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Experimental investigation on heat transfer performance of Fe_2O_3/water nanofluid in an air-finned heat exchanger

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HIGHLIGHTS

- Overall heat transfer coefficient in the car radiator measured experimentally.
- Nanofluids showed greater heat transfer performance compared with water.
- Increasing liquid and air Re increases the overall heat transfer coefficient.
- Increasing the inlet liquid temperature decreases the overall heat transfer coefficient.

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ABSTRACT

In this paper, the overall heat transfer coefficient of water based iron oxide nanofluid in a compact air-cooled heat exchanger has been measured experimentally under laminar flow conditions. The concentrations of 0.15, 0.4 and 0.65 vol.% of stabilized Fe_2O_3/water nanofluid have been examined with variation of flow rates in the range of 0.2–0.5 m^3/h. For better dispersion of iron (III) oxide nanoparticles in water, 0.8 wt% polyethylene glycol has been added and pH has been adjusted to 11.1. The air-cooled heat exchanger is consisted of 34 vertical tubes with stadium-shaped cross section and air makes a cross flow through the tube bank with variable flow rates ranging from 740 to 1009 m^3/h. Also, hot working fluid enters the heat exchanger at different temperatures including 50, 65, and 80 °C. The results demonstrate that increasing the nanofluid flow rate and concentration and the air Reynolds number can improve the overall heat transfer coefficient and heat transfer rate whereas enhancing the inlet temperature has a negative effect on the overall heat transfer coefficient and a positive effect on the heat transfer rate. Meanwhile, the maximum enhancements of the overall heat transfer coefficient and heat transfer rate compared with base fluid (distilled water) are respectively equal to 13% and 11.5% which is occurred at the concentration of 0.65 vol.%.

1. Introduction

Heat transfer is one of the most important and most applicable engineering sciences; its applications become very important with respect to the subject of energy crisis and energy consumption optimization in various industrial processes. For decades, efforts have been done to enhance the heat transfer rate, reduce heat transfer time, minimize size of heat exchangers, and finally increase energy and fuel efficiencies. These efforts include passive and active methods such as using fins [1], compact heat exchangers [2], channels with non-circular cross sections [3], microchannels [4] etc. The addition of solid particles into heat transfer media has long been known as one of the useful techniques for enhancing the heat transfer rate [5,6], although a major consideration when using suspended millimeter or micrometer sized particles is that they have the potential to cause some severe problems such as abrasion, clogging, high pressure drop and sedimentation of particles. Recent progresses in nanotechnology help us to produce nanometer sized particles that their mechanical and thermal properties are completely different from the millimeter or micrometer sized particles. Choi [7] was the first to employ the nanometer sized particles in conventional fluids (water or ethylene glycol) and showed considerable increase in the nanofluid thermal conductivity. Since then some studies have been done on nanofluid properties that found nanofluids have better properties such as heat transfer improvement and stability, reduction in energy for pumping the fluid, reduce clogging and eventually decrease in costs compared to the use of the suspended micro particles.

There are several published studies on the convective and overall heat transfer coefficients for nanofluids and most of them show

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Nomenclature

A	Total heat transfer area (m^2)
C_p	Specific heat (J/kg K)
D_h	Hydraulic diameter (m)
F	Logarithmic temperature correction factor (dimensionless)
G	Gap between two fins (m)
h	Convective heat transfer coefficients (W/m^2 K)
H	Height (m)
k	Thermal conductivity (W/m K)
L	Length (m)
$\dot{m}$	Liquid mass flow rate (kg/s)
n	Shape factor
Nu	Nusselt number (dimensionless)
P	Perimeter (m)
Pe	Peclet number (dimensionless)
Pr	Prandtl number (dimensionless)
q	Heat transfer rate (W)
Q	Volume flow rate (m^3/s)
Re	Reynolds number (dimensionless)
t	Thickness (m)
T	Temperature (K)
U	Overall heat transfer coefficient (W/m^2 K)
W	Width (m)

Greek letters

φ	Volume fraction of nanoparticles
μ	Viscosity (kg/m s)
ρ	Density (kg/m^3)
ψ	Particle sphericity
η_f	Efficiency of a single fin
η_o	Overall surface efficiency of a finned surface

Subscripts

air	Air flow
bf	Base fluid
c	Cold
exp	Experimental
f	Fin
h	Hot
i	Inside
in	Inlet
LMTD	Logarithmic mean temperature difference
nf	Nanofluid
o	Outside
out	Outlet
p	Particle
s	Surface
t	Tube of the air cooler
th	Theoretical
w	Water

that these coefficients are enhanced compared with that of the base fluid. Farajollahi et al. [8] conducted an experiment for heat transfer characteristics of γ-Al_2O_3/water and TiO_2/water nanofluids in a shell and tube heat exchanger under turbulent flow conditions. They observed that the overall heat transfer coefficient at a constant Peclet number increases with nanoparticle concentration for both nanofluids. The maximum enhancement of the overall heat transfer coefficients for γ-Al_2O_3/water and TiO_2/water nanofluids compared with the base fluids were approximately 20% and 24%, respectively. Leong et al. [9] studied the effect of air Reynolds number, coolant Reynolds number in the application of 0–2 vol.% Cu/ethylene glycol nanofluids in an automobile radiator. Their results showed at a constant Reynolds number the overall heat transfer coefficient of nanofluid is 15% higher than that of the base fluid and also about 3.8% heat transfer rate enhancement was achieved with the addition of 2% copper nanoparticles. Fotukian et al. [10] examined the turbulent convective heat transfer coefficient and pressure drop of alumina/water nanofluid in a circular tube. They showed that the maximum increase in the convective heat transfer coefficient of Al_2O_3/water nanofluid compared with pure water was 48% for 0.054 vol.% at Reynolds number of 10,000. Jwo et al. [11] performed an investigation to analyze the effects of concentration, inlet flow temperature, and flow rates on the overall heat transfer coefficient of Al_2O_3/water nanofluid in a multichannel heat exchanger (MCHE). They observed that the overall heat transfer coefficient ratio was higher at higher nanoparticle concentrations and mass flow rates but the effect of temperature on the above mentioned coefficient was reverse. Guo et al. [12] obtained 60% convective heat transfer coefficient enhancement compared to (60/40) ethylene glycol/water base fluid with 2 vol.% γ-Fe_2O_3 nanofluid under laminar flow conditions in a circular tube. Peyghambarzadeh et al. [13] investigated the effect of Al_2O_3/water nanofluid in concentration of 0.1–1 vol.% on the performances of turbulent flow convective heat transfer coefficient of an automobile radiator. Authors have found that the convective heat transfer coefficient has been improved in comparison with the base fluid up to 45%. They also have determined that with the enhancement in nanofluid Reynolds number and temperature, convective heat transfer coefficient increases. In other work, Peyghambarzadeh et al. [14] used different concentrations of water and ethylene glycol as a base fluid which is conventionally used in the car's radiators. They have figured out that the convective heat transfer coefficient of Al_2O_3/ethylene glycol nanofluid showed an increase of about 40% compared with the base fluid in the best conditions. Zamzamian et al. [15] investigated experimentally the effect of Al_2O_3 and CuO nanofluids in ethylene glycol base fluid on convective heat transfer coefficient in two kinds of heat exchangers, plate and double pipe heat exchangers at different nanofluid concentrations and various temperatures under turbulent flow. They concluded that the enhancements of forced convective heat transfer coefficients of 1 wt% alumina nanofluid compared to the base fluid were 26.2% and 38.3% for double pipe and plate heat exchangers at 75 °C, respectively. These enhancements for 1 wt% Cu nanofluid in the mentioned heat exchangers were 37.2% and 49.33% at 75 °C. Leong et al. [16] studied the convective heat transfer coefficient and overall heat transfer coefficient of copper nanofluid in a shell and tube heat recovery exchanger. It was observed that about 16.9% and 9.5% enhancements were recorded for ethylene glycol with 1% copper nanoparticles compared with the base fluid, respectively. For 2 vol.% water based copper nanofluid, 33.4% and 10.11% enhancements for convective heat transfer coefficient and overall heat transfer coefficient in laminar flow were recorded compared with the base fluid. Sundar et al. [17] presented an experiment in plain circular tube in turbulent flow of Fe_3O_4/water nanofluid at the concentrations of 0–0.6 vol.% and concluded the enhancement of 30.96% and 10.01% in convective heat transfer coefficient and friction factor compared with water, respectively at Reynolds number of 22,000. Pandey et al. [18] reported a study of turbulent flow heat transfer characteristics in a corrugated plate heat exchanger using nanofluid containing Al_2O_3/water nanofluid at different concentrations (0–4 vol.%). The maximum enhancements of convective and overall heat transfer coefficients for 2 vol.% alumina nanofluid compared with base fluid are more than 11% and 10%, respectively. Hung et al. [19] presented an experimental investigation of thermal characteristics of Al_2O_3/water nanofluid with 0.5 to 1.5 wt% as coolant in an air-cooled heat exchanger. Their results show that the maximum enhancement of heat exchange is of 40% which was obtained at the