IMPROVEMENT THE INCOMPRESSIBLE AIR FLOW MIXING AND HEAT TRANSFER MECHANISM BY A COMBINATION OF SUDDEN ENLARGEMENT STEP AND ORTHOGONAL SLOT JETS

KHUDHEYER S. MUSHATET
Mech. Eng. Dept., College of Engineering, Thiqar University
Nassiriy, aIraq
Email: Khudheyer2004@yahoo.com

Abstract— *This study summaries a computational analysis to predict the turbulent flow and heat transfer characteristics of a sudden expansion channel with confined jets issuing orthogonally. The bottom wall of the sudden expansion is hot while jets and main cross flow is at isothermal cold temperature. The effect of number of impinging jets and sudden expansion ratio on flow structure and heat transfer is investigated for Re_{in}=40000 and Re_j=14000 respectively .The mixed turbulent flow and heat equations are modeled by the continuity, Navier-Stockes and energy equations while the effect of turbulence in the flow is by a k-є. These equations are discretised on a well chosen staggered non uniform grid by a finite volume method. A developed computer code based on a SIMPLE algorithm is used. The findings show that using impinging slot jets with a sudden expansion cross flow significantly enhanced the heat transfer. This improvement is clearly noticed as the number of jets increasing.*
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Keywords— *Sudden expansion; Impingement cooling; CFD*

I. INTRODUCTION

Heat transfer Augmentation by creating a separated flows by both geometrical modifications and impinging jets is one of considerable importance. These tools enhance the performance of thermal systems encountered in engineering and technological utilize as cooling of electronic equipment, cooling of turbine blades, drying of food products and engine combustion chambers. Impinging jets made the interest of scientists increases because these jets increase the heat transfer coefficients for both loacal and average quantities, and hence enhancement the heat transfer. Extensive work on a classical sudden expansion flow documented by many authors.

There is very little studies on cross flow with impinging jets and to the knowledge of the author, there is no study documented on a turbulent sudden expansion cross flow with impinging jets. When reviewing the literature of this topic, one can find many authors studied the laminar and turbulent flow in a sudden expansion channel or impinging jets flows.

Sang and Ota [1] verified experimentally the effect of circulated flow due to conda effect on local Nusselt of profile . It was clarified a different variation of local Nusselt number at the walls as a result to this effect. The analysis of heat transfer improvement at axisymmetric sudden enlargement both experimentally and numerically was made by Dae et al.[2].I was disclosed that the maximum Nusselt number obtained between 9 and 12 step heights from the enlargement step. The turbulence encountered in the flow on a heat transfer was analyzed by Sugawara et al.[3]. They verified that for high turbulence intensity, the heat transfer coefficient is higher than that gained for a small value of turbulence. The effect of the presence of jet orthogonally issuing on a flat plate was studied by Huang and Genk[4]. Different turbulence models were examined by Pathnk et al.[5] to study a jet issuing orthogonally to a cross flow. It was clarified that utilize Reynolds stress model gave a better performance in three dimensional flow compared with those using standard k-ϵ model. Katti and Prabhu[6] performed a study on an impingement of a circular jet on a flat plate in presence of a detached rib. It was found there is an increase in Nusselt number from the stagnation point to detached rib for the considered rib configuration. Al-Ramh[7] used multi internal impinging jets to enhance the heat transfer from a hot plate. A lattice Boltzman method was used to perform the numerical analysis. The results showed that the melti internal jets provide an increase in heat transfer more than a channel for low jets height. Zhang et al.[8] performed a numerical study on three dimensional flow and heat transfer characteristics of impingement/diffusion cooling. The variation of local heat transfer through effused perforated plate tested experimentally by Hyung and Dong[9]. A maximum heat transfer was pointed at a stagnation region. The orientation of ribs on impingements/effusion cooling system was experimentally tested by Yong et al.[10]. The cooling effectiveness of full-coverage film cooled wall of jets holes inclined at 35^0 and 90^0 with impingement jets was studied by Sang et al. [11]. They verified that the angle 35^0 indicated a higher film cooling effectiveness than90^0. Jia et al. [12] made a numerical study to show the effects of jet flow on the flow and heat transfer characteristics. The results disclosed that turbulence intensity besides the velocity profile at entrance of the jet has profound influence on heat transfer improvement. Various five versions models of low Reynolds number k-ϵ were adopted by Wang and Mujumdar [13]to predict the heat transfer under a turbulent slot air jet. A comparison with their experimental results was made.

Wanasi and Monnoyer[14] studied the fluid flow and heat transfer of combined swirling and straight impinging jet arrays. It was found that the swirl motion affecting the resulting mixing for a small distance from the nozzle exit. However its intensity decreases rapidly.

A. *Problem Description*

In the present work, Analysis is computationally performed for prediction the mixed turbulent flow and heat transfer in a sudden enlargement step cross flow with orthogonal rectangular jets. the slot jets impinging vertically on the cross flow. The bottom wall of this flow configuration is maintained at constant hot temperature, while the cross flow and impinging jets at a constant cold temperature. Schematically layout for this problem statement is exhibited in Fig.1

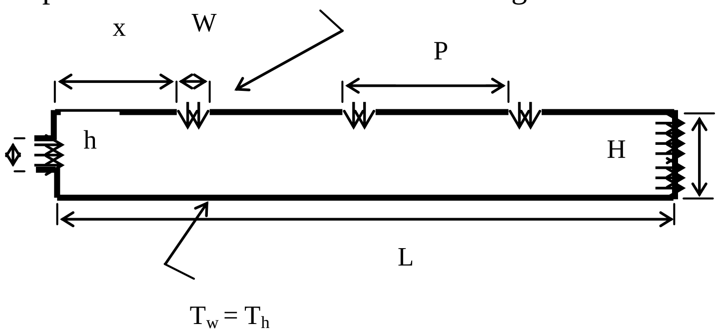


Fig1.schematic diagram of the problem, H=0.05m, L=0.4m, x=0.0492m, H/W=11 and P/W=4

II. Mathematical Formulation and Numerical Analysis

Assuming incompressible flow , the continuity, Navier-Stockes and energy governing the physical problem are represented by the following equations are used to model the turbulent flow and heat transfer.

$$\frac{\partial}{\partial x_i}(\rho U_i)=0 \qquad (1)$$

$$\frac{\partial U_i U_j}{\partial x_j}=\frac{-\partial P}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\mu\frac{\partial U_i}{\partial x_j}-\overline{\rho u_i u_j}\right) \qquad (2)$$

$$\frac{\partial U_i T_j}{\partial x_j}=\frac{\partial}{\partial x_j}\left(\frac{\mu}{\Pr}\frac{\partial T_i}{\partial x_j}-\overline{\rho u_i t_j}\right) \qquad (3)$$

A. *The Turbulence Model*

Completion the above governing equations requires modelling turbulent stresses and heat fluxes two transport governing equations k-ε model , one for turbulence and the other for its dissipation are included[15].

$$\frac{\partial \rho k U_i}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + \rho\left(G_b - \varepsilon\right)$$
(4)

$$\frac{\partial \rho \varepsilon U_j}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + \rho\frac{\varepsilon}{k}\left(C_{1\varepsilon} G_b - C_{2\varepsilon}\,\varepsilon\right)$$
(5)

$$G_b = \mu_t\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\frac{\partial u_i}{\partial x_j}$$
(6)

$$\mu_t = \rho c_\mu \frac{k^2}{\varepsilon}$$
(7)

The model coefficients are (σ_k; σ_ϵ; $C_{1\epsilon}$; $C_{2\epsilon}$; $C\mu$) = (1.0, 1.3, 1.44, 1.92, 0.09), respectively [15]

B. *Boundary Conditions*

$$\mathrm{Re}_{in} = \frac{U_{in} h}{\nu}, \quad \mathrm{Re}_j = \frac{U_j B}{\nu}, \quad k_{in} = 0.05 U_{in}^{\ 2},$$
$$k_j = 0.05 U_j^{\ 2}$$
$$\varepsilon_{in} = k_{in}^{\ 1.5} / \lambda h \quad , \quad \varepsilon_j = k_j^{\ 1.5} / \lambda B \quad ,$$
$$\lambda = 0.005$$

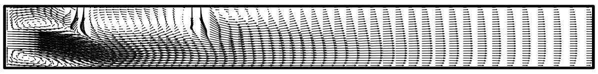
At the walls no slip condition was incorporated. The wall function laws[19] were used to treat the large steep gradients near the walls. The local Nusselt number on the hot wall is defined as:

$$Nu = \frac{\partial \theta}{\partial Y}, \; \theta = \frac{T - T_c}{T_h - T_c}, \; Y = \frac{y}{H}$$

III. Results and Discussion

The obtained results for turbulent flow and heat transfer are presented as follows:

Fig.2. demonstrates flow field by a velocity vectors and stream lines. It is clear that the impinging jets creates a complex mixing zones with a sudden expansion main flow. As a results, these essential changes in the flow structure affects the heat transfer enhancement from the bottom surface. The sudden expansion recirculation region size and its strength is greatly affected the expected trace of impinging jets. The near impinging jet to the sudden expansion pushes the flow towards the lower surface, consequently affecting the sudden expansion recirculation zone and increasing the cooling of the surface. After the second jet, in spite of the recirculation zone, the flow seems to be a uniform where it is no affected by impinging jets and the combined flow boundary layer is affected by the walls viscous action.



a. velocity vectors

b. stream lines

Fig. 2 Distribution of computed velocity vectors and stream lines for Re_{in}=40000, Re_j=14000 and ER=3.5

The effect of number of impinging jets on local Nusselt number on the bottom hot surface is illustrated in Fig.3. It is shown that when number of jets increasing, the local Nusselt number increases due to increase the mixing flow regions represented by creating recirculation zones that enhance the heat transfer. The figure shows, a comparison with local Nusselt number variation of classical sudden expansion without impinging jets. It is worth to illustrates here that impinging jets are considerably affected the local Nusselt number. However the increase is greater at x>0.2.

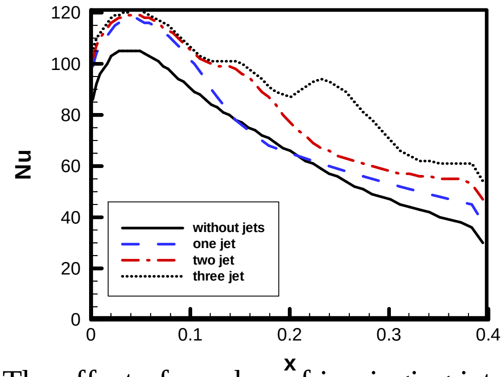


Fig. 3 Local Nusselt number variation on the lower hot wall for different numbers of impinging jets, Re_{in}=40000, Re_j=14000 and ER=3.5

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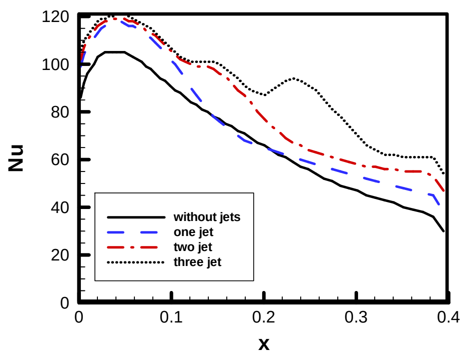

Fig. 4 Local Nuselt number variation on the lower hot wall for different values of expansion ratio, Re_{in}=40000 and Re_j=14000

IV. CONCLUSIONS

The turbulent mixing flow and heat transfer of sudden enlargement with orthogonal rectangular jets has been numerically deduced. From this study, it is concluded that using impinging slot jets with a sudden enlargement cross flow improve noticeably the heat transfer. The heat transfer is improved by increasing the number of jets. Besides, The heat transfer is decreased as the sudden enlargement region increases. However this behavior is reflected near the sudden enlargement.

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NOMENCLATURE

G	generation term, Kg/m.sec^3
H	height of the channel, m
ER	expansion ratio (H/h),-
k	turbulent kinetic energy, m^2/s^2
Nu	local Nusselt number, -
P	pressure, N/m^2
Pr	Prandtl number, -
Re_{in}	Channel Reynolds number,-
Re_j	jet Reynolds number,-
T_h	hot wall temperature, Ċ
T_c	inlet cold temperature, Ċ
U_{in}	Velocity at a sudden expansionl inlet

Greek symbols:

ϵ	turbulence dissipation rate, m^2/s^3
μ	Dynamic viscosity, N.s/m^2
μ_t	turbulent viscosity, N.s/m^2
ρ	air density, Kg/m^3
Γ_{eff}	Effective exchange coefficient, kg/m.s
σ_k; σ_ϵ	turbulent Schmidt numbers, -

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