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Numerical investigation of three methods for improving heat transfer in counter-flow heat exchangers

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ABSTRACT

The present study investigates the thermal performance and fluid characteristics of counter flow heat exchangers (CFHEs) computationally. Increasing heat transfer rate in heat exchangers depends on various parameters such as channel geometry, the geometry of obstacles in the channel, frequency and amplitude of corrugated plate, and other factors. In this simulation, the influence of parameters contains the effects of the geometry of the obstacles, the corrugated plate between the channels, the elastic plate between the channels, the frequency and wavelength of the corrugated plate, and its effect on increasing the heat exchanger efficiency have been studied in detail. The numerical method is the finite element method, and a complete set of Navier-Stokes equations are solved unilaterally using the Petrof-Galerkin method. It has been concluded that all methods will improve the performance of the CFHEs. Among the obstacles placed in the channels, the rectangular and edge obstacles show better results. In the case of a corrugated mid-plate, with increasing the wave in mid-plate between channels, heat transfer rate (HTR) increases to a certain amount. It was observed that the elasticity of the mid-plate between two channels and the sinusoidal pulse flow would improve HTR in CFHEs.

1. Introduction

Currently, heat exchangers have a wide range of industry applications. They are widely used in space heating, refrigeration, power plants, petrochemical plants, petroleum refineries and sewage treatment [1]. There are many types of heat exchanger designs for various applications. The major types of heat exchanger include double pipe, shell-tube, plate and shell, plate fin, and phase change heat exchangers. The flow in a heat exchanger can be arranged as parallel flow, counter flow, and cross flow. Plate heat exchanger (PHE) has been widely used in the fields of energy transport due to its favorable characteristics, such as high heat transfer coefficient, easy maintenance, compact size and convenience to increase the heat transfer area, etc. In-depth research on PHEs is required to widen its range of application [2]. Increase heat transfer in industrial processes to reduce the size, increase thermodynamic efficiency or reducing the pumping power is of paramount importance. So that the different methods used to increase the HTR. This purpose, usually conducted by increasing the heat transfer or heat exchange area per unit volume or both met.

Vera and Linan [3] analyzed multilayered, counter-flow, parallel-plate heat exchangers numerically and theoretically.

They developed a two-dimensional model to find analytical expressions and their approximations for the fully developed laminar counter-flow in long parallel-plate heat exchangers. Zhan et al. [4] used an experimentally validated model to understand the influence of operational and geometrical parameters of the cross-flow and counter-flow exchangers on the different metrics of cooling performance. Overall the counter-flow exchanger demonstrated the better cooling effectiveness and higher cooling capacity than the cross-flow system. However, the energy efficiency of the counter-flow system is often seen to be lower than that of the more conventional cross-flow dew point system. The shape of the cross-section of the heat exchanger also has a significant effect on efficiency. Hasan et al. [5] studied the effect of channel geometry on the performance of a counter-flow MCHE (main cryogenic heat exchanger). The influences of channel shapes such as circular, square, rectangular, triangular, and trapezoidal were evaluated by numerical simulations. In their studies, decreasing the volume of each channel or increasing the number of channels increased the heat transfer, but the required pumping power and pressure drop were also increased. The channel with a circular shape resulted in the best overall performance. Yilmaz et al. [6] studied microchannel heat exchangers with ducts of arbitrary cross-sections to find the optimum shape hydraulic diameter and the maximum heat transfer. They found that the maximum dimensionless heat and the optimum dimensionless hydraulic diameter strongly depend on the duct shape factor for a given pressure drop and the Prandtl number. Mushtaq et al. [7] numerically

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Nomenclature

CFHEs	Counter flow heat exchangers
A	Surface area … m^2
C_p	Specific heat … $J/(kgK)$
Re	Reynolds number
D_h	Hydraulic diameter … m
K	Thermal conductivity … W/m.K
T	Temperature … K
L	Channel length … m
h	Convection heat transfer coefficient … $W/m^2 K$
Nu	Nusselt number
P	Pressure … pa
u	Fluid x-component velocity … m/s
v	Fluid y-component velocity … m/s
w	Fluid z-component velocity … m/s
V	Flow velocity … m/s
t	Time … s
HTR	Heat transfer rate
ΔP	Pressure drop across heat exchanger … pa
f	Friction factor

Greek Symbols

μ	Fluid dynamic viscosity … Pa.s
ρ	Fluid density … Kg/m^3
η	Performance factor

Subscripts

c	Cold fluid
f	Fluid
h	Hot fluid
in	Inlet
out	Outlet
s	Solid

investigated the hydrodynamics and heat transfer in a counter flow microchannel heat exchanger (CFMCHE). A 3-D developing flow and 3-D conjugate heat transfer were solved using CFD software FLUENT 6.3. They showed that the effect of the shape of the channels on heat transfer and pressure drop for different channel cross-sections such as circular, square, rectangular, ISO-triangular and trapezoidal. The circular channels give the best overall performance (thermal and hydraulic) among various channel shapes. Increasing the value of Reynolds number lead to decrease the effectiveness and increase the pressure drop and as a result, the performance decreased. Collins et al. [8] investigated the flow and heat transfer in corrugated passages. An experimental and numerical study of flow and heat transfer was conducted for a crossed-corrugated geometry. The effects of corrugation angle, geometry, and Reynolds number were investigated.

Among the passive methods to increase the effectiveness of heat exchangers, methods based on deformation of the duct walls of the broad welcome. Numerous empirical studies and numerical analysis and in particular for fluid flow in channels with waveform (ripple) walls have been made. Ismail et al. [9] have had a comprehensive review of studies conducted in this area. Based on these studies, wave-shaped walls, strengthened the transverse flow in a channel and in this way, help the displacement of more heat. Also, the pressure drop in the corrugated channels is more than channels with smooth walls. Besides, it is possible that the heat transfer rate is also reduced at the specific locations locally. However, it seems that by optimizing the shape of the wall, the average rate of convection will increase and will be maintained the pressure drop at an acceptable level. Channel-specific shapes, such as wavy channels, leading to mixing flow and separation of the boundary layer and creating the secondary flow in the channel. Since the wavy surfaces of the walls did not create the amputation in the Channels, resulting in reduced particle deposition on the channel. The waveform in the flow direction, disrupt the flow and causing the flow becomes complex. Sui et al. [10] studied HTR in the three-dimensional rectangular sinusoidal channel in the laminar flow regime. And it was observed that the Nusselt number increases compare to increase the friction coefficient is remarkable.

Typically, the conventional corrugated primary surface has a sinusoidal cross-section curve. In order to improve the aero-thermal performance, various studies on the modification of the corrugation profile have been conducted. Zhang and Che [11] studied the effect of corrugation profiles, such as anisosceles triangle, trapezoidal, rectangular and elliptic corrugations, on the aero-thermal performance of the heat exchanger. Focke [12] carried out a study on the "asymmetrically corrugated" plate type heat exchanger, which have channels of different cross-sectional flow area. It was found that these asymmetric profiles have a lower heat transfer rates compared to the conventional sinusoidal symmetric surfaces. Tauscher and Mayinger [13] carried out numerical and experimental studies on heat transfer enhancement in plate heat exchangers with rib-roughened surfaces, which are also wavy configurations. They tested for various configurations of the ribs: shape, width, height, groove angle, spacing, angle, and arrangement patterns. They found out that the ribs show their best effects in regions where they can induce turbulence. They generalized that turbulence promoters (ribs in this case) show the best performance in the transition region from laminar to turbulent flow. Elshafei et al. [14] presented heat transfer and pressure drop results in corrugated channels. They discussed the effect of channel spacing and phase shift of the corrugations on the heat transfer and the pressure drop. They showed that

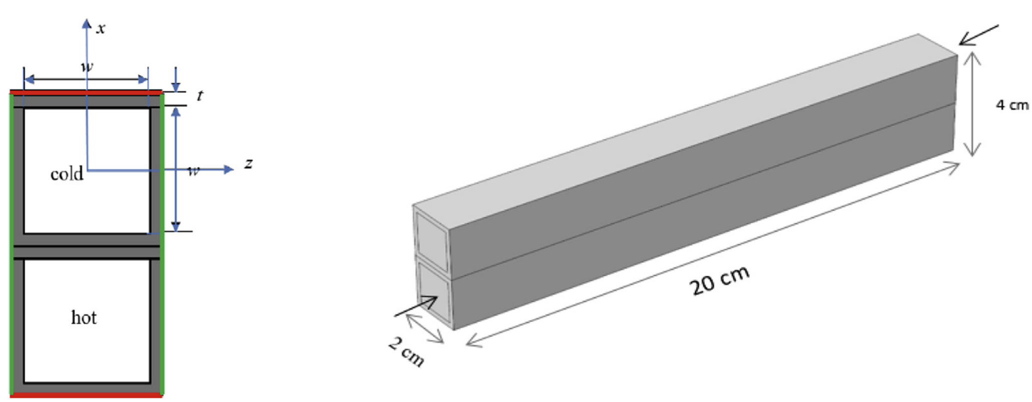

Fig. 1. Designed prototype model.