer characteristics of ZnO-water nanofluids were investigated. Experiments were conducted with ZnO-water nanofluids at particle volume concentrations up to 0.1 volume %, constant subcooling of 20°C, pressure 2 bar, mass flux 400 kg/m^2s and heat fluxes up to 500 kW/m^2 with variable. Effect of heat flux and nanofluid concentration on heat transfer coefficient of ZnO-water nanofluids was investigated. Study reveals that heat transfer coefficient increases with ZnO-water nanofluids.

Introduction

Nanofluid technology has emerged as a new technique in recent years. Nanofluid was created by S.U.S. Choi[1] as a next generation fluid that may revolutionize heat transfer. Nanofluid is envisioned to describe a fluid in which nanometer sized particles are suspended in conventional heat transfer basic fluids. Conventional heat transfer fluids, including oil, water, acetone and ethylene glycol mixture are poor heat transfer fluids. Nanofluid suspensions that contain solid particles have effective thermal conductivity by their mixing effects. Since the thermal conductivity of solid metals is higher than that of fluids, the suspended particles are expected to be able to increase the thermal conductivity and heat transfer performance.

Yu *et al.*[2] modified Maxwell model with the assumption that the base fluid molecules close to the solid surface of the nanoparticles form a solid-like layered structure. Hence the nanolayer works as a thermal bridge between the liquid base fluid and the solid nanoparticles, and this will enhance the effective thermal conductivity.

Kakaç *et al.*[3] measured the the thermal conductivity of the nanoparticle materials, metallic or nonmetallic such as Al_2O_3, CuO, Cu, SiO_2, TiO_2, and found typically order-of-magnitude higher than the base fluids even at low concentrations, result in significant increases in the heat transfer coefficient.

In the past, particles of millimeter or micron scale have been added to fluids to enhance thermal conductivity; however, all of the studies using the concept have been faced with severe problems including sedimentation, abrasion, clogging and increased pressure drop of the flow channel due to the large size of the particles. Furthermore, the abrasive actions of the particles cause erosion of components and pipe lines. Heris *et al.*[4] nano-particles used in nano-fluids commonly have a small average size, below 100 nm in diameter. Relative large surface area of nanoparticles increases the stability and reduces the sedimentation of nanoparticles. A more dramatic improvement in heat transfer efficiency is expected as a result of decreasing the particle size in a suspension because heat transfer takes place at the surface of the particles.

Prajapati *et al.*[5] measured the effect of Al_2O_3-water nanofluid on heat transfer characteristics in convection. They observed that heat transfer increases with addition of the Al_2O_3 nanoparticles in the distilled water, because of increased thermal conductivity of Al_2O_3nanofluid, heat transfer through increased solid-liquid interface layers and nanoparticle driven natural convection.
He *et al.*[6] measured the thermal conductivity of TiO_2nanofluids flowing through a straight vertical pipe under both the laminar and turbulent flow conditions. The measured effective thermal conductivity of the nanofluid increased with increasing nanoparticle concentration in a non-linear fashion and decreased with particle size.

Suriyawong *et al.*[7] investigated the heat transfer characteristics for nucleate pool boiling of TiO_2–water nanofluids at concentrations of 0.00005, 0.0001, 0.0005, 0.005, and 0.01 vol. % at atmospheric pressure. With regard to heat transfer on a copper surface with a surface roughness of 0.2 μm, it was found that at nanofluids concentrations of not more than 0.0001 vol. %, there was an increase in heat transfer, compared with base fluid. At the concentration of 0.00005 vol. %, the heat transfer coefficient increased by about 7% and at the concentration of 0.0001 vol. %, the heat transfer coefficient increased by about 15%. In contrast, when the concentration of nanofluids was more than 0.0001 vol. %, the heat transfer decreased when compared with base fluid.

K.B. Rana *et al.*[8] performed experiments in subcooled flow boiling of ZnO–water nano-fluids with different low particle concentrations ($\leq$ 0.01 volume %) in horizontal annulus at heat fluxes from 100 to 450 kW/m^2 and flow rates from 0.1 to 0.175 lps at 1 bar inlet pressure and constant subcooling of 20ºC to determine bubble behavior and heat transfer with flow rates of ZnO. They observed that increase in heat flux leads to increase inbubble diameter, the heat transfer coefficient increases with increase in heat flux and particle volume fraction of ZnO.

E.K. Goharshadi *et al.*[9] measured thermal conductivity, viscosity and surface tension of ZnOnano-fluids with ethylene glycol (EG) and glycerol (G) as the base fluids. They observed that the thermal conductivity of ZnO/EG and ZnO/G nano-fluids

Corresponding author. Tel./fax: 07442473923
E-mail address: omshankar.prajapati@gmail.com

increased nonlinearly up to 10.5% and 7.2% respectively as the volume fraction of nano-particles increased up to 3% by volume. The ratio of the viscosity of the nano-fluid and the viscosity of the base fluid increased with increase in concentration and decrease in temperature. The ratio of surface tension of the nano-fluid and the surface tension of the base fluid increased with increase in the volume fraction ofthe solid nano-particles.

Das *et al.*[10] performed various sets of experiments to determine the effective thermal conductivity of Al_2O_3 and ZnOnanofluid by varying their concentration and also by increasing temperature. Nanofluid was prepared by mixing Al_2O_3 and ZnO nanoparticles in the fluid having 60:40 EG/W by mass and by varying their volume concentration from 1 % to 10 %. It was observed that the thermal conductivity ratio increases as temperature increases and also with an increase in volume fraction.

Ethylene glycol-based nanofluids have attracted much attention in the application as engine coolant[11–13] due to the low-pressure operation compared with a 50/50 mixture of ethylene glycol and water, which is the nearly universally used automotive coolant.

Experimentation

Preparation of Nanofluid

Preparation of nanofuids is the first key step in applying nanophase particles to changing the heat transfer performance of conventional fluids. The nanofluid does not simply refer to a liquid-solid mixture. Some special requirements are necessary, such as even suspension, stable suspension, durable suspension, low agglomeration of particles and no chemical change of the fluid. In general, these are effective methods used for preparation of suspensions: (1) changing the pH value of suspension, (2) using surface activators and/or dispersants, (3) using ultrasonic vibrations. In UVM machine, the ultrasonic energy is produced by converting electrical energy into mechanical vibrations by using generator and piezo-electric transducers. Dry zinc oxide nanoparticles and distilled water were used to prepare nanofluids. In order to break down the large agglomerates, ultrasonication was applied for 8–12 hours to mix a preset amount of nanoparticles with water to give certain nanoparticle concentration. The power available in the ultrasonic bath is 300 W and the ultrasonic frequency is 27±3 kHz. The prepared Nanofluids concentrations were very low (≤ 0.1 volume %) in this study. Therefore, agglomeration of nanoparticles is expected to be less.

Experimental Setup

The schematic diagram of the experimental test setup is shown in Fig. 1. The closed loop test facility of 10 liter capacity mainly consists of ultrasonic vibration mixer, storage reservoir, circulating pump, flow meter, electrically heated horizontal annular test section, condenser and heat exchanger. The working fluid is pumped from the reservoir to the test section via flow meter. The mixture of working fluid and steam from the exit of the test section passes through a horizontal condenser and counter flow heat exchanger before returning to the reservoir. Condenser condenses the steam into water and heat exchanger reduces the excess temperature and controls the temperature of working fluid before recirculation.

The test section as shown in Fig. 2 is 780 mm long and consists of an electrically heated rod and an outer borosilicate glass tube of 21.8 mm inner diameter. The heater is 12.7 mm diameter hollow stainless steel rod welded to solid copper rods at both ends. The test section is easily dismountable. The heater rod is fitted with transparent glass tube by two teflon corks at both ends. In the glass tube, fluid flows over the surface of heater rod. The heated length of 500 mm is located 230 mm downstream of the inlet plenum and thus allowing for the flow to fully develop. An input 415 V, 3 phase AC power is stepped down to 0–32 V DC power by using 64 kVA DC regulated power supply by which a large range of heat fluxes are applied to the test section. The applied heat flux in the test section, qis given as

$$\text{Heat flux} \qquad q = \frac{V * I}{\pi D L}$$

where V, I, D and L are the measured voltage & current provided to test section, diameter and length of the test section respectively. The losses from the projected portion of the copper rod outside the glass tube were calculated and subtracted from applied heat fluxto get the actual heat transfer to the fluid.

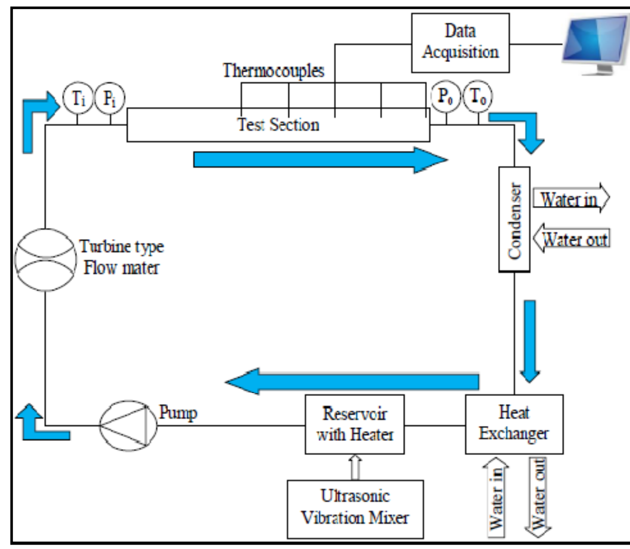

Figure 1: Schematic of Experimental Setup

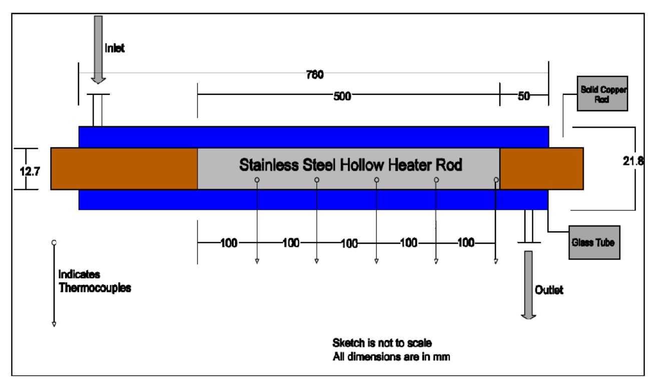

Figure 2: Test section and position of thermocouples

The bulk temperature of the fluid was measured by averaging the inlet and outlet temperatures of the fluid at the test section. Surface temperature of heater rod at various locations was measured by five miniature thermocouples which were embedded on it. All these thermocouples are of Omega make, (JMQSS-IM050U-300) 1 mm wire diameter, J-type, ungrounded and covered with stainless steel sheath. Location of all these thermocouples is shown in Fig. 2. All thermocouples are connected to Omega make Data Acquisition System, OMB-DAQ-55 which is further connected to computer. Data from the thermocouples can be recorded and stored in the computer at any point of experiment. Static pressure at the inlet of the test section was measured by using a Keller make pressure sensor which has a range of 1–10 bar with an accuracy of ±0.1%. Electronet make, FL-204 4-wire turbine type flow meter with flow range of 0.02–

0.3 lps was used for measuring the flow rate. It has less than 100 ms response time with an accuracy of ±1%. The experimental test loop with test section was cleaned with dilute H_2SO_4 solution to remove oxides and fouling residue after every test on one nanofluid concentration. Before the test on another concentration of nanofluid, heater rod of test section was dismounted from the glass tube and cleaned with very fine (Grade P-320) sand paper and assembled again. The boundary conditions for measured parameters are shown in Tables 1.

Table 1: Boundary conditions

S. No.	*Parameter*	*Range*
1	Volume fraction	0 - 0.1%
2	Heat flux (kW/m^2)	0 - 500
3	Mass flux (kg/m^2 s)	400
4	Pressure (bar)	2

Results and Discussion

Figure 3 shows variation of thermal conductivity of ZnO-water nanofluid with particle volume fraction. The thermal conductivity of base fluid (distilled water) is 0.61 (W/mK). The figure shows the increment of thermal conductivity with particle volume fraction. The surface to volume ratio of the nanofluid is very high and the thermal conductivity of ZnO higher than water, therefore the thermal conductivity of nanofluid is enhanced.

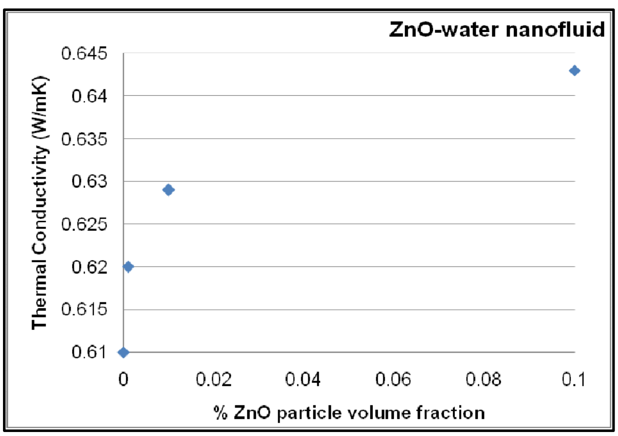

Figure 3: Thermal conductivity enhancement of ZnO-Water nanofluid.

Experimental data in Fig. 4 show that heat transfer coefficient, h (kW/m^{2}K) of ZnO-water nanofluid increases gradually with heat flux. Study reveals that heat transfer increases with heat flux applied at all given range of percentage ZnO-water nanofluids due to increased energy gain to the nanoparticles.

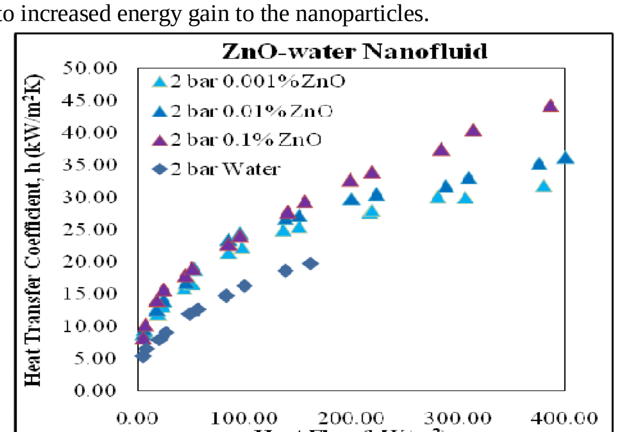

Figure 4: Variation of heat transfer coefficient with heat flux

Conclusions

An experimental facility with adequate instrumentation has been modified and erected to study heat transfer characteristics of ZnO-water nanofluid and report information on heat transfer characteristics of ZnO-water nanofluid in convective heat transfer within the boundary conditions. The working fluid was electrically heated in horizontal annular test section. All the instruments in test set up were properly calibrated as per guidelines given by American Society of Mechanical Engineers. Convective heat transfer experiments were carried out to study heat transfer behavior of ZnO-water nanofluid, compare them with base fluid (distilled water) and obtain data on heat transfer characteristics. Finally, the results of the present investigation aresummarized as follows:

1. The thermal conductivity of base fluid increases with addition of ZnO nanoparticles.
2. Heat transfer coefficient increases with heat flux.
3. Heat transfer performance improved with particle volume fraction of ZnO-water nanofluid.

Acknowledgement

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