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Experimental study on the heat transfer and flow characteristics of nanofluids in the built-in twisted belt external thread tubes

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ABSTRACT

In order to study the heat transfer and flow characteristics of fluid flowing through the built-in twisted belt external thread tubes, in the Reynolds number range of 2000–12,000, the heat transfer and flow characteristics were studied respectively for the Cu, Al, Al_2O_3, Fe_2O_3, multiwalled carbon, and Graphite nanofluids with the mass fraction of 0.1–0.6%. The results show that the Cu nanofluids has the best convective heat transfer effect among numerous nanofluids, and the heat transfer characteristics reach the optimum when the mass fraction of Cu nanofluids is 0.5%. The heat transfer performance of built-in twisted belt external thread tubes increased 50.32% compared to the horizontal tube, indicating that built-in twisted belt external thread tubes has the ability to strengthen heat transfer. With the decrease of the pitch, the heat transfer coefficient and flow resistance were both increased. According to the experimental data, the comprehensive analysis of hot performance coefficient was carried out and the correlation of convective heat transfer and flow resistance in the built-in twisted belt external thread tubes was obtained.

1. Introduction

Since 1990s, the researchers began to explore the application of nano materials technology in the field of heat transfer enhancement, and a new generation of efficient heat transfer and cooling technology was studied. In 1995, the Argonne National Laboratory of the United States, Choi et al. [1] put forward a new concept – nanofluids for the first time.

In recent years, scholars at home and abroad have conducted a lot of research on nanofluids technology. Thermal physical properties of nanoparticles, Xuan [2] discuss the relevant laws of nanoparticle properties, particle size, particle fraction, fluid suspension stability and fluid temperature impact on the thermal conductivity of nanofluids. The results show that at the rated Reynolds number, the nanoparticles suspended in the fluid can effectively enhance the heat transfer process, the nanofluids has a higher heat transfer coefficient than the original base fluid. Noreen Sher Akbar et al. [3–6] intended for investigating the effects of heat flux and induced magnetic field for the peristaltic flow of different nanoparticles.

Many researchers have used nanofluids in different types of heat pipes to get better heat transfer performance as mentioned in the review articles [7–10]. Most of them observed an improvement in heat transfer with nanofluids even though a few reported negative result. Only a few researchers have considered nanofluids as working fluid in loop heat pipes. Duangthongsuk [11] study the effect of heat transfer and pressure drop of TiO_2-water nanofluids in double countercurrent heat transfer, the results show that the convective heat transfer coefficient of the nanofluids is improved 6–11% compared with the base fluid, and the convective heat transfer coefficient increases with the increase of mass flow rate and the decrease of the temperature of the nanofluids. Xuan et al. [12] studied the flow and convective heat transfer characteristics of Cu-water nanofluids in conventional and small channel flat tubes. It is found that the convective heat transfer coefficient can be increased by adding nanoparticles to the liquid and the flow resistance is not increased significantly, which shows that adding a small amount of nanoparticles in water will not cause additional resistance loss. Some scholars [13–16] examined the Magnetic fluid dynamics 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. Darzi [17] study heat transfer and flow characteristics of Al_2O_3-water nanofluids in the casing tube heat exchanger, the results show that the nanofluids have great application prospects in the field of heat transfer enhancement, and in the experiment, the friction resistance is little

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Nomenclature

A	effective heat transfer area, m^2
C	specific heat capacity, J $kg^{-1}\cdot°/C^{-1}$
D	diameter of the inner wall, m
f	flow friction factor
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
$\underline{Q}$	average heat flow, W
$\overline{Q}$	average heat flux, $W\cdot m^{-2}$
q	flow, $kg\cdot s^{-1}$
Re	Reynolds
ΔT	temperature difference, °C
T	temperature, °C
u	flow rate, m s^{-1}
λ	thermal conductivity, $W\cdot m^{-1}\cdot K^{-1}$
μ	dynamic viscosity, Pa·s
ν	kinematic viscosity, $m^2\cdot s$
ρ	density, $kg\cdot m^{-3}$
φ	nanoparticles volume fraction, %
ω	nanoparticles mass fraction, %

Greek symbols

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

changed compared with the base fluid. Utomo [18] studied the convective heat transfer characteristics of nanofluids in a horizontal tube under the condition of laminar flow, the results show that the addition of nanoparticles has a great influence on the thermal properties of the fluid, so the heat transfer efficiency of the fluid is further enhanced. The development of nanotechnology has become a widely used, interdisciplinary, and development potential of the technology and has also become one of the main research directions to solve the energy problem.

Smithberg and Landis [19] studied the theory of twisted belt for the first time. A twisted belt was inserted into a tube to enhance heat transfer and the manufacturing process was simplified 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. Many scholars have carried out a more detailed and comprehensive study on the twisted belt. The diameter of tube, the twisted belt twist rate, fluid Prandtl number effects of different aspects of twisted belt tube performance to do a detailed overview.

Maddah [20] studied the heat transfer characteristics of the nano fluids in a twisted tape tube, the experiment was carried out in a twisted tape tube with different concentration of nanofluids, the results show that the nanofluids can effectively enhance the heat transfer effect, twist ratio have a significant effect on the change of heat exchange and frictional resistance in the twisted. Bhadouriya [21] experimental studied inner tube for reversing square tube, the outer tube is an annular casing device of the circular tube, characteristics of heat transfer and friction resistance of air flow, the experimental results indicate that the ring parameter is small, the friction coefficient and the Nusselt number is greater. Liu [22] has a Numerical simulation study on the formation and development of spiral vortex in short twisted tape, it is found that the radial velocity is the main factor for the formation of eddy current, the size of the twisted ratio directly influences the formation of the spiral vortex. Azmi [23] numerical simulation studied convective heat transfer characteristics of SiO_2 nanofluids in a twisted tape tube, and the analysis is carried out, compared with water in the built in twisted tape, the heat transfer coefficient of the SiO_2 nanofluids with a volume fraction 3% is increased 94.1%, friction coefficient is increased 160%. Sivasharmugam et al. [24], the spiral twisted belt is applied to the heat exchanger, twisted belt with twisted ratio Y is 4.149, 4.95, 5.882, 8.54, 15.649, the tube is used in the heat exchanger, which has obvious effect on the industrial application, it is found that the enhancement amplitude is inversely proportional to the Reynolds number Re, when the twisted belt with twisted ratio Y is 4.149, the enhanced amplitude is relative to the ordinary heat exchanger enhanced 44.7%. Kumar [25]applied the helical twisted belt methodology to solar water heaters, and determined the twisted ratio range to be 3–12. It turns out: solar water heaters inserted with a twisted belt can improve the heat transfer effect about 18–70%, but also increase the resistance 87–132%.

The first paper on the study of heat transfer enhancement of the external screw thread is proposed by the American scholar Lawson [26] in 1966. In recent years, many scholars at home and abroad have carried out a lot of research on the methods of heat transfer enhancement, such as rough surface and extended surface, these enhanced heat transfer methods have improved the heat transfer effect to different extent, when the fluid flows in the threaded tube, the inner surface of the spiral shape is raised to causes the laminar flow in the region of the transition zone is formed in a vertical vortex, the vortex causes periodic disturbance of the raised part of the Laminar flow medium, cause fluid particle in boundary layer disturbance into disorganized turbulent state, when fluid flows through the raised parts and produce new vortex and the vortex flow direction is always perpendicular to the flow direction of medium laminar, which makes the flow state of the transition zone can change, thermal resistance becomes small, the heat transfer rate increase [27]. At present, there is a certain market in the thread tubes heat exchanger or heat exchange element, it has been widely used in the petroleum industry of our country and used in heat exchangers, and some are used in the boiler flue tube. The test shows that when the thermal resistance of the tube external fluid is controlled by the thermal resistance, the appearance of the threaded tube is about 2.5 times larger than the same horizontal tube heat exchanger, to make up for the deficiency of heat transfer coefficient of the tube outer membrane, improve the heat transfer effect. Reduce the size and weight of the heat exchanger. In addition, the threaded tube heat exchanger has a Strong antifouling ability and corrosion resistance ability, has a Long use cycle.

The thermal efficiency of a high-heat-exchange tube is known to be significantly higher than that of a common copper tube [28–32]. Thus, the heat transfer characteristics of nanofluids in an the built-in twisted belt external thread tubes were studied in