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Original Research Paper

Investigation of turbulent heat transfer and nanofluid flow in a double pipe heat exchanger

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ABSTRACT

In present study, heat transfer and turbulent flow of water/alumina nanofluid in a parallel as well as counter flow double pipe heat exchanger have been investigated. The governing equations have been solved using an in-house FORTRAN code, based on finite volume method. Single-phase and standard k-ε models have been used for nanofluid and turbulent modeling, respectively. The internal fluid has been considered as hot fluid (nanofluid) and the external fluid, cold fluid (base fluid). The effects of nanoparticles volume fraction, flow direction and Reynolds number on base fluid, nanofluid and wall temperatures, thermal efficiency, Nusselt number and convection heat transfer coefficient have been studied. The results indicated that increasing the nanoparticles volume fraction or Reynolds number causes enhancement of Nusselt number and convection heat transfer coefficient. Maximum rate of average Nusselt number and thermal efficiency enhancement are 32.7% and 30%, respectively. Also, by nanoparticles volume fraction increment, the outlet temperature of fluid and wall temperature increase. Study the minimum temperature in the solid wall of heat exchangers, it can be observed that the minimum temperature in counter flow has significantly reduced, compared to parallel flow. However, by increasing Reynolds number, the slope of thermal efficiency enhancement of heat exchanger gradually tends to a constant amount. This behavior is more obvious in parallel flow heat exchangers. Therefore, using of counter flow heat exchangers is recommended in higher Reynolds numbers.

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1. Introduction

One of the important effective factors in heat transfer of fluids is thermal conductivity of fluid. The common fluids used in industries have low capability in heat transfer. Therefore, from the industrial perspective, there is a demanded need in industries to develop, use and progress of fluids with higher heat transfer coefficients. In recent years, novel methods have been used for heat transfer enhancement and removing high heat flux. One of these methods is using nanofluids. The experimental results indicate that thermal properties of nanofluids are greater than base fluid. For instance, by adding almost 1–5% of nanoparticles to the base fluid, thermal conductivity increases up to 20% [1]. The amount of this enhancement depends on different factors such as shape, dimension, material and concentration of nanoparticles [2,3]. It is notable that in primary experiments, the physical and thermal properties of nanofluid has been obtained in the base temperature and specific environment. Das et al. [4] investigated the effect of temperature on nanofluid properties for the first time. This study has been done for water/Al_2O_3 nanofluid with volume fractions of 1 and 4% and revealed that temperature increment has noticeable influence on thermal conductivity enhancement and the reduction of dynamic viscosity. Naphon et al. [5] experimentally studied the behavior of titanium nanofluid in heat pipes. He figured out that for 10% of nanoparticles, the thermal efficiency enhances up to 10.66%. Namburu et al. [6] numerically investigated the effect of properties variations on heat transfer of turbulent flow inside a pipe. They also studied the effect of nanoparticle dimension. Their results showed that in a specific Reynolds number and for a nanofluid

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Nomenclature

C_p	heat capacity, J/kg K
D	tube diameter, m
F	friction factor
H	convective heat transfer coefficient, W/m^2 K
K	thermal conductivity, W/m K
L	tube length, m
Nu	Nusselt number
Q	heat transfer, W
R	radius of the tube, m
Re	Reynolds number
t	distance between the internal and external tube diameter, m
T	temperature, K
U_{in}	inlet velocity in x directions, m/s

Greek symbols

ρ	density, kg/m^3
μ	dynamic viscosity, Pa s
ε	heat exchanger efficiency
φ	nanoparticles volume fraction

Super- and Sub-scripts

Av	average
b	balk
f	base fluid (Distilled water)
C	cold
eff	effective
H	hot
in	inlet
max	maximum
min	minimum
nf	nanofluid
out	outlet
r	radius
p	solid nanoparticles

with 6% of CuO nanoparticle, Nusselt number enhances to 36%. Chun et al. [7] experimentally studied the effect of using nanoparticles on heat transfer performance in a double pipe heat exchanger under laminar regime. They found that surface properties, volume fraction and geometrics of nanoparticles are the main factors in heat transfer improvement. Zarringhalam et al. [8] experimentally investigated the convection heat transfer coefficient of water/CuO nanofluid with different volume fractions of turbulent flow through a counter flow double pipe heat exchanger. They figured out that by increasing Reynolds number and volume fraction of nanoparticles to 2%, the convection heat transfer enhances to 57%. Zhaoa et al. [9] numerically investigated the water/Al_2O_3 nanofluid flow in a smooth tube under constant temperature and heat flux. Their numerical results represented that adding nanoparticles to base fluid improves the heat transfer and pressure drop of the working fluid in different Reynolds numbers and temperatures. Bagherzadeh et al. [10] numerically studied the water/CuO and water/Ag nanofluids flow inside the coiled tubes under constant temperature and heat flux in the laminar flow. They investigated thermal conductivity with four equations and figured out that the obtained results from homogeneous model are closer to the experimental results. Hashemi et al. [11] experimentally studied the heat transfer and pressure drop of oil/CuO nanofluid inside the horizontal coiled tubes under constant heat flux. Their results illustrated that the delay in thermal boundary layer formation due to existence of nanoparticles enhances the convection heat transfer coefficient. Hojjat et al. [12] experimentally studied the convection heat transfer of a non-Newtonian nanofluid (DI water/CuO, Al_2O_3, TiO_2) inside the circular tubes in turbulent flow regime. They figured out that by increasing Peclet number, the convection heat transfer and Nusselt number enhance. Hemmat Esfe et al. [13] experimentally studied the heat transfer and pressure drop of water/double-walled carbon nanotubes (DWCNT) nanofluid inside a double pipe heat exchanger under turbulent regime. Their findings showed 25% enhancement for convection heat transfer coefficient of nanofluid with 0.4% of nanoparticles, compared to the base fluid. Abbasian Arani and Amani [14] experimentally studied the effect of nanoparticles diameter of water/TiO_2 nanofluid on the convection heat transfer and pressure drop inside a counter flow double pipe heat exchanger. Their results indicated that by reducing the nanoparticle diameter, Nusselt number enhances, but this enhancement is not absolute because in diameter of 20 nm, Nusselt number values are higher compared to the diameter of 10 nm. Darzi et al. [15] experimentally studied the water/Al_2O_3 nanofluid inside a double pipe heat exchanger. Their results depicted that adding nanoparticles to the base fluid creates impressive potential for heat transfer enhancement and thermal efficiency of heat exchanger. Chun et al. [16] investigated the convective heat transfer coefficient of oil/alumina nanofluids in different volume fractions in a double pipe heat exchanger under laminar regime. They reported that the reason of heat transfer enhancement of nanofluids is the concentration of nanoparticles in thermal boundary layer near walls and particles motion. Garoosi et al. [17] numerically studied the heat transfer performance of a heat exchanger filled with nanofluid and found that adding solid nanoparticles to the base fluid has great effect on heat transfer enhancement rate. Shahmohammadi and Beiki [18] numerically studied the heat transfer and pressure drop of γ/Al_2O_3 nanofluid inside a shell and tube heat exchanger under turbulent regime. Their results indicated that by increasing the flow rate and number of baffles, heat transfer and pressure drop enhance. However, the increase of nanoparticles does not have a considerable influence on pressure drop intensification. Ebrahimnia-Bajestana et al. [19] numerically and experimentally studied the water/TiO_2 nanofluid inside a tube. Their results depicted that adding nanoparticles to base fluid enhances the heat transfer rate up to 21%. Other experimental and numerical studies are usually investigating a nanofluid inside simple geometrics like cavity [20], channel or microchannel [21–24], vertical annulus [25] or inside a tube or microtube [26,27]. In present study, heat transfer and turbulent fluid flow of water/alumina nanofluid in a double pipe heat exchanger are numerically investigated. In this research, effects of nanoparticles volume fraction and Reynolds number on temperature variations of base fluid, nanofluid and wall, thermal efficiency, Nusselt number and convective heat transfer coefficient has been investigated. According to the abundant application of heat exchangers in heat transfer of power plant equipment, the results of this research can be used in many industries, especially oil, gas and petrochemical industries.

2. Problem statement, geometrics and boundary conditions

In this research, turbulent flow and heat transfer parameters of water/Al_2O_3 nanofluid in a double pipe heat exchanger by using finite volume method have been investigated. In this study, the heat exchanger with a long length has been modeled in which

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