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Original Research Article

Heat transfer characteristics of silver/water nanofluids in a shell and tube heat exchanger

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ABSTRACT

An experimental study is carried out to investigate the heat transfer characteristics of silver/water nanofluids in a shell and tube heat exchanger. The test matrix is worked out in the turbulent regime with Reynolds number varying between 5000 and 25,000, particle volume concentrations of 0.01%, 0.03% and 0.04% and for heat flux varied between 800 W/m^2 and 1000 W/m^2, which is sourced from a solar flat plate collector. The influence of mass flow rate, inlet temperature and volume concentration on the LMTD, effectiveness, convective heat transfer coefficient and pressure drop are studied. The results showed an increase in convective heat transfer coefficient and effectiveness of silver/water nanofluids as the particle volume concentration is increased. A maximum enhancement in convective heat transfer coefficient of 12.4% and effectiveness of 6.14% is recorded. It is also observed that the apparent increase in the heat transfer coefficient is due to the enhanced thermo-physical properties of the nanofluids, and delayed development of boundary layer in the entrance regions due to the addition of nanoparticles.

1. Introduction

From the stage of proven laboratory sized testing and real-time miniature devices, the research in heat exchange process using nanofluids has considered for large scale heat exchangers. A way of improving the heat transfer performance of common fluids such as water, oil, aqua ethylene glycol etc. is to suspend various types of small solid particles in conventional fluids to form colloidal solutions. Ahuja [1,2] conducted experiments on the enhancement of heat transport in the laminar flow of water with micro-sized polystyrene suspension, which showed a significant enhancement in the Nusselt number and heat exchanger effectiveness with the resultant fluid when compared to the base fluids. Hetsroni and Rozenblit [3] investigated the thermal interaction between liquid and solid mixtures consisting of water and polystyrene particles in a turbulent flow. In spite of polystyrene's low thermal conductivity, the turbulence intensification provided enhancement in heat transfer. However, increased pumping power, clogging, agglomeration, sedimentation and erosion are some of the adverse effects of micro-particles. This issue has been rectified with the use of stable nano-sized particulate colloids (nanofluids), and this has paved the way for

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Nomenclature

A	Area, m^2
A_p	collector plate area, m^2
c	capacitance
C_p	specific heat capacity, J/kg K
D	diameter, m
h	convective heat transfer coefficient, W/m^2 K
k	thermal conductivity, W/m K
L	length, m
LMTD	logarithmic mean temperature difference
m	mass flow rate, kg/s
NTU	number of transfer units
Pr	Prandtl's number
r	cylindrical coordinates
Re	Reynolds number
U	overall heat transfer coefficient, W/m^2 K

Subscript

c	cold fluid
ci	cold fluid inlet
co	cold fluid outlet
h	hot fluid
hi	hot fluid inlet
ho	hot fluid outlet
i	inside surface of the wall
nf	nanofluid
o	outside surface of the wall
p	nanoparticle
w	wall

Greek symbols

ε	effectiveness
ϕ	volume fraction
ρ	density, kg/m^3
μ	dynamic viscosity, kg/m s

researchers to further investigate the enhancement of convective heat transfer.

The literatures have showed a variety of combination of particles and base fluid those provide enhancement in heat transfer. [4–13]. Godson et al. [14] has reviewed various researches dedicated to nanofluid heat transfer for various applications. The intensification of turbulence or eddy, suppression of the boundary layer, dispersion of the suspended particles, besides the augmentation of thermal conductivity and the heat capacity of the fluid were suggested to be the possible reasons for heat transfer enhancement. However, most of the previous studies on nanofluids have been performed with the use of metal oxide nanoparticles with relatively high concentrations. Using high concentrations of metal oxide nanoparticles leads to the problem of higher pressure drop that leads to higher pumping power. It will be interesting to study the heat transfer characteristics of pure metal nanoparticles with relatively low concentrations (<1%), since very limited number of studies exist in literature regarding the study of heat transfer characteristics of pure metal nanofluids in a shell and tube heat exchanger, hence the present study deals with the heat transfer characteristics of silver/water nanofluid with low volume concentrations of silver nanoparticles varying from 0.01%, 0.03% and 0.04%. The experiments are conducted for a heat flux ranging from 800 W/m^2 to 1000 W/m^2, and the Reynolds number is varied from 5000 to 25,000.

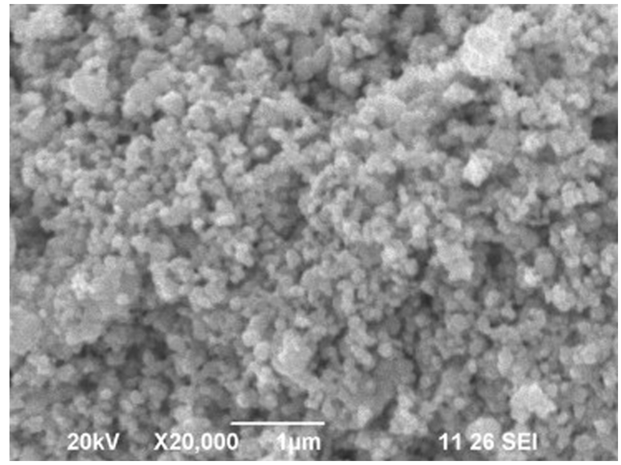

Fig. 1 – SEM image of 0.04 vol% concentration of silver nanoparticles.

2. Nanofluid preparation and thermo-physical properties

Silver nanofluids with particle volume concentrations of 0.01%, 0.03% and 0.04% are prepared by suspending the required amount of silver nanoparticles in water. Polyvinyl pyrolidine (PVP) is used as the surfactant. The mixture is composed of Ag (silver) nanoparticles with average diameter of 54 nm and PVP, dispersed in water. In order to produce required particle volume fractions, dilution with water followed by a stirring action is affected. Moreover, an ultrasonic vibrator whose frequency ranges from 0 to 100 Hz is used to sonicate the solution continuously for approximately 30 min in order to break down agglomeration of the nanoparticles. The silver nanoparticles are further characterized by using scanning electron microscope (SEM) and Zeta potential analyzer. Fig. 1 shows the SEM image of silver nanoparticles taken for 20,000× magnification. It is observed that the nanoparticles are well dispersed with certain level of agglomeration. The agglomerated nanoparticles are finely grinded in a ball grinder before adding to base fluid for sonication. Fig. 2 shows the zeta potential distribution versus total counts of the silver nanoparticles. The zeta potential is the measure of the electric potential at the slip plane between the bound layer of diluent molecules surrounding the particle, and the bulk solution. The measurement of zeta potential allows predictions about the storage stability of colloidal systems. In general, the particles aggregation is unlikely to appear if the particles are charged