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Research Paper

Experimental investigation on heat transfer and flow resistance of drag-reducing alumina nanofluid in a fin-and-tube heat exchanger

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HIGHLIGHTS

- Heat and fluid flow with simultaneous addition of surfactant and nanoparticles.
- CTAC surfactant decreases the pressure drop and heat transfer.
- Nanoparticles increases both pressure drop and heat transfer.
- Adding both chemicals, heat transfer was increased and pressure drop was decreased.

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ABSTRACT

One of the main drawbacks of using nanofluids as a heat transfer media which limited its application in industries is higher pressure drop in comparison with the conventional fluids. In this research, it is the aim to decrease the nanofluid pressure drop using drag reducing agent (DRA). Water based γ-alumina nanofluids at different concentrations were mixed with different concentrations of cetyltrimethylammonium chloride (CTAC) surfactant to reduce the nanofluid pressure drop. On the other hand, it is very important to know that the addition of DRA could decrease the heat transfer performance of the system. So, it is a complicated problem since we have two objective functions (pressure drop and heat transfer) which are varied inversely. The addition of nanoparticles increases both objective functions while the addition of DRA decreases both of them. Results showed that the use of 0.2 %wt nanofluid (without the addition of DRA) causes %20 heat transfer enhancement with the penalty of %5 increase in pressure drop. It was also obtained that at the optimum condition, which was the highest concentration of CTAC (100 ppm) and the highest concentration of nanoparticle (0.2 %wt), the overall heat transfer coefficient enhancement of %17.2, and the friction factor reduction of %4.8 could be obtained in comparison with pure water.

1. Introduction

The deficiency of energy becomes one of the most serious constraints to the development of modern society, and energy conservation is undoubtedly becoming the greatest challenge to engineers. Industrial processes have to be rendered as economically viable as possible. Energy saving method has to be applied as much as possible in the energy consuming industrial facilities to reduce the cost of products. Heat transfer enhancement (HTE) techniques and flow drag reduction (DR) techniques are the two important aspects for energy saving in different processes. HTE can save energy through increasing the heat transfer coefficient to reduce the energy consumption, while flow DR can reduce the electricity consumption of pumping. Therefore, how to reduce flow resistance and improve heat transfer coefficient is always of crucial significance.

A very small amount of relatively higher thermal conductivity nanometer-sized particles (less than 100 nm), when dispersed uniformly and suspended stably in conventional fluids, can provide dramatic improvements in the thermophysical properties of the base fluids. Nanofluid (nanoparticle fluid suspension) is the term coined by Choi in 1995 [1]. Numerous experimental studies have been conducted to investigate the thermal properties and hydrodynamics of the nanofluids that majority of them have reported positive effect of nanofluids on the heat transfer coefficient. Xuan and Li [2] measured the heat transfer coefficient of Al_2O_3/water nanofluid and reported 35% enhancement at 2 vol% of alumina nanoparticles. Wen and Ding [3] studied the heat transfer in laminar flow regime under constant heat flux boundary condition using Al_2O_3/water nanofluid. They have reported that

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Nomenclatures

A	area (m^2)
A_{in}	inside surface area (m^2)
A_{out}	outside surface area (m^2)
A_f	surface area of the fin (m^2)
C	concentration (ppm or %wt)
Cp	specific heat (J/kg K)
CTAC	cetyl trimethyl ammonium chloride
D_h	hydraulic diameter (m)
DR	drag reduction
F	logarithmic temperature correction factor
t_f	fin thickness (m)
G	Gap between two fins (m)
g	Gravity acceleration (m/s^2)
h	heat transfer coefficient (W/m^2 K)
h_{fs}	frictional head
k	thermal conductivity (W/m K)
L	length (m)
$\dot{m}$	mass flow rate (kg/s)
Nu	Nusselt number
n	Shape factor
Pr	Prandtl number
p	pressure (Pa)
P	perimeter (m)
Q	volume flow rate (l/h)
Re	Reynolds number
T	temperature (K)
u	velocity (m/s)
U	overall heat transfer coefficient (W/m^2 K)
W	width (m)

Greek symbols

φ	volume fraction of particles
Ψ	Particle sphericity
η	fin efficiency
η_o	surface efficiency
η_f	efficiency of a single fin
μ	dynamic viscosity (Pa s)
ρ	density (kg/m^3)

Subscripts

bf	base fluid
f	fin
i	inside
LMTD	logarithmic mean temperature difference
o	outside
nf	nanofluids
th	Theoretical
p	particles
s	surfactant
w	water

increasing the Reynolds number and concentration of nanoparticles, especially at the entrance region, increases the heat transfer coefficient of nanofluid. Raei et al. [4] studied the turbulent convective heat transfer and flow characteristics of γ-Al_2O_3/water nanofluid in a double tube heat exchanger. Results showed that nanofluids had higher Nusselt number than pure water. Also, the Nusselt number increased by increasing particles volume fraction, flow rate as well as temperature of nanofluid. They also reported that the greatest enhancement in the heat transfer coefficient and the friction factor obtained at 0.15 vol% concentration of nanoparticles which were 23 and 25%, respectively. Peyghambarzadeh et al. [5] studied the heat transfer coefficient of Al_2O_3/water nanofluid in a car radiator. They observed the heat transfer enhancement of about 45% compared with pure water.

Many other metallic or non-metallic nanoparticle formed nanofluids also show a significant increase in thermal conductivity compared with their base fluids [6]. Due to the remarkably enhanced heat transfer performance of nanofluid compared to its base fluids such as water, oil and ethylene glycol mixture, nanofluids have been thought to be the next generation of heat transfer fluids, capable of offering exciting possibilities. The possible mechanism of heat transfer enhancement in nanofluids is the increasing of specific surface area in nanoparticle, the Brownian motion of nanoparticles in base fluid, existing of liquid layering around nanoparticles, ballistic rather than diffusive thermal transport in the nanoparticles and so on [7,8].

On the other hand, the presence of solid particles in fluids makes the nanofluids have a higher viscosity than base fluids which increases the pressure drop significantly in liquid circulating system [9,10]. So, the additional required pumping power and associated operating cost is in accordance with its natural tendency. Due to its significant drawbacks, replacement of the conventional heat transfer fluids such as in DHC (District Heating and Cooling) system with nanofluids has not become practically feasible.

However, it is known for more than 50 years that adding a minute amount of drag-reducing polymer or surfactant additives in conventional fluids such as water may cause a dramatic frictional drag reduction of turbulent flow in pipe or channel (the so-called Toms' effect) [11]. This kind of fluids is known as viscoelastic fluids. The shear viscosity of drag reducing fluids was found to be roughly equal to water, while temperature and concentration were shown to have great impact on the drag reducing effect of fluid [12–15]. At a high concentration, viscosity increases as the fluid temperature decreases. In the study of rheological properties with drag reducing fluids [16,17], the flow characteristics were studied at a certain range of Reynolds number. The results showed the aqueous solution mixed by surfactant CTAC and NaSal produced a random flow, and the phenomenon was caused by the viscoelastic interaction of CTAC solution and showed a significant drag reducing effect. In a word, according to the above described documents, the aqueous solution mixed by surfactant CTAC and NaSal comparing with other drag reducing fluids had a big advantage in drag reducing performance, but it was greatly influenced by temperature and fluid flow.

Nanofluids and drag reducing fluids in enhancing heat transfer and reducing fluid flow resistance both have advantages and disadvantages, respectively; therefore, this paper focuses on viscoelastic- nanofluid and viscoelastic fluid. In the study of convection heat transfer characteristics [18,19], the heat transfer potential was studied and the thermal conductivity and viscosity were measured. The results showed: successful heat transfer depends on fluid temperature, concentration of nanoparticles and surfactant CTAC. And as the temperature rises, the reducing degree of resistance and heat transfer coefficient are gradually reduced; however the heat transfer characteristics of nanofluids without any surfactant additives will be enhanced and its viscosity also increases. Heat transfer characteristics of nanofluids can be applied to solve heat transfer deterioration of drag reducing fluids. In the study of flow characteristics [20–22], it can be concluded that synergies of viscoelastic nanofluids are closely related to fluid concentration, velocity and temperature. The convective heat transfer coefficient and friction coefficient of non-Newtonian fluid increased with adding nanoparticles. The viscoelastic nanofluids almost have no difference in terms of fluid resistance with traditional drag reducing fluids.

In the study of the fundamental physical properties [23,24], the thermal conductivity, shear viscosity and stability were investigated.