CHEMICAL ENGINEERING TRANSACTIONS

VOL. 57, 2017

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Sauro Pierucci, Jiří Jaromír Klemeš, Laura Piazza, Serafim Bakalis

ISBN 978-88-95608- 48-8; **ISSN** 2283-9216

DOI: 10.3303/CET1757208

Numerical Study on Heat Transfer Enhancement in a Rectangular Duct with Incline Shaped Baffles

Parkpoom Sriromreun[*a], Paranee Sriromreun[b]

[a] Department of Mechanical Engineering, Faculty of Engineering, Srinakharinwirot University, NakhonNayok 26120, Thailand
[b] Department of Chemical Engineering, Faculty of Engineering, Srinakharinwirot University, NakhonNayok 26120, Thailand
prakpum@g.swu.ac.th

This research is aimed to study on heat transfer enhancement in a heat exchanger by installing inclined shape baffles to create co-rotating vortex flow using the Computational Fluid Dynamics (CFD) method with the k-ε and RNG models. According to the FLUENT program, air is used as the test fluid which consists of the rectangular duct with a height (H) of 30 mm, and the Reynolds number (Re) in a range of 12,000 to 35,000. It is important to study the Nusselt number, Nu and the friction factor, f in order to earn the result from their relation analysed for the Thermal performance Enhancement Factor (TEF). As a results, the experiment of CFD showed a smooth duct and shaped baffles duct (with baffle-to channel-height ratios (e/H) at 0.1, 0.2 and 0.3 and the angle of attack (α) 30°, 45° and 60°) comparing with another research (Benjapol; et al. 2014). It is found that Nu and f are related in a range of -10% to +10%. While the velocity vector and temperature contours indicated that the increasing of α and the baffles height can increase co-rotating vortex flow in spite of decreasing TEF. The optimum α is 45° with e/H 0.3 which represents the highest TEF at 1.74.
Keyword: CFD, Heat exchanger, *k-ε* model, Inclined baffle

1. Introduction

The development of Heat transfer is an essential kind in many industries because there have been highly competitive both the production and creation. It is believed that the thermal enhancement technology is important to apply in many engineering systems such as a dryer, heat exchanger, refrigeration, automobile manufacturing. The technique for heat transfer augmentation is widely used in the industrial heat exchanger by installing the tabulators, rib/baffles, fins in order to create co-rotating vortex for increasing convective coefficient and leading to higher Thermal performance Enhancement Factor (TEF) [Gentry and Jacob, 2002].
This study is aimed to investigate the characteristics of heat transfer in various baffle shaped. For example, Karwa [2003] studied on the effect of rectangular ducts with transverse baffles, inclined baffles, 60° V-continuous and 60° V-discrete patterns. According to the friction, it reported that the V-continuous and the V-discrete provided the maximum and minimum of friction factor for of all patterns in their work. Tanda [2004] found that the V-continuous ribs provided better TEF than the V-discrete ribs. Lau et al. [1991] and Promvonge [2010] investigated on the channel with 60° V-baffles influenced on TEF, Lau et al found that the range of pitch to baffles height ratios (P/e) = 0.1 provided the highest TEF. While Promvonge investigated the ration between baffles and height (e/H) = 0.1, 0.2, 0.3 and P/H = 1, 2 and 3 which found that the maximum heat will be e/H = 0.1 and P/H = 1provided the highest TEF. Jin et al. [2015] created the numerical method in heat transfer on the different angles. As a result, it reported that 45° provided the highest TEF. Moreover, there are several research investigated about arrangement of baffles such as Layek et al. [2007] investigated on heat transfer of duct with baffle related to roughness pitch and height of baffles or P/e between 4.5 and 10. It is reported that P/e of 6 provided the highest TEF. Skullong et al. [2014] studied on the triangular wavy ribs which are placed on upper wall at (P/H) 0.5, 1 and 2. It is found that the ribbed-grooved upper wall at P/H = 0.5 yields the highest thermal performance. Jedsadaratanachai et al. [2009] studied the heat transfer on a square duct with 10, 20, 30 double V-Ribbed strip inserts which found that 10 Double V-Ribbed provided highest TEF. Kanoknaikarn et al. [2009] studied on effect of Rib-inclined angle of 30°, 45°, 60° and 90° on

Heat Transfer in a Wavy Ribbed having P/H = 3 and e/H = 0.3. It is reported that wavy ribbed provided better TEF than the 90^{o} ribbed, Wavy Ribbed with 30^{o} provided highest TEF. Hoonpong et al. [2013] studied about friction factor and performance enhancement in a square duct heat exchanger with 60^{o} and 90^{o} baffles inserts with e/H = 0.2, 0.3 and P/H = 1.5 which TEF showed the higher value friction factor despite the high pressure. Sriromreun (2012) studied on experimental and numerical heat transfer enhancement of baffles with 45^{o} Z-shaped baffles at e/H = 0.1, 0.2, 0.3 and P/H = 1.5, 2, 3. It is reported that e/H = 0.1, P/H = 1.5 provided the highest TEF.

According to the past literature, they have been studied on heat exchanger with different baffles arrangement; however, in this study will develop the baffles to increase enhancing rate. The advantage of this pattern can be complement and installation all the arrangement to the heat exchanger.

In this research brought the experimental to investigate numerically the characteristics and effect of heat transfer using the ANSYS FLUENT to show velocity vector and temperature contours the air. The Nusselt number (*Nu*) and the friction factor (*f*) were determined to find the relation of *Nu* with *f* values and develop arrangement of baffles to increase the thermal performance.

2. Computational Models and Numerical Method

Based on the above assumptions, the air flow in channel is steady state and incompressible fluid governed by the continuity, the Navier–Stokes equations with k-ε, RNG and the energy equations will be discretized by the Quadratic upstream interpolation for convective kinetics differencing scheme (QUICK) for convective and diffusion term, respectively. These equations can be written as follows:

The channel model were analyzed by Continuity equation, Momentum equation, Energy equation in the Cartesian tensor these equations can be written as follows:

Continuity equation:

$$\frac{\partial}{\partial x_i}(\rho u_i) = 0 \tag{1}$$

Momentum equation:

$$\frac{\partial(\rho u_i u_j)}{\partial x_i} = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} - \rho\overline{u_i' u_j'}\right)\right] \tag{2}$$

Energy equation:

$$\frac{\partial}{\partial x_i}(\rho u_i T) = \frac{\partial}{\partial x_j}\left((\Gamma + \Gamma_t)\frac{\partial T}{\partial x_j}\right) \tag{3}$$

Where ρ is the density of air, x is the length of test section, u is the velocity of air, P and T is the pressure and the temperature of air, respectively.

Where Γ and Γ_t are molecular thermal diffusivity and turbulent thermal diffusivity, respectively and are given by

$$\Gamma = \frac{\mu}{\Pr} \text{ and } \Gamma_t = \frac{\mu_t}{Pr_t} \tag{4}$$

Where μ and μ_t is the viscosity and the turbulent viscosity of air, Pr and Pr_t is the prandtl number and the turbulent prandtl number of air.

All the governing equations (1), (2), (3) were discretized by the QUICK numerical scheme, decoupling with the Semi-implicit method for pressure-linked equations (SIMPLE) algorithm (Suluksna, 2009) and solved using a finite volume approach. The solutions were converged when the normalized residual values were less than 10^{-4} for all variables.

There are three parameters of interest in the present work, 1) friction factor 2) Nusselt number and 3) Thermal performance enhancement factor (TEF), The friction factor, f is computed by pressure drop, Δp across the length of the periodic channel, p as

$$\Delta p = f\,\frac{\rho L \bar{v}^2}{2D} \tag{5}$$

The Nusselt number which can be written as

$$Nu_D = \frac{hD}{k} \tag{6}$$

Where h and k is heat transfer coefficient and the thermal conductivity of air, respectively.
The thermal performance enhancement factor (TEF) is defined as

$$TEF = \left(\frac{Nu_b}{Nu_0}\right)\left(\frac{f_b}{f_0}\right)^{-1/3} \tag{7}$$

Where Nu_b and f_b stand for Nusselt number and friction factor for the Baffles channel, respectively. Nu_o and f_o stand for Nusselt number and friction factor for the smooth channel, respectively.

3. Simulation of flow configuration

The flow system is a horizontal rectangular duct with incline shaped baffles repeatedly placed on lower wall has width (W) 300 mm. The duct is divided into 3 sections: entry (450 mm), test section (0.38 m) with constant heat flux (12.5 kW/m^2) on lower wall, and exit (80mm). The duct height (H) 30 mm, the detail of the full length baffle channel is shown in Figure 1a whereas a module of the computational domain due to periodical flow along the incline shaped baffles is displayed in Figure 1b. For the advantages of the computation domain, the number of mesh and calculating time can be reduced 10 times from the duct geometry. The baffles have angle of attack (α) 30^o, 45^o and 60^o respectively at baffle-to channel-height ratios (e/H) 0.1, 0.2 and 0.3.

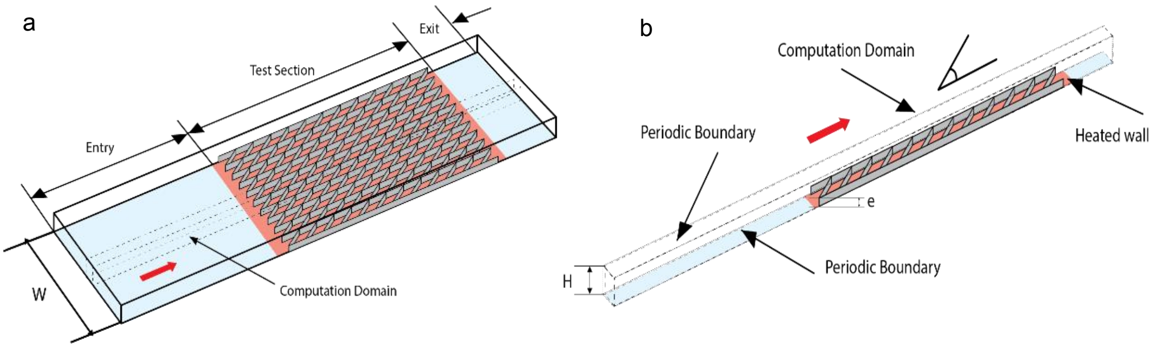

Figure 1: a) Duct geometry, b) Computational domain of flow.

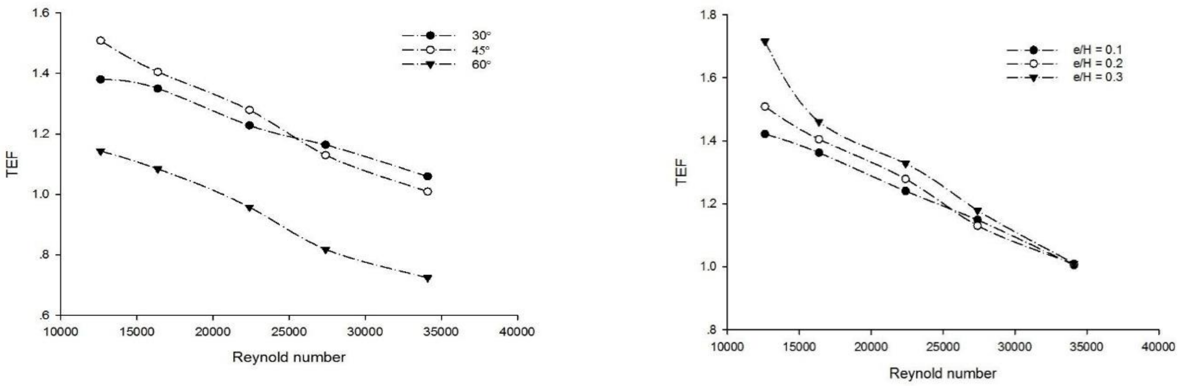

Figure 2: a) Variation of TEF with Re at 0.2, b) Variation of TEF with Re at = 45^o.

4. Experimental results and discussion

The experimental result with $e/H = 0.2$ for all angles of attack shown in Figure 2 reported that $\alpha = 45^o$ provided the highest Nu_b/Nu_o, this is because the angle of attack can effect on the number of baffles, then $\alpha = 45^o$ where has the optimum number of baffles effect on increase Nu_b value with medium f_b value then the relation of Nu_b with f_b. Values are provided the highest TEF shown in Figure. 2 a). To discussion experimental effect of baffles at same angle of attack (45^{o}) for all e/H is presented in Figure2 b). It is found that higher e/H causes to increase, at 0.3 provided the highest TEF and *e/H* = 0.2 and 0.1.

The Reynold number (Re) is defined as

$$Re = \frac{uD}{v} \quad (8)$$

Where υ is the kinematic viscosity of air and *D* is the hydraulics diameter of test section.

5. The results from simulation

5.1 Verify the accuracy of the simulation

Comparison the results from simulation with experimental [Kangvantham et al., 2014] in the same conditions that and are in range of ±10%.

5.2 Effect of Reynold number (Re)

The velocity vector and temperature contours of rectangular duct with $\alpha = 45^{o}$ at *e/H* = 0.2 are presented in Figure 3, it is apparent that increase Re cause to tempestuous velocity vectors and gives higher heat transfer enhancement. At Re 34,100 temperature contours showed spread of color temperature throughout rectangular duct however the Thermal performance Enhancement Factor (TEF) tends to decrease with decreasing of Nu_b/Nu_o , constant f_b/f_o and increase of Re.

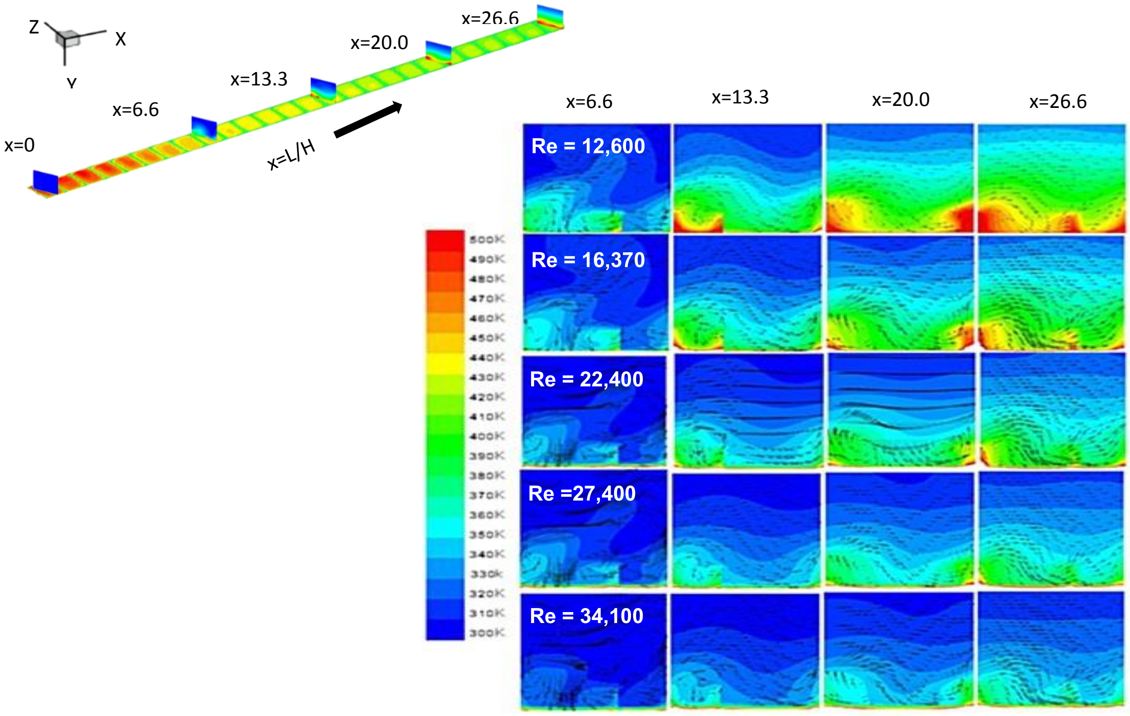

Figure 3: Effect of Reynold number (Re) with velocity vectors and temperature contours in $\alpha = 45^{o}$ at e/H = 0.2

5.3 Effect of baffle-to channel-height ratios (e/H)

Figure 4 showed characteristic of flow and heat transfer in the form of velocity vectors and temperature contours for rectangular duct with inclined shape baffles, $\alpha = 30^{o}$, $45^{o}$and 60^{o} at *e/H* = 0.1, 0.2 and 0.3. At Re = 12,600, x = L/H = 26.67 consider velocity vectors *e/H* = 0.3 is more co-rotating vortex flows than *e/H* = 0.1 and 0.2, respectively cause height of baffles effect on air flow through rectangular duct will attack baffles easily, create tempestuous of flow that effect on the cool air on top wall can attack baffles easily, create tempestuous of flow that effect on the cool air on top wall can attack heat plat at the bottom wall to get higher heat transfer. Consider temperature contours found that the lower temperature displayed on dark blue colour of *e/H* = 0.3 is less than *e/H* = 0.2 and 0.1, respectively so *e/H* = 0.3 gives the highest heat transfer.

5.4 *Effect of* angle of attack (*α*)

Figure 4, the co-rotating vortex flows tends to increase with increasing of α. Although α = 60^o provides the highest co-rotating vortex flows, air flows on top wall do not attack heat plate on bottom wall as well. Consider velocity vectors and temperature contours found that α = 45^o, air flows bounce around heat plate on bottom wall and showed temperature are range of 440 K to 500 K that displayed on yellow colour to red colour. α = 45^o provides the highest heat transfer than α = 60^o and 30^o, respectively.

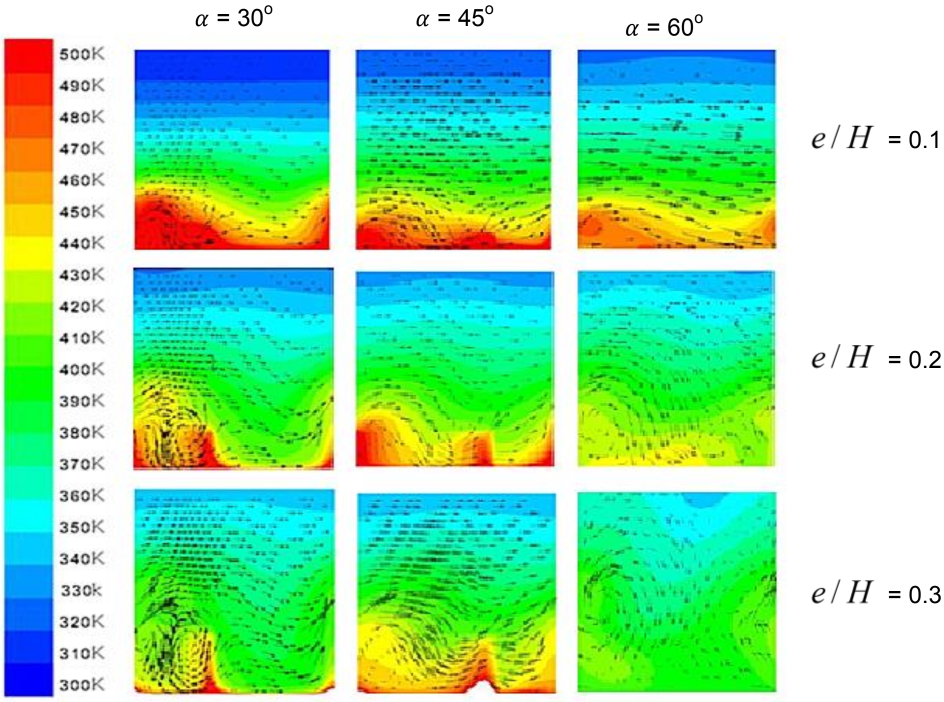

Figure 4: velocity vectors and temperature contours in α = 30^o, 45^o and 60^o, e/H = 0.1, 0.2 and 0.3, Re= 12,600 at x = L/H = 26.67.

6. Conclusions

The simulation results concluded that lowest Re will provide optimum heat transfer. Consider velocity vectors and temperature contours found that increasing ratio of *e/H* cause to thermal exchange in rectangular duct better, *e/H* = 0.3 gives higher heat transfer than, *e/H* = 0.2 and 0.1, respectively. Increasing α gives the turbulence intensity of the flow better, temperature contours found that α = 45^o provide the highest temperature so α = 45^o at *e/H* = 0.3, type of baffles to get optimum TEF = 1.74 at Re = 12,600.

Acknowledgments

The funding of this research work is supported by Strategic Wisdom and Research Institute Srinakharinwirot University (SWU, Grant number: 787/2558) and SWU Academic Outreach Services.

Reference

Gentry M. C., Jacobi A. M., 2002, Heat transfer enhancement by delta-wing-gene rated tip vortices in flat-plate and developing channel flows, J Heat Trans-T Asme 124, 1158-1168.

Hoonpong P., Suwannapan S., Promvonge P., Skullong S., 2013, Performance enhancement in a square duct heat exchanger with baffles inserts, The 9th Mahasarakham University Research, Mahasarakham, Thailand.

Jedsadaratanachai W., Junsangsuk D., Promvonge P., 2009, Heat transfer enhancement in a square duct with double v-ribbed strip inserts, The 23th Conference of the Mechanical Engineering Network of Thailand, Chiang Mai, Thailand.

Jin D., Zhang M., Wang P., Xu S., 2015, Numerical investigation of heat transfer and fluid flow in a solar air heater duct with multi V-shaped ribs on the absorber plate, Energy, 89, 178-188.

Kanoknaikarn J., Tasjaruen T., Promvonge P., 2009, Effect of rib- incline angle on heat transfer in a wavy ribbed channel, The 23th Conference of the Mechanical Engineering Network of Thailand, Chiang Mai, Thailand.

Karwa R., 2003, Experimental studies of augmented heat transfer and friction in asymmetrically heated rectangular ducts with ribs on the heated wall in transverse, inclined, V-continuous and V-discrete pattern, International Communications in Heat and Mass Transfer, 30, 241-250.

Kangvantham J., Butprom B., Jantarasak P., Rattanasiriphibun P., 2014, Thermal performance enhancement of incline shaped baffle sets in a rectangular duct, Mechanical Engineering Srinakharinwirot University, Nakornnayok (in Thailand).

Lau S. C., Kukreja R. T., Mcmillin R. D., 1991, Effects of V-shaped rib arrays on turbulent heat transfer and friction of fully developed flow in a square channel, International Journal of Heat and Mass Transfer, 34, 1605-1616.

Layek A., Saini J. S., Solanki S. C., 2007, Heat transfer and friction characteristics for artificially roughened ducts with compound turbulators, International Journal of Heat and Mass Transfer, 50, 4845-4854.

Promvonge P., 2010, Heat transfer and pressure drop in a channel with multiple 60[degrees] V-baffles, International Communications in Heat and Mass Transfer, 37, 835-845.

Skullong S., Kwankaomeng S., Thianpong C., Promvonge P., 2014, Thermal performance of turbulent flow in a solar air heater channel with rib-groove turbulators, International Communications in Heat and Mass Transfer, 50, 34-43.

Sriromreun P., Thianpong C., Promvonge P., 2012, Experimental and numerical study on heat transfer enhancement in a channel with Z-shaped baffles, International Communications in Heat and Mass Transfer, 39, 945-952.

Suluksna K., 2009, Computational Fluid. Dynamics, Suranaree University of Technology, NakhonRatchasima, Thailand.

Tanda G., 2004, Heat transfer in rectangular channels with transverse and V-shaped broken ribs, International Journal of Heat and Mass Transfer, 47, 229-243.