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Effects of blockage ratio and pitch ratio on thermal performance in a square channel with 30° double V-baffles

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ABSTRACT

This article presents flow configurations and heat transfer characteristics in an isothermal square channel with 30° double V-baffles. The influences of blockage ratios (b/H, $BR=0.05$–0.25) and pitch ratios (L/H, $PR=1$–2) for Reynold numbers, $Re=100$–1200 are investigated numerically. The 30° double V-baffles are placed on both two opposite walls of the square channel with in-line arrangement and each V-tip pointing downstream. The numerical results are presented in four parts; accuracy validations, flow structures, heat transfer behaviors and performance evaluations. It is found that the use of the double V-baffles performs higher heat transfer rate and pressure loss than the smooth channel with no baffle. The rise of the blockage ratio and reducing the pitch ratio lead to the increase in heat transfer rate and pressure loss. The optimum thermal enhancement factor is found to be about 3.2 at $PR=1$, $BR=0.10$ and $Re=1200$.

1. Introduction

The investigations of performance improvements in heat exchangers have been extensively reported by many researchers. The studies can be divided into two methods; a numerical method and an experimental method. Due to the limitations of the experimental investigation and also the high cost of materials, the investigations by using the numerical method have been widely used for study flow visualizations and heat transfer characteristics in the heat exchanger system. For examples, Promvonge and Kwankaomeng [1] numerical investigated the influences of 45° staggered V-baffles in a rectangular channel on flow configurations and heat transfer characteristics of the laminar regime at $Re=100$–1200. They reported that the use of V-baffle can induce a pair of vortex flows called "P-Vortex" that helps to increase in heat transfer rates and thermal performance in the heating system. They also concluded that the thermal enhancement factors are around 2.6 and 2.7 for the V-upstream and V-downstream, respectively. Kwankaomeng and Promvonge [2] studied the thermal performance improvement in a square channel with 30° inclined baffle on one wall by using the numerical method. They found that the maximum Nusselt number ratio and thermal enhancement factor over the range studied are found to be about 7.9 and 3.1, respectively, for $BR=0.3$ and $PR=1.5$ at the highest Reynolds number, $Re=2000$. Promvonge et al. [3] numerical studied the 30° inclined baffles placed on both the upper and lower walls of the square channel. They claim that the inclined baffles generate counter-rotating vortex flows over the test channel for all cases and the maximum thermal

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Nomenclature

BR	flow blockage ratio, (b/H)
b	baffle height, m
D	hydraulic diameter of square channel, m
f	friction factor
h	convective heat transfer coefficient, $\text{W m}^{-2}\,\text{K}^{-1}$
k	thermal conductivity, $\text{W m}^{-1}\,\text{K}^{-1}$
L	cyclic length of one cell (or axial pitch length, H), m
Nu	Nusselt number $(=hD/k)$
p	static pressure, Pa
Pr	Prandtl number (Pr=0.707)
PR	pitch or spacing ratio, L/H
Re	Reynolds number $(=\rho UD/\mu)$
T	temperature, K
u_i	velocity in x_i-direction, m s^{-1}
U	mean velocity in channel, m s^{-1}

Greek letter

μ	dynamic viscosity, $\text{kg s}^{-1}\,\text{m}^{-1}$
Γ	thermal diffusivity
α	baffle inclination angle or angle of attack, degree
TEF	thermal enhancement factor $(=(Nu/Nu_0)/(f/f_0)^{1/3})$
ρ	density, kg m^{-3}

Subscript

0	smooth channel
in	inlet
pp	pumping power
w	wall

performance is around 4. Promvonge et al. [4] presented that the use of 45° inclined baffles on one wall performs higher heat transfer rate and thermal performance with less pressure loss than the 90° baffle. Sripattanapipat and Promvonge [5] studied the influences of diamond-shaped baffles on heat transfer and pressure loss for laminar regime, Re=100–600. They summarized that the diamond baffles with the flow attack angles of 5–10° give better thermal performance than the flat baffle for all Reynolds number values. Lei et al. [6] presented the influences of helical baffles in a heat exchanger with various configurations. They found that the two-layer helical baffles perform better thermal performance than the single-helical baffle. Ary et al. [7] studied on both numerical and experimental methods for inclined perforated baffles on flow structures and heat transfers in a rectangular channel. They reported that the two baffles perform the best thermal performance in comparison with other cases. Lei et al. [8] numerical investigated the influences of the flow attack angles for inclined baffles in a heat exchanger channel. They reported that the rise of the flow attack angle leads to the increase in heat transfer rate when $\alpha < 30°$. Yongsiri et al. [9] studied the effects of inclined detached-ribs in a channel on flow structure and heat transfer at turbulent regimes, Re=4000–24,000, with numerical method. They found that the effect of flow attack angle is insignificant at the low Reynolds number. Muthusamy et al. [10] investigated the effects of the conical cut-out turbulators (convergent mode and divergent mode) in a circular tube on heat transfer, friction loss and thermal performance. They concluded that the divergent-mode turbulators at PR=3 perform the maximum heat transfer rate around 315%. Kongkaitpaiboon et al. [11] presented the heat transfer and flow structure in a heat exchanger tube with circular-ring turbulators. They found that the heat transfer is around 57–195% for using the circular-ring turbulators. Bopche and Tandale [12] experimental investigated the influences of the U-shaped turbulators in a solar air heater channel for Re=3800–18000. They reported that the enhancements are around 2.82 and 3.72 times higher than the smooth channel for heat transfer and friction loss, respectively. The literature reviews for turbulators in heat exchanger channels were reported by Alam et al. [13,14].

According to literature reviews above, the use of inclined baffle, diamond-shaped baffle, helical baffle and V-baffle can help to improve the thermal performance and heat transfer rate in heating channels. It is found that the V-shaped baffle performs the best thermal performance in comparison with the other shapes, especially, V-tip pointing downstream. In this present work, the double V-shaped baffles are installed in the square channel on both the upper and lower walls with in-line arrangement and each V-tip pointing downstream. The use of double V-shaped baffles is a main aim to generate vortex flows, impinging jet flow and also help to better heat transfer distributions over the test channel.

2. Flow descriptions

2.1. Double V-baffle geometry and arrangement

The channel configuration and computational domain for the double V-baffles which placed on both the upper and lower walls in a square channel are displayed in Fig. 1. The 30° double V-baffles are arranged with in-line and V-tip pointing downstream. The fully-developed periodic; velocity field and thermal profile repeat itself from one module to another, apply to the numerical domain [15]. The influences of blockage ratios (b/H, BR=0.05–0.25) and pitch ratios (L/H, PR=1–2) are investigated. Due to this investigation aims to study preliminary results to improve heat transfer and performance, which using the double V-shaped baffles, therefore, the laminar regime (Re=100–1200) are used in the computational domain.