Energy Conversion and Management 151 (2017) 573–586

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Application of a novel conical strip insert to improve the efficacy of water–Ag nanofluid for utilization in thermal systems: A two-phase simulation

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ARTICLE INFO

Keywords:
Water–Ag nanofluid
Twisted conical strip inserts
Eulerian–Lagrangian approach
Heat transfer enhancement
Particle dispersion
Figure of merit

ABSTRACT

In this research, hydrothermal characteristics and energy efficiency of the water–Ag nanofluid in a circular tube equipped with twisted conical strip inserts are investigated through the two-phase Eulerian–Lagrangian approach. The novel inserts under study are a combination of twisted tape inserts and conical strip inserts. Both staggered and non-staggered alignments for the strip inserts are examined. The effects of different forces including drag force, thermophoretic force, Brownian force and lift force are considered. Application of the strip inserts intensifies flow mixing and disturbance in boundary layer and therefore, increases Nusselt number and friction factor compared with the plain tube. The non-staggered alignment disturbs the boundary layer with a greater intensity than the staggered alignment, such that a completely swirling flow is developed for this configuration. The results show that heat transfer for the non-staggered alignment is higher than that for the staggered alignment, while the merit characteristic is greater for the staggered alignment. Moreover, the temperature and velocity distributions are more uniform for the non-staggered alignment. Additionally, Nusselt number augments by increasing either concentration or Reynolds number, whereas friction factor decreases with Reynolds number increment and intensifies by increasing the concentration. The nanofluid has a greater merit than pure water for utilization in this geometry. Meanwhile, the non-staggered alignment causes a more intense nanoparticle migration compared with the staggered alignment.

1. Introduction

Today, Heat Exchangers (HEXs) are widely exerted throughout multiple-industrial fields including air conditioning and power generation [1–4]. To meet the needs of the cost reduction and energy saving, several approaches have been applied experimentally and numerically in order to enhance the efficiency and performance of these devices [5].

Among these attempts, heat transfer augmentation has been always played significant role to improve the overall performance of HEXs [6–8]. The micro-fin tube [9] and helically rib-roughened [10] are some well instances which have been developed for heat transfer improvement. Furthermore, many kinds of tube inserts have been studied for the heat transfer enhancement. Due to convenience of manufacturing, installation and maintenance, this approach has become popular in HEXs.

Due to generating the spiral flow and distributing the flow in viscous layers near the wall, using the twisted tapes and wire coil inserts are some well-known facilities for heat transfer improvement in laminar and turbulent flows [11–13]. A review on these methods is addressed in [14]. The broken twisted tapes [15], segmented twisted tapes [16], helical screw tapes [17] and serrated twisted tapes [18] are some examples for twisted tapes facilities.

Conical strip is another kind of inserts for heat transfer enhancement [19,20]. Comparing heat transfer enhancement and pressure drop increment proves that these stripes increase energy efficiency of thermal devices remarkably. Fan et al. [21,22] investigated the geometry parameters including slant angle and pitch in a circular tube

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http://dx.doi.org/10.1016/j.enconman.2017.09.025
Received 23 July 2017; Received in revised form 5 September 2017; Accepted 9 September 2017

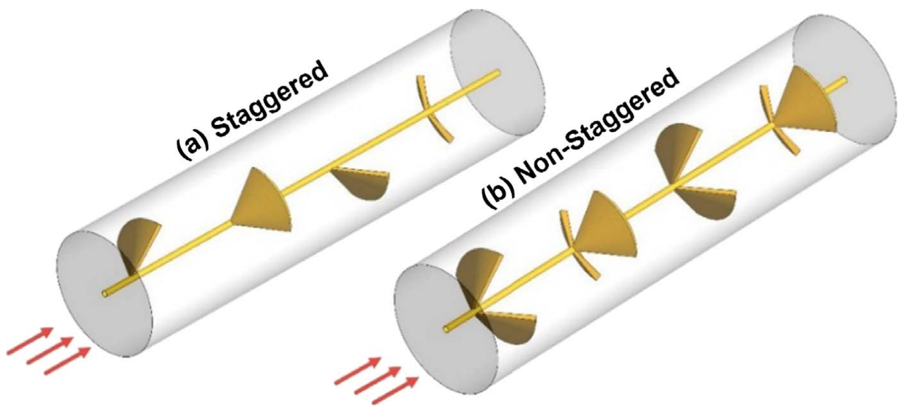

Fig. 1. Geometry under study: (a) staggered alignment and (b) non-staggered alignment.

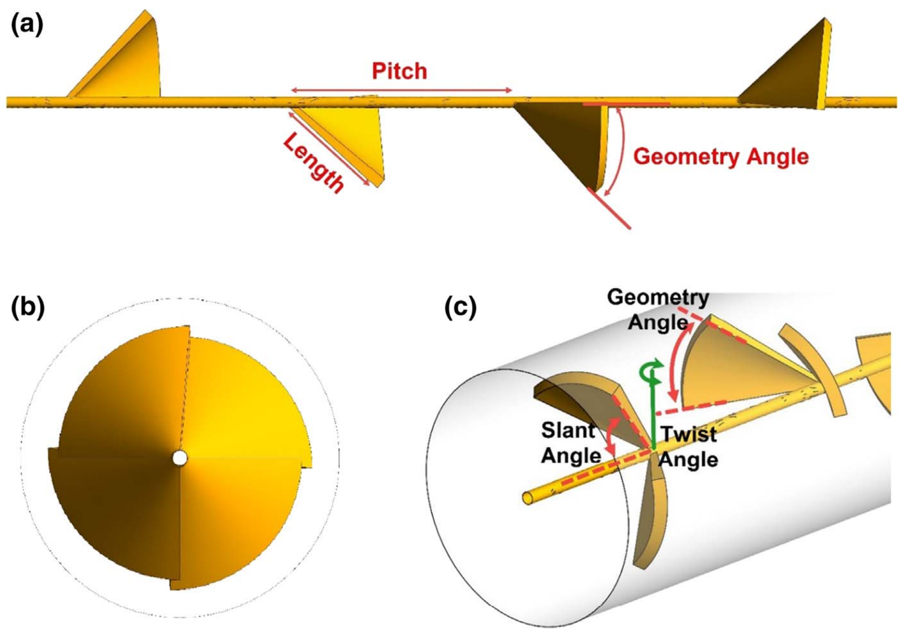

Fig. 2. Schematic of the inserts: (a) longitudinal view, (b) transverse view and (c) different angles.

fitted with conical strip inserts by using pure water as working fluid. Both turbulent and laminar flow regimes were investigated. The results showed that higher Nusselt number is obtained at larger slant angle and smaller pitch. Moreover, the impact of slant angle on Nusselt number and friction factor was more significant than that of the pitch. Another geometry parameter including twist angle was investigated in turbulent flow with pure water as coolant in such configuration [23]. It was found that the increase of twist angle causes the reduction of Nusselt number and friction factor.

Over the past few years, dispersing solid nanoparticles in a base fluid has been employed in HEXs significantly to enhance heat transfer. Many studies have shown that nanofluids can impressively enhance the fluid thermal conductivity and consequently, the heat transfer performance will be improved [24–29]. In addition, nanofluids accompanying other heat transfer augmentation methods like twisted tapes have been utilized in order to increase the thermal performance. Zheng et al. [30] used a nanofluid in a heat exchanger with inserted conical strip. The sensitivity analyses with effects of design parameters (i.e. Reynolds number, conical strip filling ratio and pitch ratio) on Nusselt number and friction factor ratio were examined. They showed that increasing the Reynolds number and conical strip filling ratio enhances the heat transfer rate, while increasing the pitch ratio leads to an opposite trend. Mokhtari et al. [31] performed a three-dimensional numerical simulation to investigate the effect of magnetic field on the heat transfer of magnetic nanofluid inside a tube which was equipped with twisted tape. As per the achieved results, Nusselt number enhanced more than 200% when it flowed through tube with twisted tapes. Sundar et al. [32] experimentally evaluated turbulent convective heat transfer and friction factor of a nanofluid flowing within a uniformly heated circular tube with and without twisted tape inserts. Heat transfer and friction factor enhancement for the nanofluid with concentration of 0.6% in a tube with twisted tape insert was 51.88% and 1.231 times compared to water flowing in a plain tube under same Reynolds number. Wongcharee and Eiamsa-ard [33] examined heat transfer, friction and thermal performance of CuO–water nanofluid in a circular tube equipped with modified twisted tape with alternate axis. By using the twisted tape, Nusselt number increased up to 12.8 times of the plain tube. Moreover, the simultaneous application of the nanofluid and twisted tape improved Nusselt number up to 13.8 times of the plain tube.

Today, due to the great cost of experimental platforms, the computation fluid dynamics (CFD) simulation has become an effective tool to predict the results in industrial and laboratory scales [34–37]. Most of the studies carried out on nanofluids have applied the single-phase approach for numerical simulation [38–41], which considers a nanofluid as homogenous fluid with effective properties. Although this method has presented rather good results in several situations, it is not able to consider the important effects such as Brownian motion, thermophoresis, slip between phases, and so forth. This issue becomes very important specifically in applications that have a severe flow mixing. A