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Experimental studies on heat transfer and pressure drop characteristics for new arrangements of corrugated tubes in a double pipe heat exchanger

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ABSTRACT

Heat transfer, pressure drop and effectiveness in a double pipe heat exchanger made of corrugated outer and inner tubes have been experimentally investigated in this paper. Both of the inner and outer tubes were corrugated by means of a special machine. New various arrangements of convex and concave corrugated tube were investigated. Heat transfer coefficient was determined using Wilson plots. Hot water (inner tube) and cold water (outer tube) inlet temperatures were maintained at around 40 °C and 8 °C respectively. Experiments were performed over the Reynolds number range of 3500–18,000, based on the hydraulic diameter of the annular space between the two tubes. Hot water Reynolds number was kept constant at around 5500. Findings indicated that the outer tube corrugations and arrangement type of corrugated tubes have significant effect on thermal and frictional characteristics. Maximum effectiveness was obtained for heat exchanger made of concave corrugated outer tube and convex corrugated inner tube.

1. Introduction

The apparatus used to implement the exchange of heat between two fluids that are at different temperatures while keeping them from mixing with each other is termed a heat exchanger. They are used in a great amount of applications, such as heating and air conditioning systems, chemical processing, power production and aeronautical applications. The weight and size of heat exchangers used in space or aeronautical applications are very significant parameters, and in these cases, costs of heat exchanger production are enumerated as a secondary consideration. However, heat exchangers are designed to obtain maximum heat transfer, low pressure drop, high effectiveness, minimum volume and weight, and also low cost. Several techniques have been employed for these purposes. Generally, these methods can be categorized into three principal types: (1) using of nanofluids (2) coarsening heat exchanger surfaces and (3) inserting fluid turbulators. Coarsening surfaces can improve the thermal performance of heat exchanger by increasing fluid mixing and turbulence level of the fluid flow. Corrugated tubes can be introduced as one of the coarsening surface methods and they can be classified into two main types: inward concave corrugated tubes and outward convex corrugated tubes. Both of them are studied in present paper.

Numerous experiments on thermal and frictional characteristics of corrugated tubes have been carried out. Many researchers have investigated the heat transfer and flow characteristics of fluid in a single horizontal corrugated tube, and some of the researchers focused on the using of corrugated tube as the inner tube of a double pipe heat exchanger.

Publications on characteristics of a single corrugated tube and double pipe heat exchangers made of corrugated tubes are summarized chronologically as follows. Rainieri and Pagliarini [1] experimentally studied on convective heat transfer in the entry region of corrugated tubes at different pitch ratios for Reynolds number range between 90 and 800. Ethylene glycol was employed as the working fluid. Their findings showed that for $Re > 200$ the helical corrugation significantly induces swirl component. Besides, the results showed that in the turbulent flow the Nusselt number is independent on the corrugation shape. Ahn [2] studied experimentally on heat transfer in the annuli with corrugated inner tubes for water flow rate in $700 < Re < 13{,}000$ regime. Vicente et al. [3] performed an experiment about heat transfer and isothermal pressure drop in corrugated tubes for laminar and transition flow.

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Nomenclature

A	inner tube area, m^2
c	specific heat, J/kg °C
D	tube diameter, m
e	corrugation height, m
D_h	hydraulic diameter, m
f	friction factor
h	heat transfer coefficient, W/m^2 °C
k	thermal conductivity, W/m °C
L	tube length, m
$\dot{m}$	water mass flow rate, kg/s
NTU	number of thermal units
p	corrugation pitch, m
Pr	Prandtl number
Re	Reynolds number
r	shell outlet (inlet) radius, m
T	temperature, °C
Q	heat transfer rate, W
U	overall heat transfer coefficient, W/m^2 °C
V	mean velocity, m/s
W	total uncertainty in the measurement
X	independent variable

Greek symbols

μ	dynamic viscosity, kg/m s
ν	kinematic viscosity, m^2/s
ε	effectiveness
Δp	pressure drop, Pa
ΔT	temperature difference, °C
ρ	density, kg/m^3

Subscripts

ave	average
c	cold fluid
exp	experimental
E	enhanced
h	hot fluid
in	inlet
i	inner
LMTD	logarithmic mean temperature difference
NE	non-enhanced
o	outer
out	outlet
s	smooth

Their findings indicated that the corrugated tubes increase the heat transfer and friction factor about 30% and 25% respectively. Rozzi et al. [4] performed a comparison between smooth and helically corrugated wall tubes in a shell and tube heat exchanger. They observed that in the fully developed turbulent flow regime a moderate overall heat transfer enhancement can be achieved but with a very high pressure loss increase. Laohalertdecha and Wongwises [5] experimentally investigated the effects of corrugation pitch on the condensation heat transfer and pressure drop of R-134 inside horizontal corrugated tube. Their findings demonstrated that the heat transfer coefficient and pressure drop of corrugated tube are higher in comparison with the smooth tube for all experimental conditions. Pethkool et al. [6] studied the turbulent heat transfer enhancement in a heat exchanger using helically corrugated tube. They used the corrugated tube as the inner tube of heat exchanger while the smooth tube was employed for the outer tube of heat exchanger. Their results showed that the Nusselt number and friction factor are 3.01 and 2.14 times above the smooth tube. Laohalertdecha et al. [7] studied the evaporation heat transfer coefficient and two-phase friction factor for R-13a flowing through horizontal corrugated tube. The test section was made of corrugated inner tube and smooth outer tube. They presented some correlations for Nusselt number and friction factor as function of Reynolds number, corrugation pitch, corrugation depth, and inside diameter. Wongcharee and Eiamsa-ard [8] executed an experiment to study the heat transfer enhancement by using CuO–water nanofluid in corrugated inner tube equipped with twisted tape. They showed that, the maximum thermal performance factor of 1.57 is found with the use of nanofluid of 0.7% by volume in the corrugated tube equipped with twisted tape at twist ratio of 2.7 and Reynolds number of 6200. Garcia et al. [9] studied on the influence of artificial roughness shape on heat transfer enhancement: corrugated tubes, dimpled tubes and wire coils. Aroonrat et al. [10] carried out an experimental investigation on evaporation pressure drop and heat transfer of R-134 through a vertical corrugated tube. Lately, Darzi et al. [11] experimentally investigated the convective heat transfer and friction factor of Al_2O_3/water nanofluid in helically corrugated tube. Their findings showed that the heat transfer and friction factor increase by increasing nanofluid concentrations in plain and helical corrugated tube while its effects are more significant in helical corrugated tubes. A summary of the works is reviewed in Table 1.

As described above, most of the works were carried out employing smooth tube as the only inner tube of a double pipe heat exchanger. There is no study on the using of corrugated tubes as the outer tube of a double pipe heat exchanger. So the main scope of the present study is the simultaneous use of corrugated tube as outer and inner tube of a double pipe heat exchanger. Moreover new different arrangements of concave and convex corrugated tubes are investigated. Tests were performed for volume flow rate range 5–25 L/min of the annular space between the two tubes fluid flow (Reynolds number range of 3500–18,000). The inner tube (warm water) volume flow rate was kept at 15 L/min (Reynolds number of 5500). The results of this study are provided as Nusselt number, friction factor, effectiveness, NTU (Number of thermal units) and thermal performance factor of heat exchanger.

2. Experimental configuration

2.1. Experimental apparatus

A schematic illustration and photographic representation of the test set-up are shown in Fig. 1. The system basically includes two closed flow loops (hot water and cold water loops) and a test section. Hot water loop (inner tube) consists of a water pumps, a Rotameter, electrical heater, hot water tank, fan, control valves, and a dimmer (to control the power of electrical heater). Cold water loop (annulus) consists of a water pump, a Rotameter and control valves. The temperature of the cold water loop is controlled by a cooling unit. The cooling unit consists of a compressor, condenser (with R-12 refrigerant), evaporator and an expansion valve. Indeed, the evaporator is inserted in the cold water tank. Besides, incline-U tube manometer and digital thermometers were put into the flow at the inlets and outlets of the test section to measure the bulk temperatures and pressure drop of flow. As seen in Fig. 1 the tubes of the test section were placed between two grooved insulating end-plates. Four screwed steel rods were used to hold and adjust the position of the two end-plates. Inside of the inner tube has been occupied with hot water, while the annular space between the two