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An experimental investigation on the effects of surfactants on the thermal performance of hybrid nanofluids in helical coil heat exchangers☆

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ABSTRACT

In the present study, the effects of surfactants on the thermal performance of the hybrid nanofluid (Alumina–Silver) at constant wall temperature and laminar flow have been experimentally studied in a helical coil heat exchanger. Different surfactants such as anionic Sodium Dodecyl Sulfate (SDS) and nonionic Poly Vinyl Pyrrolidone (PVP) in the concentration of range of 0.1–0.4 wt.% are employed. It is found that the thermal performance can be maximized by using the 0.2 vol.% hybrid nanofluid and 0.1 wt.% SDS anionic surfactant in the helical coil. The maximum thermal performance in the presence of hybrid Alumina–Silver nanofluid and SDS anionic surfactant is 16% higher than that of the pure distilled water. The presented results can have potential application in process intensification and optimum design of heat exchangers.

1. Introduction

Effect of curved pipes on the thermal performance enhancement of fluids and nanofluids has been investigated for design of new heat exchangers in recent years. Most results have shown that the fluid thermal performance is improved because of creating more contact surface and centrifugal force [1–4]. For the first time in 1995, Choi [5] discussed the effect of nanofluid on thermal conductivity. After that, a lot of researches who have investigated the thermo-physical properties of nanofluid, reported the thermal conductivity enhancement in comparison with the base fluid [6–11].

Suresh et al. [11,12] have investigated the thermal performance of alumina and copper oxide nanofluid using the twisted tape inserts in tube under constant heat flux and laminar flow conditions. They have concluded that under constant thermal conditions in the twisted tape, copper oxide nanofluid shows better performance as compared to the alumina nanofluid. In addition, copper oxide nanofluid imposes higher pressure drop as compared to the alumina nanofluid and the use of twisted tape increases this pressure drop to a greater extent.

Hybrid nanofluid is a new class of nanofluid which is made of two or more particles in combination with different percentages. The topic has attracted many researchers' attention in recent years. Most of them have found out that using nanocomposites in the base fluid results in improving thermal performance [12–16]. Lots of researches have also investigated the effects of surfactants on the stability of the nanoparticles [17–22].

Since there are limited information on the effect of surfactants on thermal performance of hybrid nanofluids in the helical coil heat exchangers, the variations of Nusselt number, pressure drop and thermal performance in the presence of different compositions of SDS anionic and PVP nonionic surfactants are experimentally investigated in this work.

2. Experimental

2.1. Set-up and instruments

According to Fig. 1, testing devices include stainless steel tank and temperature and pressure control systems. The tank is fully insulated with rock wool in order to avoid heat loss and a 2 kW heater is immersed in the tank to supply the required heat. In order to measure the inlet and outlet pressure, a very sensitive pressure transmitter has been used (SENSYS, 0.5BCIA PSCH). Two accurate thermocouples of T-type have been used for accurate measurement of the inlet and outlet temperatures. In addition, six thermocouples of K- type have been installed at various locations to measure the surface temperatures of the helical coil. Flow rate is estimated by an ultrasonic system with the accuracy of about 0.05 l per minutes. The used coil is made of copper, which its physical features are shown in Table 1. The device is first calibrated with pure water and then the main testing is started with hybrid nanofluid at different concentrations. As soon as the temperature reaches to a saturation state (constant temperature of 95 °C), we started to collect data including inlet and outlet temperature, inlet and outlet pressure as well as the surface temperature. An experiment has been repeated at least two times to ensure that the date is accurate. The employed hybrid nanofluid contains Alumina(97.5%)–Silver(2.5%)

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Nomenclature

C_p	Specific heat ($J\cdot kg^{-1}\cdot K^{-1}$)
d	Inside diameter of tube (m)
D	Diameter of coil (m)
h	Heat transfer coefficient ($W\cdot m^{-2}\cdot K^{-1}$)
K	Thermal conductivity ($W\cdot m^{-1}\cdot K^{-1}$)
L	Length of tube (m)
Nu	Average Nusselt number
Re	Reynolds number
T	Temperature (K)
U	Average velocity ($m\cdot s^{-1}$)
Greek letters	
ΔP	Axial pressure drop (Pa)
η	Thermal performance factor
ρ	Density ($kg\cdot m^{-3}$)
μ	Dynamic viscosity (Pa·s)
φ	Nanoparticle volume fraction (%)
Subscripts	
C	Coiled tube
ex	Experimental
f	Base fluid
nf	Nanofluid
nfs	Nanofluid with surfactant
p	Particle
S	Straight tube
th	Theoretical
w	Wall

nanocomposite with an average diameter of 80 nm (with spherical shape). The mixed hybrid nanofluids at a constant concentration 0.2 vol.% and using different concentrations of Sodium Dodecyl Sulfate (SDS) anionic and nonionic Poly Vinyl Pyrrolidone (PVP) surfactants in the range of 0.1–0.4 wt.% are provided by intense mixing via an ultrasonic device. There are numerous ways to prepare nanoparticles, one of which is Sol–gel. One of the advantages of this method is to prepare nanocomposites with high purity. Initially a homogenous suspension including solvent and precursor is solved and then the homogenous solution is turned into Sol by hydrolysis. After provoking the particles in Sol by HCl and NaOH, they join together and form a wet gel. Then after separating the solution and drying it, the nanoparticles are formed. Fig. 2 shows the TEM (transmission electron microscopy) images of dispersed nanoparticles in distilled water. The specifications of the employed nanoparticles and surfactants used in this study are presented in Tables 2 and 3. The measurement accuracies of different instruments are given in Table 4 as well.

Table 1
Geometrical characteristics of the Helical Coil (mm).

Tube	d	t	L	D	λ	N
Helical coil	5	1	2600	65	15	10

2.2. Determination of experimental Nusselt number

The thermophysical characteristics of the nanofluid are calculated according to the following equations: [23–25].

$$\rho_{nf} = (1-\varphi)\cdot\rho_f + \varphi\cdot\rho_P \tag{1}$$

$$\mu_{nf} = \frac{\mu_f}{(1-\varphi)^{2.5}} \tag{2}$$

$$(\rho\cdot C_P)_{nf} = (1-\varphi)\cdot(\rho\cdot C_P)_f + \varphi\cdot(\rho\cdot C_p)_P. \tag{3}$$

Thermal conductivity is also calculated using the following equation [26]:

$$\frac{k_{nf}}{k_f} = \frac{k_P + 2k_f - 2(k_f - k_P)\cdot\varphi}{k_P + 2k_f + (k_f - k_P)\cdot\varphi}. \tag{4}$$

The experimental convective heat transfer coefficient and the Nusselt number are determined according to the following equations:

$$\bar{h}(\exp) = \frac{\dot{m}\cdot c_p\cdot(T_{b_1} - T_{b_2})}{A\cdot(T_w - T_b)_M} \tag{5}$$

$$\overline{Nu}(\exp) = \frac{\bar{h}(\exp)\cdot d}{k_{nf}} \tag{6}$$

where $(T_w - T_b)_M$ is a logarithmic temperature difference.

3. Results and discussion

3.1. Heat transfer rate in the presence of ionic surfactant

The trend of variation of hybrid nanofluid Nusselt number at different concentrations of anionic surfactant (SDS) is shown in Fig. 3. Comparing with the case of distilled water, the Nusselt number increases as anionic surfactant concentration is increased. As shown, an increase in the Reynolds number leads to an increase in heat transfer

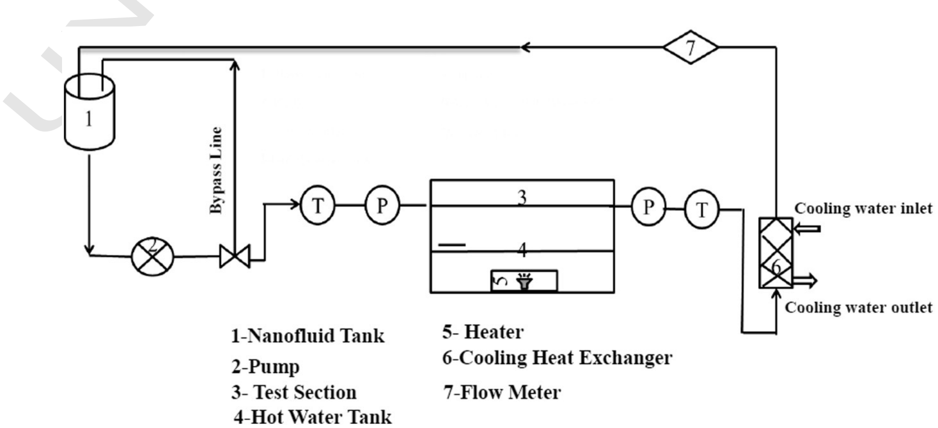

Fig. 1. The experimental set-up employed in the present study.

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