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Improved heat transfer and flow resistance achieved with drag reducing Cu nanofluids in the horizontal tube and built-in twisted belt tubes

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ABSTRACT

Experimental studies were performed to investigate drag reducing nanofluids' convective heat transfer coefficient and flow resistance coefficient at Reynolds numbers ranging from 2000 to 18000. Added 0–0.5% mass fraction of Cu nanoparticles into a concentration of 100–400 $mg \cdot kg^{-1}$ cetyl trimethyl ammonium chloride (CTAC), which is a drag reducing fluid. The ratio of two kinds of fluids was explored to find a suitable composition and preparation to define their overall convective heat transfer and flow characteristics. Results indicated that the addition of sodium salicylate (NaSal) in CTAC with deionized water creates an improved drag reducing fluid with stability. When the drag reducing fluid concentration reached 200 $mg \cdot kg^{-1}$, it reached its optimum drag reducing performance in horizontal tube experiments. Experiments with built-in twisted belt tubes resulted in a much improved convective heat transfer characteristic. Results showed using drag reducing Cu nanofluids the heat transfer coefficient will be approximately twice as large as that found in a horizontal tube and the flow resistance coefficient is approximately ten times greater. However, even though built-in twisted belt tubes can enhance heat transfer, they also increase flow resistance. Heat transfer and flow resistance correlations of the drag reducing Cu nanofluids in a horizontal tube and built-in twisted belt tubes were compared with final results showing the calculated and experimental values to be in good agreement. When Cu nanoparticle mass fraction is 0.4%, drag reducing Cu nanofluid has the best heat transfer and drag reducing characteristics. Finally, the overall *K* factor performance were greater than 1 at different concentrations, which indicated their convective heat transfer enhancing effect was stronger than the reducing flow resistance effect so that they can be used to solve the problem of heat transfer deterioration for drag reducing fluids.

1. Introduction

Adding nanoscale solid metal or metal oxide particles into a base solution can significantly improve the thermal conductivity of a solid–liquid mixture. In industrial system applications, drag reducing fluids can reduce flow resistance of a fluid medium. Nanofluids and drag reducing fluids have advantages and disadvantages in enhancing heat transfer and reducing fluid flow resistance, respectively. Therefore, focusing on mixed drag reducing nanofluids formed by drag reducing fluids and nanofluids can complement each other in their respective shortcomings.

Nanofluid research began when Choi [1] found that the addition of solid particles into liquid can increase fluid thermal conductivity. Xuan [2] discussed the influence of nanoparticle properties on suspension stability, temperature, and thermal conductivity of nanofluids. The results showed the suspended nanoparticles remarkably enhance heat transfer process and the nanofluid has larger heat transfer coefficient than that of the original base liquid under the same Reynolds number. For the application of nanofluids in the tube, some researchers [3–5] studied the effect of heat transfer under laminar flow state. The results showed that adding nanoparticles had a great impact on the thermal properties of fluid thereby increasing heat exchange efficiency. For the natural convection heat transfer of nanofluids with numerical simulation method, some scholars [6–9] examined the magnetohydrodynamic flow of non-Newtonian nanofluid in a pipe by mathematical models. The results revealed that Nusselt number increases with an increase of nanoparticle volume fraction, Rayleigh numbers and inclination angle. Moreover the increasing Rayleigh number leads to a decrease in heat transfer enhancement and due to increase in radiation parameter, the velocity is increased. Sheikholeslami et al. [10–14] presented the magnetohydrodynamics nanofluid hydrothermal treatment in a cubic cavity heated from below. It is observed that the applying magnetic field results in a force opposite to the flow direction that leads to drag the flow and then

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Nomenclature

A	effective heat transfer area (m^2)
C	specific heat capacity ($J{\cdot}kg^{-1}{\cdot}°C^{-1}$)
D	diameter of the inner wall (m)
f	flow friction factor
H	axial length (m)
h	convective heat transfer coefficient ($W{\cdot}m^{-2}{\cdot}K^{-1}$)
l	Length (m)
Pr	Prandtl number
Pe	Berkeley number
ΔP	pressure drop (Pa)
Q	average heat flow (W)
$\bar{Q}$	average heat flux ($W{\cdot}m^{-2}$)
q	flow ($kg{\cdot}s^{-1}$)
Ra	roughness (μm)
Re	Reynolds
ΔT	temperature difference (°C)
T	temperature (°C)
Y	reverse ratio

Greek symbols

u	flow rate ($m{\cdot}s^{-1}$)
λ	thermal conductivity ($W{\cdot}m^{-1}{\cdot}K^{-1}$)
μ	dynamic viscosity ($m^2{\cdot}s$)
ρ	density ($kg{\cdot}m^{-3}$)
φ	nanoparticles volume fraction (%)
ω	nanoparticles mass fraction (%)
δ	thickness (m)

Subscripts

bf	base fluid
Exp	experiment
in	inlet
m	weight
nf	drag reducing nanofluids
out	outlet
p	nanoparticles
Reg	regression equation
v	volume
w	tube wall
water	water

reduces the convection currents by reducing the velocities. Noreen Sher Akbar et al. [15–18] intended for investigating the effects of heat flux and induced magnetic field for the peristaltic flow of different nanoparticles. It is observed that pressure gradient decreases with an increase in heat generation parameter. In short, adding most nanoscale solid metal or metal oxide particles into a base fluid can significantly improve the efficiency of convective heat transfer.

Toms first published research on drag reducing fluids in 1949 at the International Conference of Rheology, reporting that by adding a small amount of polymers in water can drastically reduce frictional resistance of turbulent pipe or channel flow [19]. This phenomenon came to be known as the Toms effect. Drag reducing additive fluids that is mixed fluids with a small amount of polymer or surfactant molecules was shown to significantly reduce their turbulent flow resistance. In the drag reducing performance, some scholars [20–21] studied the drag reducing effects of temperature and concentration to aqueous solution that are mixed by surfactant CTAC and NaSal. 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. And at a high concentration, viscosity increases as the fluid temperature decreases. In the study of rheological properties with drag reducing fluids [22–23], 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. And along with an increase in roughness of used tubes in the experiments, an increase was also noted in the friction resistance of aqueous solutions mixed by surfactant CTAC and NaSal. 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 drag reducing nanofluids formed by nanofluids and drag reducing fluids. In the study of convection heat transfer characteristics [24–26], 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 [27–29], 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 drag reducing nanofluids almost have no difference in terms of fluid resistance with traditional drag reducing fluids. In the study of the fundamental physical properties [30–31], the thermal conductivity, shear viscosity and stability were investigated. Surfactants have a significant role in terms of expediting well dispersed nanoparticles and in promoting the stability of nanofluids; moreover, the best heat transfer characteristics relate to the ratio of surfactants and nanoparticles. With the nanoparticles' volume fraction increasing and temperature decreasing, the fluid shear viscosity increases. In turbulent flow conditions, the rated range heat conductivity also increases with particle volume fraction and fluid temperature increasing, and all the physical parameters are higher than the base fluid.

Inserting a twisted belt into a tube enhances heat transfer and simplifies the manufacturing process at a low cost. Tubes with a twisted belt inside make fluid rotate. The swirling fluid enhances fluid flow velocity and the flow path near the wall, which strengthens the fluid turbulence of boundary layers as well as the mixture of boundary layer flow and main flow, thereby increasing the heat transfer effect. Masoud [32] used a variety of simulation models to compare fluid flow velocity subjected to built-in twisted belt tubes compared to the same experiment in regular tubes. The results showed: Nusselt number is inversely proportional to twisted belt space, and tubes inserting a twisted belt can enhance heat transfer