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ORIGINAL ARTICLE

Heat transfer enhancement in two-start spirally corrugated tube

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Abstract Various techniques have been tested on heat transfer enhancement to upgrade the involving equipment, mainly in thermal transport devices. These techniques unveiled significant effects when utilized in heat exchangers. One of the most essential techniques used is the passive heat transfer technique. Corrugations represent a passive technique. In addition, it provides effective heat transfer enhancement because it combined the features of extended surfaces, turbulators and artificial roughness. Therefore, A Computational Fluid Dynamics was employed for water flowing at low Reynolds number in spiral corrugated tubes. This article aimed for the determination of the thermal performance of unique smooth corrugation profile. The Performance Evaluation Criteria were calculated for corrugated tubes, and the simulation results of both Nusselt number and friction factor were compared with those of standard plain and corrugated tubes for validation purposes. Results showed the best thermal performance range of 1.8–2.3 for the tube which has the severity of 45.455×10^{-3} for Reynolds number range of 100–700. The heat transfer enhancement range was 21.684%–60.5402% with friction factor increase of 19.2–36.4%. This indicated that this creative corrugation can improve the heat transfer significantly with appreciably increasing friction factor.

1. Introduction

Basically, three approaches are available yet to enhance the rate of heat transfer, active method, passive method and the compound method [1]. A power source is essential for the active, certain surface modifications or extension, and inserts or fluid additives are used in the passive method, while the compound method is a combination of the above two methods such as surface modification with fluid vibration [2].

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Nomenclature

C_p	heat capacity at constant pressure
d	tube inside diameter
E	error
e	corrugation height
f	friction factor
F_s	safety factor
GCI	grid independence index
Gz	Graetz number
h	heat transfer coefficient
k	thermal conductivity
L	tube length
m	slope
Nu	Nusselt number
N	refinement ratio
P	pressure
p	pitch of corrugation
Pr	Prandtl number
PEC	performance evaluation criteria
q''	heat flux per unit area
R	tube inner radius
r	radial direction
Re	Reynolds number
T	temperature
u	fluid velocity
x	axial direction

Greek symbols

φ	severity index
ρ	density of fluid
v	kinematic viscosity of the fluid
μ	dynamic viscosity
θ	angular direction

Subscripts

*	dimensionless
b	bore
B	bulk
c	corrugated
en	envelope
in	inlet
n	nominal
out	outlet
s	smooth
x	local

Superscript

o	order of convergence

The motivation behind this activity is the desire to obtain more effective heat exchangers and other industrial applications [3], with the major objectives being to provide energy, material, and economic savings for the users of heat transfer enhancement technology.

In heat exchangers, corrugation and other surface modifications are commonly used because they are very effective in the heat transfer enhancement, also it is appearing very interesting for practical applications because it is a technique that promotes secondary recirculation flow, by inducing non-axial velocity components [4]. Recently, a swirl or helical flow pattern produced by employing surface modifications or any other passive technique for heat transfer enhancement is very interesting [5]. Also, Spiral corrugation increases heat transfer enhancement due to secondary flow swirls and surface curvatures pass by fluid layers, which also causes pressure losses [6].

There are few studies concerned with spirally corrugated tube. Mimura and Isozaki [7] investigated the effect of corrugations, different corrugation height and depth on friction factor and heat transfer. Withers [8,9] employed the analogy of heat, and momentum to correlate heat transfer and pressure drop expression in tubes, and the enhancement range of 2.5–3 was reported. Ganeshan and Rao [10] studied a single and multiple corrugation start on friction factor and heat transfer characteristics. Rounded corners corrugated ducts studied by Asako and Nakamura [11] to determine the characteristics of pressure drop and heat transfer. Laminar, transitional and turbulent flow in a tube with spiral flute was studied by Garimella et al. [12]. Their outcomes indicated that the most efficient in promoting the secondary flow are the fluted inner tubes. Thermal characteristics of corrugated tubes for different pitch values were studied by Rainieri and Pagliarini [13] which were used to enhance the convective heat transfer. Isothermal friction factor and heat transfer spiral corrugation of two start tubes with two-step tapes were studied by Zimparov [14]. A higher heat transfer coefficient and a friction factor were observed compared to the smooth tubes.

Experimental study of the effects of pitch-to-diameter ratio and rib-height to diameter ratios of tubes with helical corrugations on the rate of heat transfer was achieved by Pethkool et al. [15]. Their outcomes indicated that the corrugated tube's thermal performance is higher than those of the smooth tube. Spirally corrugated tubes were tested by Li et al. [16] numerically for the heat transfer evaluation. The corrugation gives better enhancement, which was concluded from their results depending on corrugation parameters of e/d and p/d.

Both friction factor and Nusselt number were experimentally studied by Saha [17]. His study covered the laminar region by employing circular duct having with a helical screw-tape insert.

Many researchers have investigated corrugated tubes before, and this study has been characterized by many features, the variable thermophysical properties of water one of them, which is the actual case of exchangers and gives results very close to the reality. In addition, a unique smooth corrugation profile was employed, and this kind of corrugation has no matches in the literature and supposes to show good thermal performance with minimum pressure drop which is the ultimate aim of all exchanger designers. Hence, the major objective of the current study was to determine the heat transfer enhancement and pressure drop characteristics of two-start spirally corrugated tube numerically, and also determine the effect of corrugation parameters e/d_n and p/d_n on heat transfer enhancement and pressure drop. This corrugation profile was chosen because it has smooth profile and can be made up at local markets with cheap price.