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Comparative analysis on thermal–hydraulic performance of curved tubes: Different geometrical parameters and working fluids

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ABSTRACT

A comparative 3–D analysis is carried out on the thermal–hydraulic performance of the curved tubes namely helical, spiral, and serpentine with different geometrical parameters. Likewise, the effects of three conventional liquid working fluids namely water, engine–oil, and ethylene–glycol inside the tubes are investigated and compared. The results show that at the same geometrical and operating conditions, the helical tube has the best performance compared to the other ones. For all the curved tubes, the geometrical parameters at the lower values display a better performance in comparison with the higher ones. It is also detected that the working fluids with the higher Prandtl numbers have greater values of Nusselt number. However the effect of Prandtl number on the friction factor is not considerable. Finally, generalized correlations are developed for each curved tube as function of Reynolds number, Prandtl number, and geometrical parameters. It seems that the results of the current work can provide helpful guidelines for designers and manufactures in order to select the optimum curved tube, geometrical parameter, and working fluid for use in the heat exchange devises based on their specific applications in the industries such as refrigeration, automobile, chemical, food, and aerospace.

1. Introduction

It has been frequently reported in literature that replacing a curved tube with the straight one enhances the thermal performance and reduces the size of heat exchange devices [1,2]. Helical, spiral, and serpentine tubes are the recognized types of the curved tubes which have been used in a wide variety of engineering applications, such as refrigeration, air conditioning, power generation, nuclear, process plants, heat recovery, food and petrochemical industries, etc. In fact, generated rotational flows due to the centrifugal forces inside the curved tubes lead to a radial heat transfer in addition to the axial heat transfer. In the other words, the presence of such secondary transport phenomena in the curved tubes significantly improves the heat transfer rate per unit volume compared to the straight ones [3]. Thus, several researchers have studied the flow and heat transfer characteristics of single–phase and two–phase flows inside the single–and–double curved tubes, both experimentally, as well as numerically.

The optimal Reynolds number for the steady, laminar, fully developed forced convection in the helical coiled tube was reported by Ko and Ting [4]. Moawed [5] studied experimentally the forced convection from outside surfaces of the helical coiled tube with different diameter and pitch ratios. The results indicated that these parameters have important effects on the average heat transfer coefficient. The effects of tube and coil diameters on flow boiling heat transfer coefficient inside the helical tube with small diameter (<3 mm) were investigated by Elsayed et al. [6]. Their results shown that decreasing the tube and coil diameter improved the heat transfer coefficient by up to 63% and 150%, respectively. The ability of a domestic water–cooled air–conditioner with the helical heat exchanger was examined by Xiaowen and Lee [7]. The experimental results indicated that the cooling coefficient improved with the inclusion of the heat recovery option by a minimum of 12.3%, and it can be further improved to 20.6% by an increase in the water flow rate. Hydrodynamic and heat transfer characteristics of the helical heat exchanger were studied both experimentally and numerically by Kumar et al. [8]. Bahiraei et al. [9] investigated the potential of improvement of the helical coil based on avoidable and unavoidable exergy destruction concepts. Results depicted considerable potential of thermodynamic optimization of helical coil tube. Jamshidi et al. [10] performed an experimental study on the shell and helical tube heat exchangers. Results indicated that the higher coil diameter, coil pitch, and mass flow rate can enhance

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the heat transfer rate in these types of heat exchangers. Also, Taguchi method was used for finding the optimum condition. A 3–D analysis was conducted to study the heat transfer characteristics of the double–tube helical heat exchangers using nanofluids (CuO–water and TiO_2–water) under the laminar flow conditions [11]. The results shown that for the CuO–water nanofluid at 2%, the heat transfer rate was approximately 14% greater than of the base fluid. Also, a CFD study was carried out on the heat transfer and pressure drop characteristics of the turbulent flow of Al_2O_3–water nanofluid inside the double–tube helical heat exchangers [12]. The results showed a different behavior depending on the parameter selected in comparison with the base fluid.

The review of literature shows that although numerous studies have been conducted on the characteristics of the helical tubes, studies on the spiral and serpentine tubes are limited. This issue was previously mentioned by Naphon and Wongwises [1]. The thermal–hydraulic characteristics of the spiral tube were investigated experimentally and numerically by Naphon [13] and Naphon and Suwagrai [14]. Nusselt number and pressure drop per unit length obtained from the spiral tube were reported about 1.50

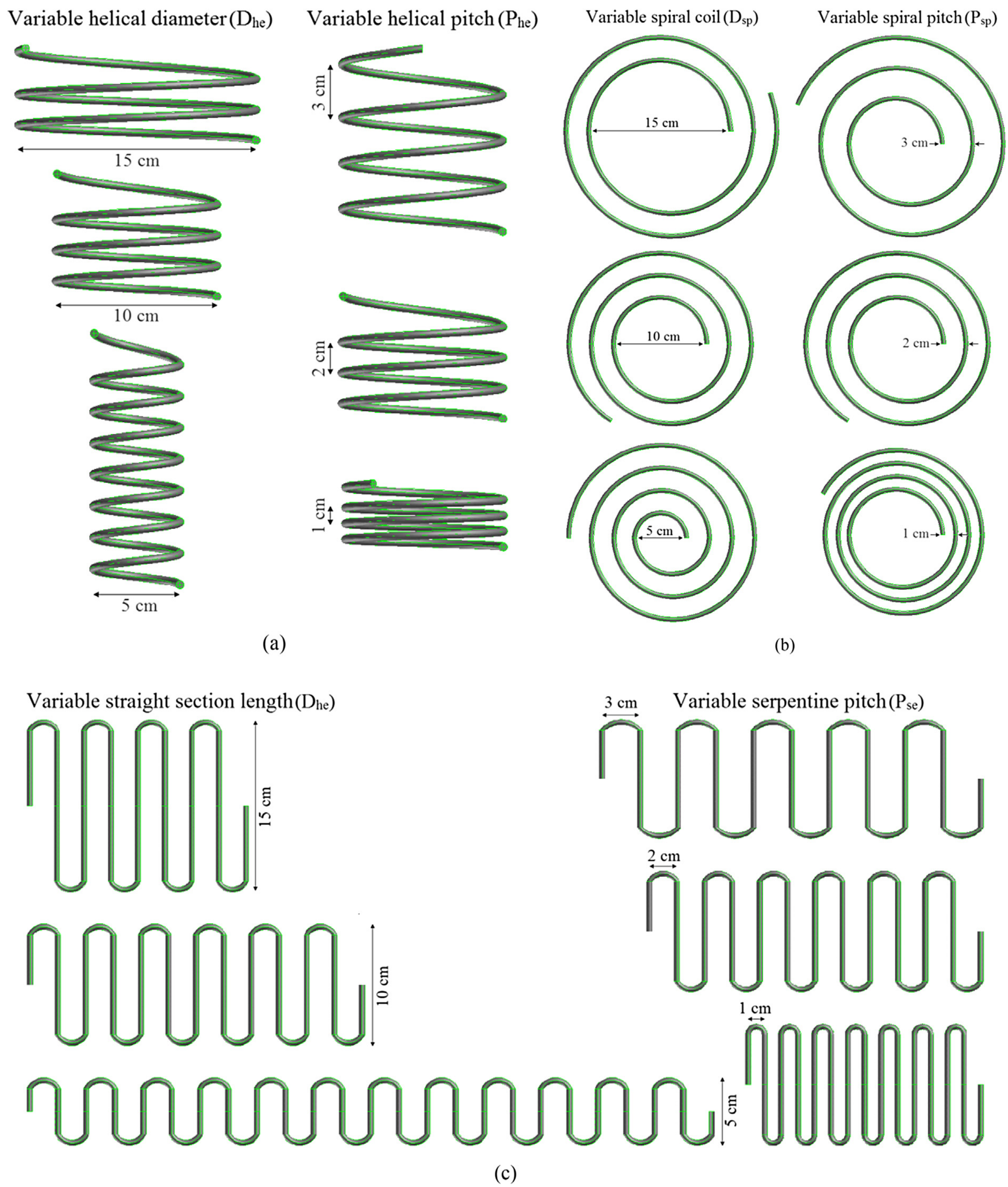

Fig. 1. Considered physical models (a) helical tubes (b) spiral tubes (c) serpentine tubes.