Flow Visualization in a Tube Flow with Various Positions of the V-baffles

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ABSTRACT— ***Flow configurations in a circular tube heat exchanger inserted with V-baffles are investigated numerically. The influences of the Reynolds numbers (Re = 3000 – 10000) and gap ratios (g/D = 0, 0.05, 0.10, 0.15, 0.20, 0.25 and 0.30) are considered with the flow blockage ratio (b/D) of the baffle around 0.20 and flow attack angle around 45°. The numerical problem is solved with the finite volume method. The numerical results are reported in terms of velocity vectors in transverse plane and the variations of the u/u_0 with various positions in the test tube. As the results, the flow profiles can separate into two parts; periodic flow profile and fully developed periodic flow profile. The reduction of the gap ratio effects for speed up rate of the fully developed periodic flow profile. The cognition of the flow structure in the tube heat exchanger inserted with the V-baffle can help to improve the accuracy of the computational domain.***

Keywords— fully developed flow profile, V-baffle, circular tube, gap ratio

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1. INTRODUCTION

The numerical investigations on flow structure in tube or channel flow had been reported by many researchers. For examples, Jedsadaratanachai *et al*. [1] formed the computational domain of the square duct heat exchanger inserted with baffles. The periodic boundaries on both flow and heat transfer were considered. They gave the assumptions for the numerical investigation on the long heating system that the periodic structures occur due to the array of the baffles. The numerical results from full domain and periodic domain were compared. They claimed that the fully developed periodic profiles are found around x/D = 7. Promvonge *et al*. [2] applied the periodic boundary for inlet and outlet of the square channel heat exchanger placed with V-baffles. They found that the fully developed periodic profiles on flow and heat transfer are around x/D = 8 downstream of the entrance region. They also concluded that the periodic module of the computational model can save computational resource and time for investigation. Jedsadaratanachai [3] numerically investigated the influences of the ribs placement on flow configuration in the test section. Jedsadaratanachai [3] concluded that the periodic flow profile is found around 2nd – 3rd module, while the fully developed periodic flow profile is detected around 6th – 9th module.

The periodic boundary was applied for the computational domain of the heating or cooling sections placed with various types of the turbulators [4-8]. The computational domains were validated with the base case and experimental results. The researchers reported that the numerical results were found in excellence agreement with the correlations of the smooth channel/tube and the values from the experiments. They also concluded that the periodic modules had reliability to predict flow and heat transfer configurations in the heating systems. The understanding on flow configuration in the tube is an important factor for the improvement of the numerical study.

In the present work, the numerical investigation on flow configuration in the circular tube heat exchanger inserted with V-baffle is reported. The influences of placement for the V-baffle (b/D = 0.20, α = 45°) in the circular tube are considered in terms of gap spacing ratio (g/D = 0 – 0.3) for the turbulent flow regime, Re = 3000 – 10,000. The numerical reports are presented in form of flow visualization and relation of the velocity with various positions in the tube flow. The periodic investigation on flow structure is a preliminary study for the improvement of the heating or cooling system. The preliminary result is an important knowledge to create the computational domain of the investigated system.

2. MATHEMATICAL FOUNDATION

The circular tube flow is solved by the continuity equation, Navier-Stokes equation and energy equation. The mathematical foundation and numerical method are referred by *Ref*. [8]. The realizable k-ε model [9] is selected for the current numerical solution.

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_j}(\rho k u_j)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\varepsilon+Y_M+S_k \quad (1)$$

and

$$\frac{\partial}{\partial t}(\rho \varepsilon)+\frac{\partial}{\partial x_j}(\rho \varepsilon u_j)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right]+\rho C_1 S\varepsilon+\rho C_2\frac{\varepsilon^2}{k+\sqrt{\upsilon\varepsilon}}+C_{1\varepsilon}\frac{\varepsilon}{k}C_{3\varepsilon}G_b+S_\varepsilon \quad (2)$$

where

$$C_1=\max\left[0.43,\frac{\eta}{\eta+5}\right],\eta=S\frac{k}{\varepsilon},S=\sqrt{2S_{ij}S_{ij}} \quad (3)$$

the constant values are as follows;

$$C_{1\varepsilon}=1.44, C_2=1.9, \sigma_k=1.0, \sigma_\varepsilon=1.2 \quad (4)$$

The governing equations are discretized by the second order upwind (SOU) scheme, decoupling with the SIMPLE algorithm, and solved by using a finite volume approach [10]. The solutions are set to be converged when the relative normalized residual are less than 10^{-5}.

The air velocity is calculated in term of Reynolds number as follow:

$$\mathrm{Re}=\frac{\rho u_0 D}{\mu}$$

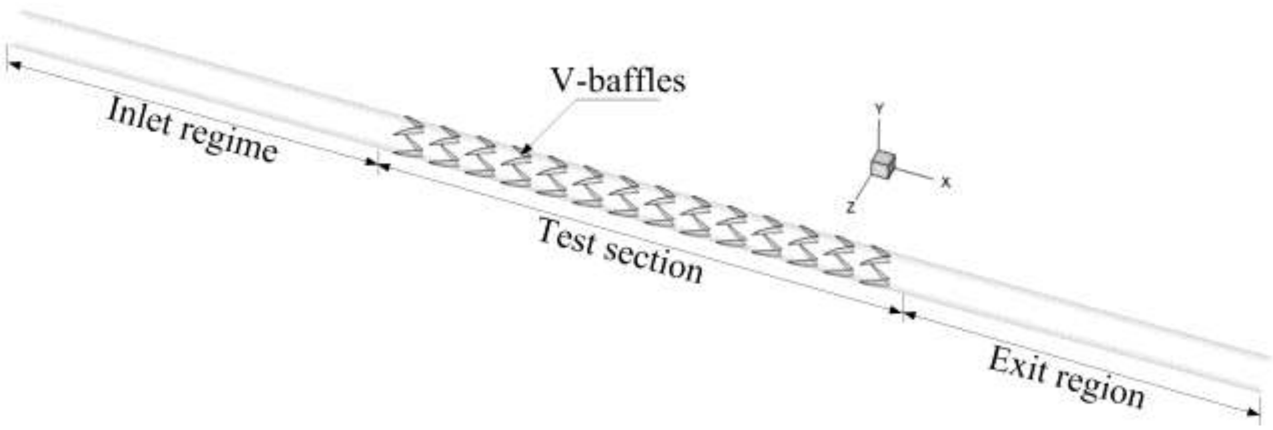
ρ, u_0 and μ is density, velocity and viscousity of the air flow at 300K. (5)

3. BOUNDARY CONDITION AND ASSUMPTION

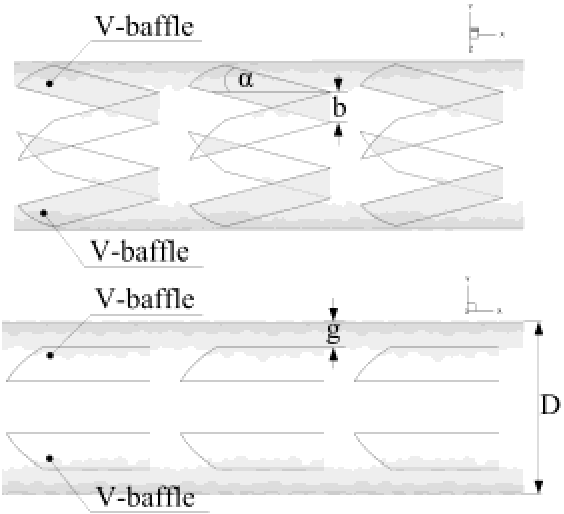
The entry and exit regions are around 10*H*, while the test section of the circular tube is around 14*H* (14 modules). The velocity inlet and pressure outlet are set for inlet and outlet of the computational domain. No slip wall condition is set for the tube wall. The flow is turbulent and incompressible. The steady condition is set for fluid flow. The body force and viscous dissipation are ignored. The air as the tested fluid is set with constant fluid properties at 300K.

4. PHYSICAL MODEL

A circular tube inserted with the V-baffle is depicted in Fig. 1*a*, while the parameter details are displayed as Fig. 1*b*. The tube diameter, *D*, is around 0.05m. The spacing between V-baffle and tube wall, *g*, is varied in terms of gap spacing ratios, g/D = 0, 0.05, 0.10, 0.15, 0.20, 0.25 and 0.30. The flow is considered for turbulent flow at the Reynolds number around 3000 to 10,000. The flow blockage ratio (b/D) and flow attack angle (α) are fixed for all cases at 0.20 and 45^{o}, respectively. The arrangement of the V-baffle is set as V-Downstream (V-tip pointing downstream). The in-line organization for the upper and lower V-baffles is selected for the present study. The longitudinal spacing between V-baffle is set around 1*D* for all investigated cases. The computational domain of the tube flow inserted with V-baffle is presented in Fig. 1*c*.



(a)



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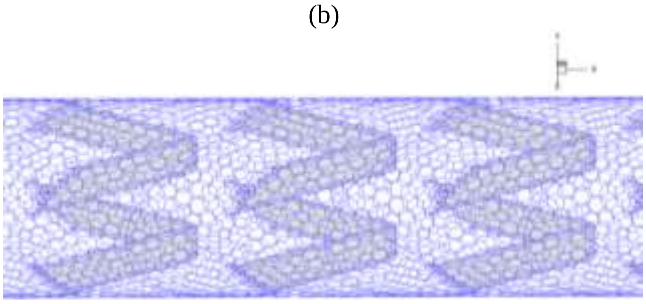


(c)

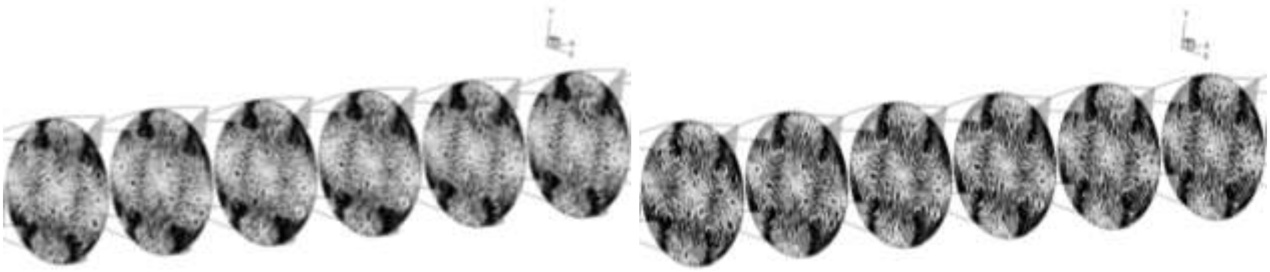
Figure 1 : (a) tube inserted with V-baffles, (b) parameters of tube flow with V-baffles and (c) computational domain.

5. NUMERICAL RESULT

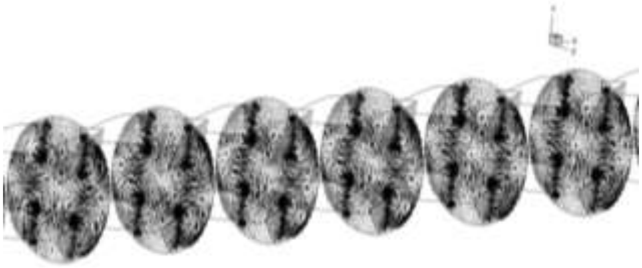
The numerical validations of the present computational domain are separated into three sections; grid independence, validation with the smooth tube and validation with the experimental results. As the preliminary study, the results show excellence agreement with the values from the correlation [11] of the smooth tube and experimental results. The number of grid around 240000 cells is selected for the present model due to the increasing of grid cell more than 240000 has no advantage for the numerical results.

5.1 Flow structure

The flow configuration in the tube heat exchanger inserted with V-baffles is reported in Figs. 2*a*, *b*, *c*, *d*, *e*, *f* and *g* for g/D = 0, 0.05, 0.10, 0.15, 0.20, 0.25 and 0.30, respectively, at Re = 6000. The flow structure is presented in term of tangential velocity vector in transverse planes at the middle of each module. In general, the vortex flow is found in all cases. This means that the V-baffle in the tube heat exchanger can generate the vortex flow through the test section. The similar flow pattern is detected in all planes for each gap ratio. This flow pattern is called "periodic flow". For g/D = 0, 0.05 and 0.30, the V-baffle can create four main vortex flows, while the V-baffle with g/D = 0.10, 0.15, 0.20 and 0.25 can generate eight main vortex flows through the test tube. The increasing number of the vortex flow is due to the gap between tube wall and V-baffle.



(a) (b)



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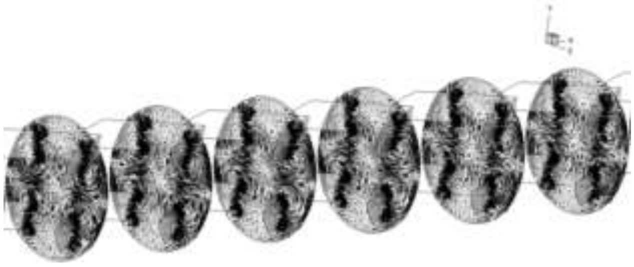

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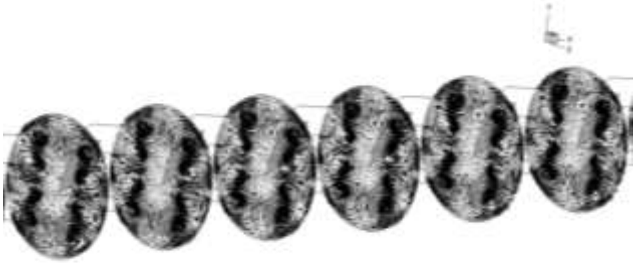

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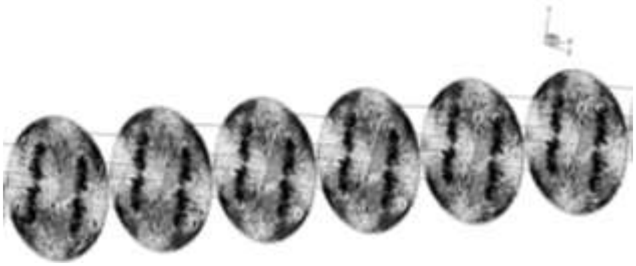

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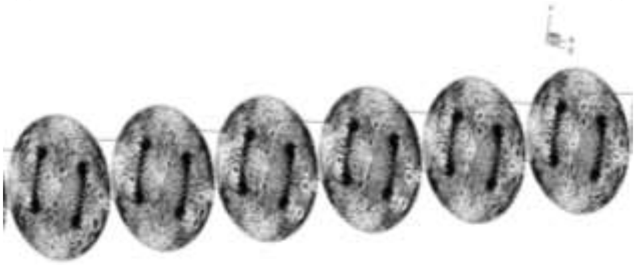
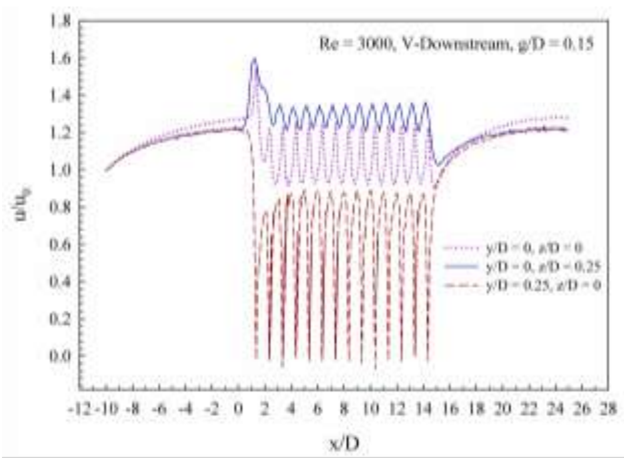


(g)

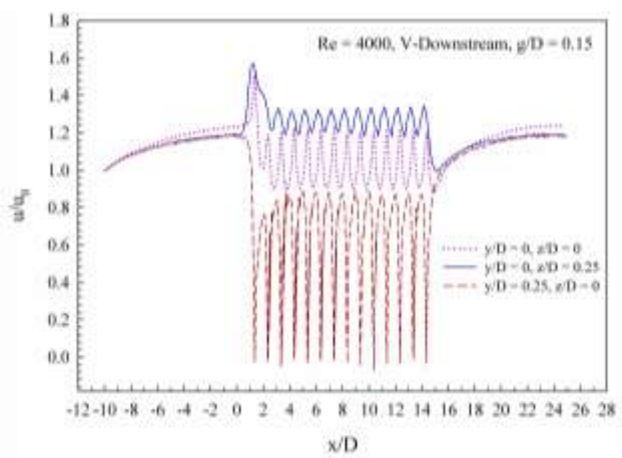
Figure 2 : Tangential velocity vector in transverse planes for (a) g/D = 0, (b) g/D = 0.05, (c) g/D = 0.10, (d) g/D = 0.15, (e) g/D = 0.20, (f) g/D = 0.25 and (g) g/D = 0.30 at Re = 6000.

5.2 Effect of Reynolds number

The effects of Reynolds number on flow configuration in the test tube inserted with V-baffle are reported in term of the variations of the u/u_0 with x/D at various positions in cross-sectional area (y/D = z/D = 0, y/D = 0 and z/D = 0.25, y/D = 0.25 and z/D = 0). Figs. 3*a*, *b*, *c*, *d* and *e* present the relations of the u/u_0 with x/D for the tube flow placed with V-baffle at Re = 3000, 4000, 6000, 8000 and 10000, respectively, for g/D = 0.15. As the figures, the flow structure can separate into two parts; periodic flow profiles and fully developed periodic flow profiles (see Fig. 4). The periodic flow profiles mean that the configurations of the velocity profiles are similarly, but the velocity values are not equally. The periodic flow profiles are detected around 1st – 10th module (x/D = 1 – 10) depended on Re and g/D values.



(a)



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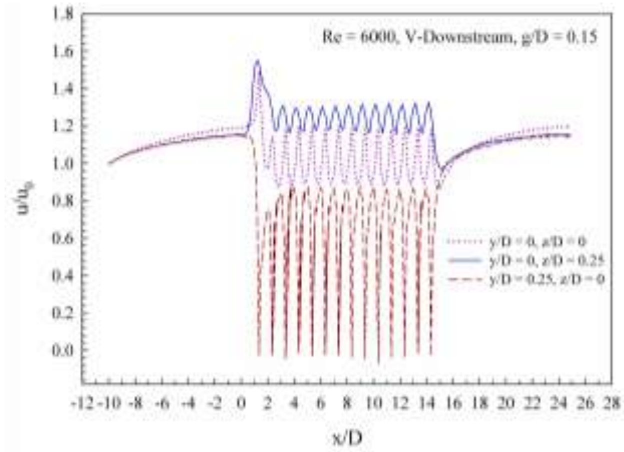

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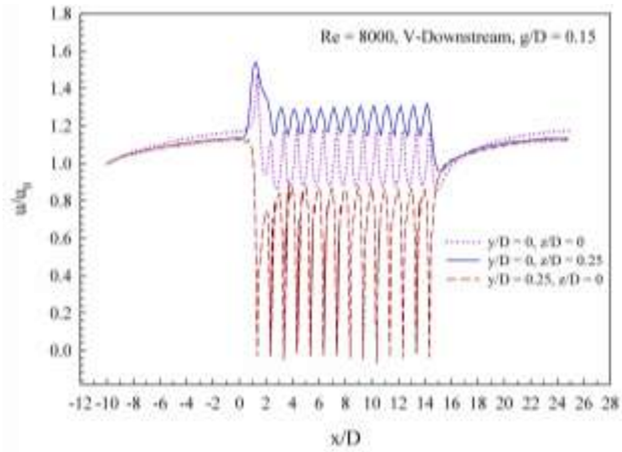

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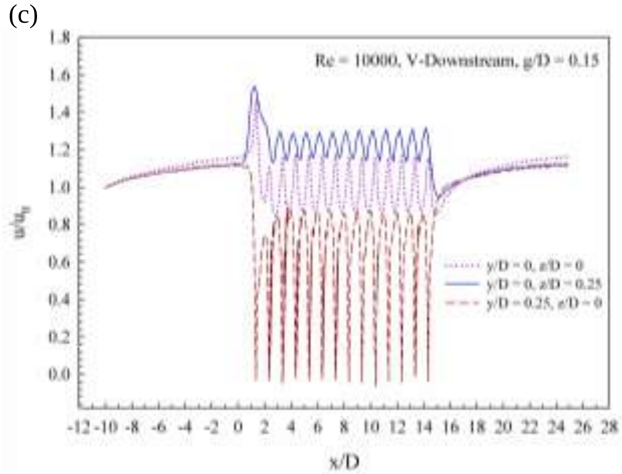

(e)

Figure 3 : Variations of the u/u_0 with x/D at various positions for (a) Re = 3000, (b) Re = 4000, (c) Re = 6000, (d) Re = 8000 and (e) Re = 10000 at g/D = 0.15.

The fully developed periodic flow profiles mean that both pattern and value of the velocity in the test tube are equally. The fully developed periodic flow profiles are found around at x/D > 5 depended on Re and g/D values. The variations of the Reynolds number have a few effect for flow structure in the tube heat exchanger inserted with V-baffle.

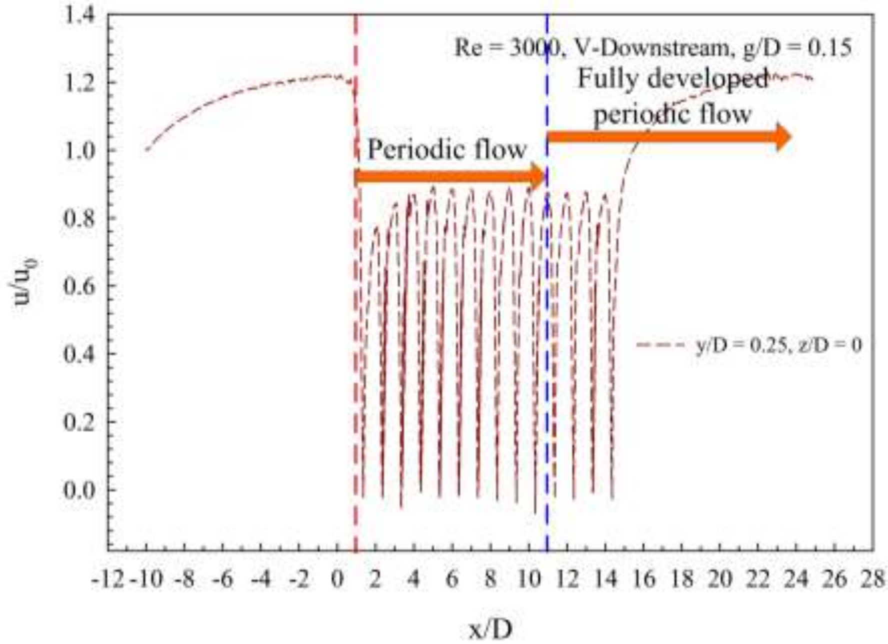

Figure 4 : Descriptions of periodic and fully developed periodic flow profiles.

5.3 Effect of gap ratio

The gaps between V-baffle and tube wall in terms of gap ratios (g/D = 0, 0.05, 0.10, 0.15, 0.20, 0.25 and 0.30) are varied. The variations of the u/u_0 and x/D at various gap ratios and positions of the V-baffle in the test tube are depicted in Figs. 5*a*, *b*, *c*, *d*, *e* and *f* for the g/D = 0, 0.05, 0.10, 0.20, 0.25 and 0.30, respectively, at Re = 6000. The flow configurations in the tube heat exchanger with various gap ratios of the V-baffle are also separated into two zones; periodic flow profiles and fully developed periodic flow profiles.

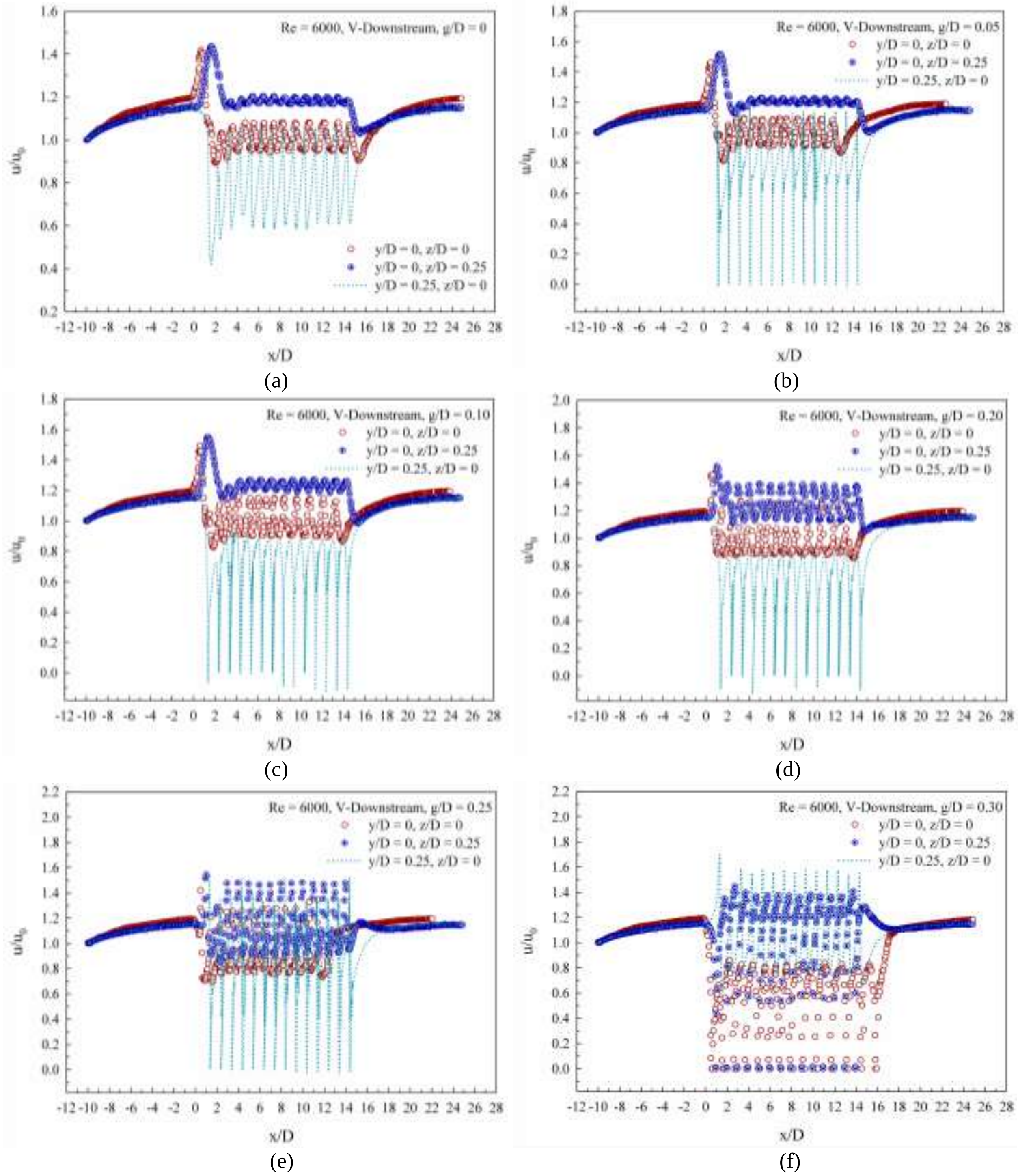

Figure 5 : Variations of the u/u_0 with the x/D at various positions for (a) g/D = 0, (b) g/D = 0.05, (c) g/D = 0.10, (d) g/D = 0.20 and (e) g/D = 0.25 at Re = 6000.

The periodic flow profiles are found at the beginning for the placement of the V-baffle, $x/D \approx 1 - 10$, after that the fully developed periodic flow profiles are detected ($x/D > 5$). The speed of the appearance for the periodic and fully developed periodic profiles dependes on *g*/*D*, *Re* and position in the test section. The gap ratios have effect for the occurring of the fully developed periodic flow profile. The V-baffles with *g*/*D* = 0 and 0.05 provide the fastest rate of the fully developed periodic flow profiles.

6. CONCLUSION

Numerical investigations on flow configuration in the circular tube heat exchanger inserted with V-baffle are presented. The effects of the gap ratios (*g*/*D* = 0, 0.05, 0.10, 0.15, 0.20, 0.25 and 0.30) and Reynolds numbers (*Re* = 3000 – 10,000) are considered for V-baffle with *b*/*D* = 0.20, flow attack angle of 45^o and longitudinal pitch around 1*D*. The main findings for the present investigation are concluded as follow:

The V-baffle in the tube heat exchanger can generate vortex flow through the test section for all cases. The flow configurations are separated into two parts; periodic flow profiles and fully developed periodic flow profiles. The variations of the Reynolds number have a few effect for the appearance of the periodic and fully developed periodic flow profiles. The reduction of the gap between V-baffle and tube wall provides increasing rate for the occurring of the fully developed periodic flow profiles, especially, *g*/*D* = 0 and 0.05.

The fully developed flow is found in similar trend with the inclined and V-shaped baffles that placed on the channel wall as *Ref*s. [1 - 3] due to the nearly pattern of the generator shape. However, the placement of the V-baffle in the test section has effects for the periodic and fully debeloped periodic flow profiles.

The knowledge on flow configuration in the tube heat exchanger inserted with various gap ratio of the V-baffle can help to set the boundary condition and also help to improve the accuracy of the computational domain. The periodic boundary can apply for the computational domain, which is a representative of the long tube flow system. The periodic module can save time for numerical investigation and also help to save computer resource.

7. ACKNOWLEDGEMENT

This research was funded by College of Industrial Technology, King Mongkut's University of Technology North Bangkok, Thailand. I would like to thank Asst. Prof. Dr. Withada Jedsadaratanachai and Assoc. Prof. Dr. Pongjet Promvonge for suggestions.

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