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Effects of smooth longitudinal passages and port configuration on the flow and thermal fields in a plate heat exchanger

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ABSTRACT

Numerical results for heat transfer with laminar or turbulent flow in a two-channel PHE are presented. The temperature, heat flux and mass flow distributions are analyzed in the case of two fluid combinations: water/water and water/engine oil. These results show that, in the case of water/engine oil, both the thermal field and the mass flow distribution are more uniform compared to the water/water case. A comparison between the original geometry and the geometry with obstructed longitudinal channels shows that the presence of these passages decreases the heat transfer rate and the friction factor. The calculated performances of the side-flow and diagonal-flow configurations differ only slightly.

1. Introduction

Plate heat exchangers (PHE) are widely used in many applications (food, oil, chemical and paper industries, HVAC, heat recovery, refrigeration, etc.) because of their small size and weight, the ease of cleaning as well as their superior thermal performance compared to other types of heat exchangers. Due to the corrugations, which induce secondary flows, boundary layer separation and turbulence at relatively low Re numbers, they are well suited to low Reynolds number flows encountered when using viscous liquids such as engine oil [1,2]. For a detailed synthesis of the applications of the PHEs see for example [3]. Several experimental and numerical studies have therefore been recently conducted in order to predict the flow and temperature distribution in PHEs. Many of the latter use simplifying assumptions.

Lozano et al. [4] analyzed the flow distribution inside one channel of a PHE for the automotive industry, without considering the heat transfer. They created and validated a 3D model which consists of a single channel. Their analysis concluded that the flow was not uniform and preferentially moved along the lateral extremes of the plates. Kanaris et al. [5] studied the flow and heat transfer in a PHE. They used a 3D model which includes two complete channels and validated it against experimental and literature data. A similar model was used by Tsai et al. [6] in order to investigate the hydrodynamic characteristics and distribution of flow inside a PHE with no heat transfer involved. Their CFD models use the real geometry of the plates, including the entire entrance and distribution zones.

Jain et al. [7] considered a 3D turbulent model with a complete cold channel and two halves of the adjacent hot channels. This model uses more realistic hydrodynamic and thermal boundary conditions; the two halves of the hot channels on either side have flat periodic boundaries. As a result, they were able to validate their model on a PHE with 13 channels. Hur et al. [8] created a similar model in order to study the heat transfer in a PHE. Although the chevron angle is the same with the one in the present study ($\varphi = 60\,^{\circ}$) and the Reynolds number varied between 249 and 1018, they used only the laminar model for all the simulations.

Galeazzo et al. [9] have modeled in three dimensions an industrial PHE with four channels. However, this PHE was a non-chevron type with five smooth plates. The authors have investigated parallel and series flow arrangements and validated it with experimental data. In their experimental work Okada et al. [10] analyzed the temperature distribution on the first and last plates of a two-channels PHE of non-chevron type. They

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Nomenclature

dA	elementary surface, m^2
C_1,C_2	constants
C_p	specific heat, J kg^{-1} K^{-1}
D_H	channel hydraulic diameter, m
f	Darcy friction factor,$f = 2\ \Delta P\ D_H/(\rho_m\ L\ u_m^2)$
g	gravitational acceleration, m s^{-2}
G_κ,G_b	rates of turbulence kinetic energy generation due to mean velocity gradients and to buoyancy respectively, J m^{-3}
h_m	average heat transfer coefficient, W m^{-2} K^{-1}
k, k_t	thermal conductivity, turbulent thermal conductivity, W m^{-1} K^{-1}
L	length of the channel, m
Nu	Nusselt number, $Nu = h_m\ D_H/k_m$
p	pressure, Pa
Re	channel flow Reynolds number, $Re = u_m\ D_H\ \rho_m/\mu_m$
S_κ, S_ε	user-defined source terms
T	temperature, K
T_m	average temperature in a channel, K
u_i, $\overline{u}_i$	i-axis velocity component and time-averaged value, m s^{-1}
u_m	mean velocity of the fluid in a channel, m s^{-1}
x_i	i-axis
X, Y, Z	coordinates
Y_M	contribution of the fluctuating dilatation to the dissipation rate (for compressible flows)
Greek letters	
ΔP	pressure loss between inlet and outlet of a channel, Pa
ε	turbulence kinetic energy dissipation rate, J kg^{-1}
κ	turbulence kinetic energy, J kg^{-1} s^{-1}
υ, υ_t	kinematic viscosity, turbulent kinematic viscosity, m^2 s^{-1}
μ, μ_t	dynamic viscosity, turbulent dynamic viscosity, Pa s
ρ	density, kg m^{-3}
σ_κ,σ_ε	constants
Subscripts	
b	refers to bulk temperature
m	refers to the average value in the channel, with properties evaluated at T_m

compared the temperature distributions for diagonal and side-flow channels, and also for upwards and downwards flow of the cold and hot fluids. To our knowledge, this is the only article with such results.

Han et al. [11] in their numerical and experimental study, described the temperature and pressure distribution on a chevron corrugated PHE with five plates (four channels). By analyzing the temperature distribution and the streamlines, the authors noticed that the flow prefers to flow to the port side. They validated the numerical results, finding similar experimental and numerical results in terms of outlet temperatures and pressure drops.

In our previous experimental [12] and numerical [13,14] articles the hydrodynamic and thermal fields in a two-channel chevron PHE were analyzed for water flow in both channels. The CFD model was satisfactorily validated for both laminar – using the laminar model – and turbulent conditions [13] – using two-equation turbulent models – by comparing the numerical and experimental temperature distributions on the PHE's exterior plates, the friction factor and the Nusselt number for each channel, as well as

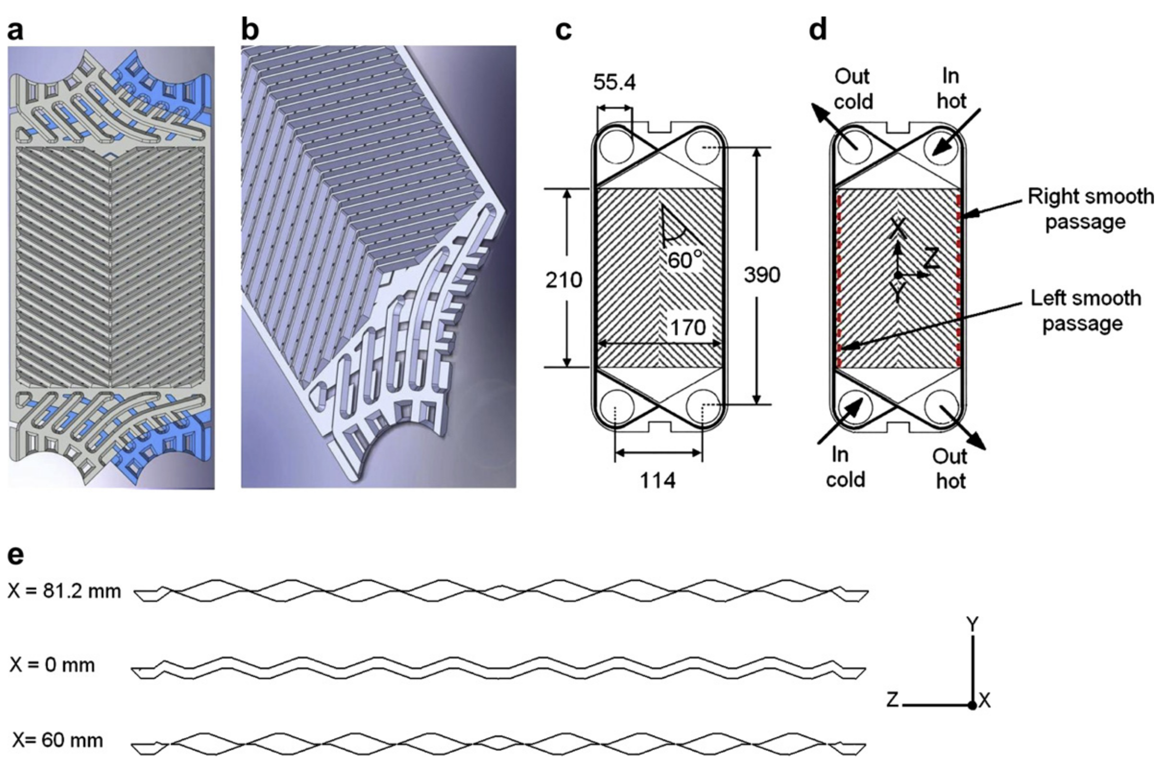

Fig. 1. (a) View of the model with 2 channels; (b) a detail of the fluid volume; (c) main dimensions in mm; (d) the coordinate system with positions of inlets and outlets; (e) Cross-sections of the channel at three positions.