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Research Article

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Effect of Spacing Distance on Heat Transfer for Two Impinging Jets

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Abstract The present work investigated the effect of nozzle configurations (two circular – two square – two rectangular) jets on heat transfer from hot impinging plate. The spacing distance (S/dh = 2, 4, 6, and 8) are considered in this study. Also, the Reynolds number ranged from 1000 (laminar flow) to 5000 (turbulent flow). The separation distance (H/d_h) is considered constant, because the study is confined jet.

Keywords Spacing Distance, Heat Transfer, Impinging Jets

1. Introduction

Heat transfer from impinging jets is a technological development that has already been used by heat transfer engineer, designers and researchers, it is known as a method of achieving particularly high heat transfer coefficients, therefore getting an enhancement of heat transfer process [1-8]. The heat transfer coefficient is also depending on Nusselt Number which is a function of Prandtl number and Reynolds number that is mainly the most affected parameter in jet impingement heat transfer process [3-12].An impinging jet can be characterized in many different ways, such as being submerged or free-surface, or being confined or unconfined. A fluid jet issuing into a region containing the same fluid is a submerged jet while a fluid jet issuing into a different, less dense, fluid is characterized as a free-surface jet [10-13].

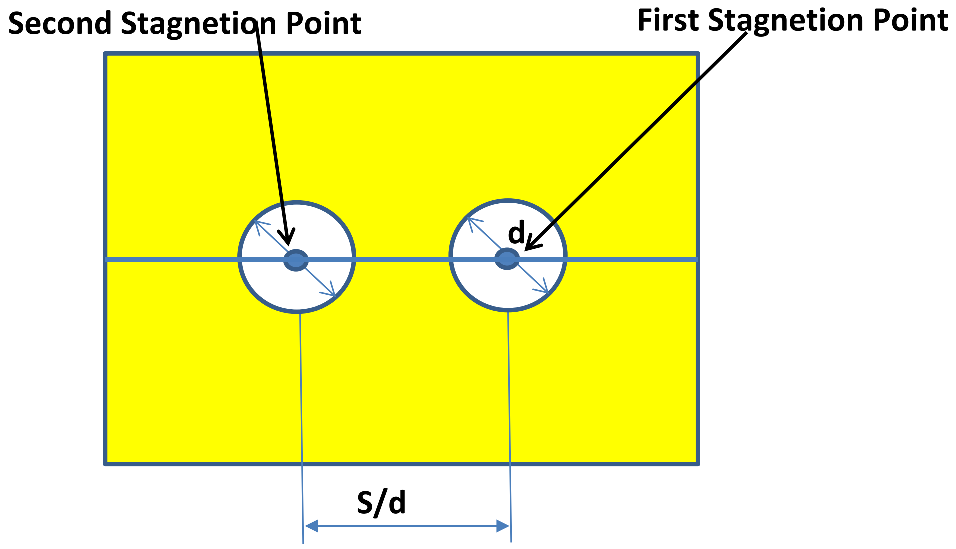
Detailed discussions of the aerodynamics of submerged jets can be found in textbooks [4-9-14], and reviews of impinging jets are also available in [3, 5]. Here, I introduce only some of the fundamental concepts and terminology for future reference. As a starting point of this section, we consider a single round. The geometric arrangement is characterized by the nozzle diameter, d, and the separation distance, H/d. It's assumed that, the jet fluid exit has a nearly uniform velocity, U, and temperature, T. The flow structures of impinging axismmetric and slot jets have been characterized and can be subdivided into three characteristic regions [15, 18]: a) the free jet region, b) the impingement (stagnation) flow region and c) the wall jet region. In the free jet region, the shear-driven interaction of the exiting jet and the ambient produces entrainment of mass, momentum, and energy. The net effects include the development of a nonuniform radial velocity profile within the jet, expansion of the jet, an increase of the total mass flow rate, and modification of the jet temperature before it impinges upon the surface. The impingement zone is characterized by a stagnation region and the turning of the jet in the radial direction, which affects a transition for a wall jet further downstream. The thickness of the impingement zone boundary layer is approximately constant [1, 3]. The wall jet region is characterized by a bulk flow in the outward radial direction. The velocity maximum occurs at approximately one jet diameter from the impingement zone for the range of the separation distance ($0 < H/d < 12$) [19-22]. The level of the jet velocity, which is eventually advected into the near-wall region, has a strong effect on the heat transfer rate. The strong aerodynamic and thermal interaction that exists between the submerged gaseous jet and the impingement surface greatly affects the local heat transfer in the stagnation and wall jet regions as well as the average heat transfer over the surface.

The present study carries out to test the effect of two jets in line array with different configurations. Three types of two jets are considered first two circular jets, second two square jets, and the last two rectangular jets. The hydraulic diameter is chosen 10 mm for all three jets. The spacing distances (S/d) between jets are varied from 2, 4, 6 and 8. The jet Reynolds number is calculated based on the flow out from jet and ranged from 1000, 2000, 3000, 4000, and 5000. Because this study is considered confined, the separation distance between jets and impinging plate are considered constant (H/d = 2). The main objective of this study are as the following:

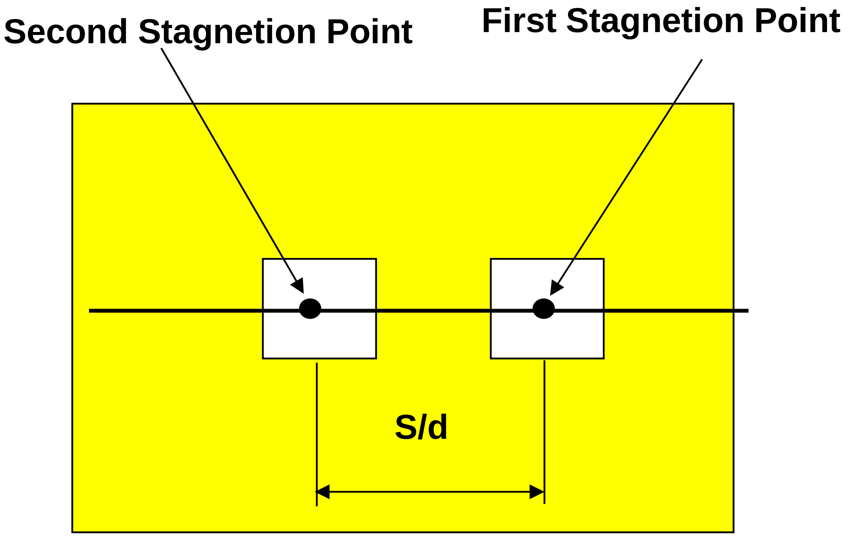
- Study the effect of local and avenge Nusselt for two jets with different configurations (Circular, Square, and Rectangular).
- Study the effect of separation distances (S/d = 2, 4, 6, and 8) on stagnation and average Nusselt number.

2. Experimental set-up

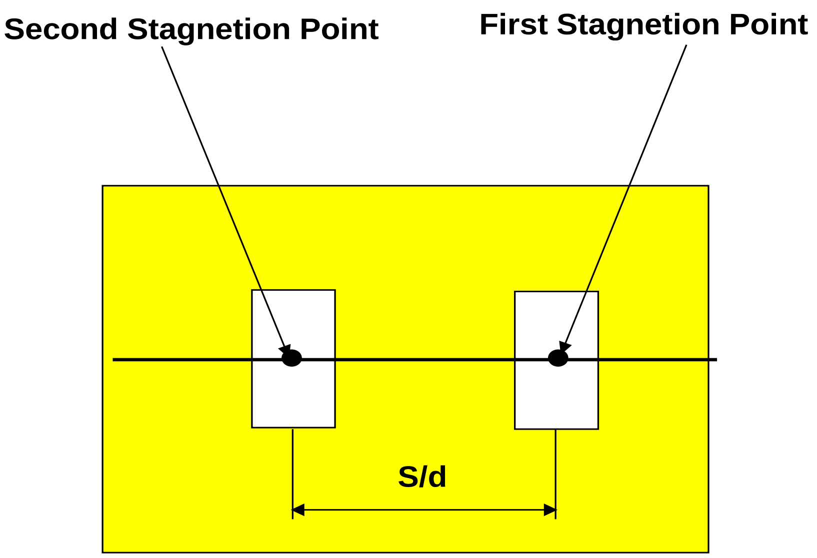
Two nozzles were used as shown in Fig. 1. Each nozzle was formed by a perforated plate with a thickness of 10. The hydraulic diameter is 10 mm for four configurations. The level of the nozzle field could be regulated to adjust different spacing between it and impingement sheet (separation distance H). This distance is constant of (H/dh = 2). The nozzles field was conducted in an aluminium frame. The infrared thermo camera was arranged vertically at a distance of 1000 mm under the metal sheet to measure the bottom surface temperature.



Two Circular Jets



Two Square Jets



Two Rectangular Jets

Figure 1: Nozzle shape and arrangement

3. Results and Discussion

3.1. Local Nusselt number

The local Nusselt number distribution for three configurations (circular – square – rectangular) with x-direction are showed in Fig. 2 to Fig. 5 for spacing distance od S/d =2.

3.1.1. Circular Two Jets

Fig. 2 to Fig. 5 illustrated the local Nusselt number for circular two jets at spacing distance (S/dh = 2, 4, 6, and 8) respectively. It observed that, the local Nusselt number distribution is symmetrical around the middle point of impingement sheet (stagnation point) for all cases of spacing distances. Where the maximum value of local Nusselt number is found at stagnation point, in other hand the minimum value is found at the middle point (X/dh = 0) for spacing distance (S/dh = 4, 6, and 8).

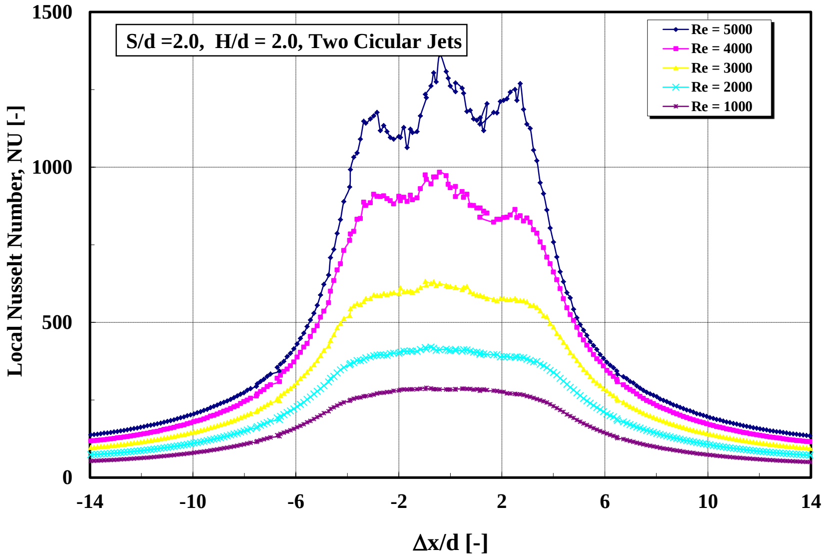


Figure 2: Local Nusselt number Distribution along the x-direction for two circular jets at S/d =2

The minimum value of the local Nusselt number is shows more clearly for spacing distance increases (S/dh ≥ 4). This result is due to; the area between two jets is increase with increase of spacing distance and then the flow interaction is decreases. Where the minimum value of local Nusselt number is 755, 630, and 335 for high

Reynolds number (Re = 5000) and for spacing distance of S/dh = 4, 6, and 8 respectively. Also, with increase the spacing distance (S/dh = 8) the each jet is considered one jet. For case of spacing distance of (S/dh =2) as shown Fig. 2. The minimum value of local Nusselt number is disappearing. It showed on maximum value at meddle of sheet center (x/dh = 0). And two jets is considered one jet, this result due to the interaction between flow jets are before impinging with sheet. Therefore, the two jets are considered one jet, and the stagnation point of each jet is nearly 1217.

On the other hand the value of local Nusselt number at the center of impinging sheet is 1389. Finally, the value of Nusselt numbers are decreases with decrees Reynolds number for all jets configurations. This result due to decrease momentum of flow goes out from jet.

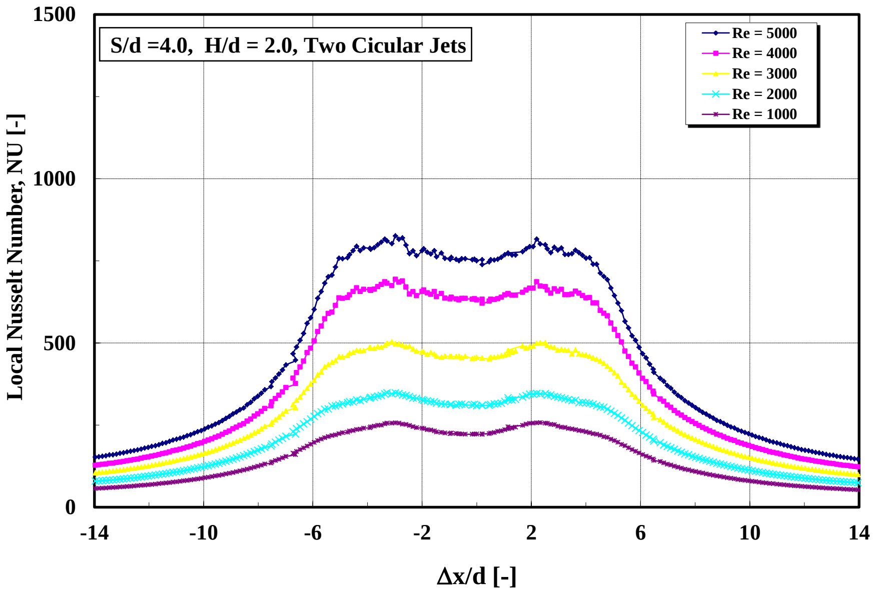


Figure 3: Local Nusselt number Distribution along the x-direction for two circular jets at S/d =4.

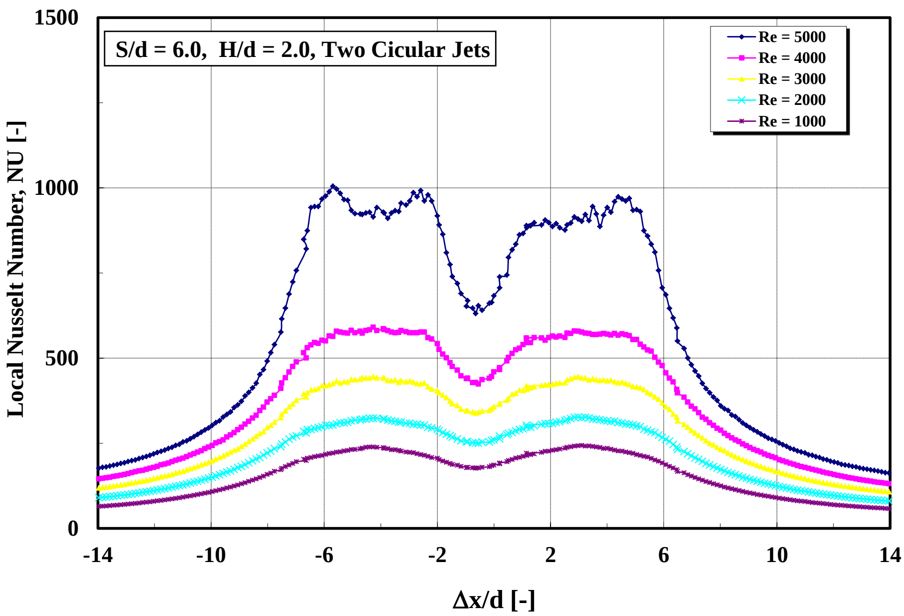


Figure 4: Local Nusselt number Distribution along the x-direction for two circular jets at S/d =6

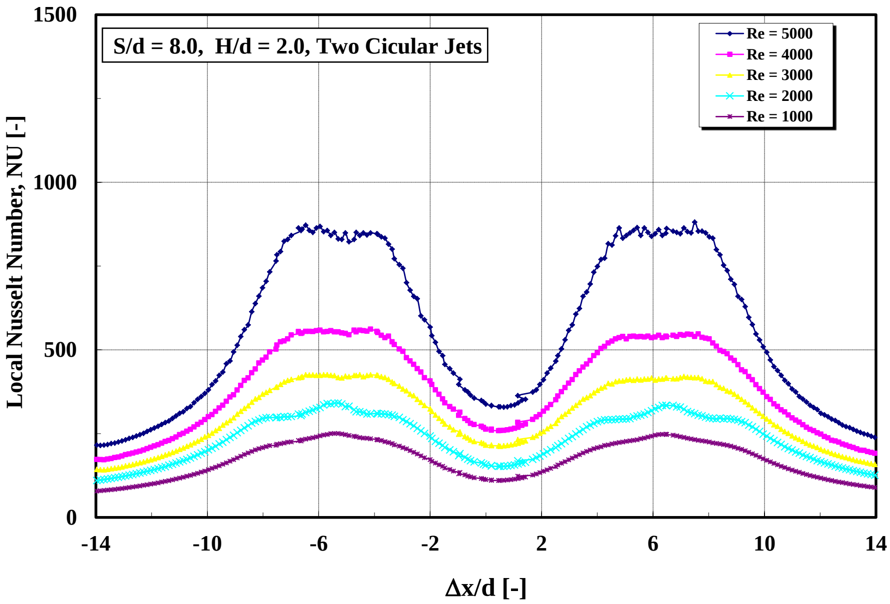


Figure 5: Local Nusselt number Distribution along the x-direction for two circular jets at S/d =8

3.2. Average Nusselt number

Fig. 6 to Fig. 8 shows the effect of Reynolds number on average Nusselt number at three differences configurations. It observed that the value of average Nusselt number increase with increase Reynolds number for all three configurations. This result due to increase of turbulent intensity with increases of Reynolds number. Also, from the figures noted that the average Nusselt number for circular two jets are garter than other square and rectangular two jets.

The value of average Nusselt number is found better for circular two jets than other confirmations. This result due to the sheer stress of flow goes out from jet is not strong in circular two jets [19].

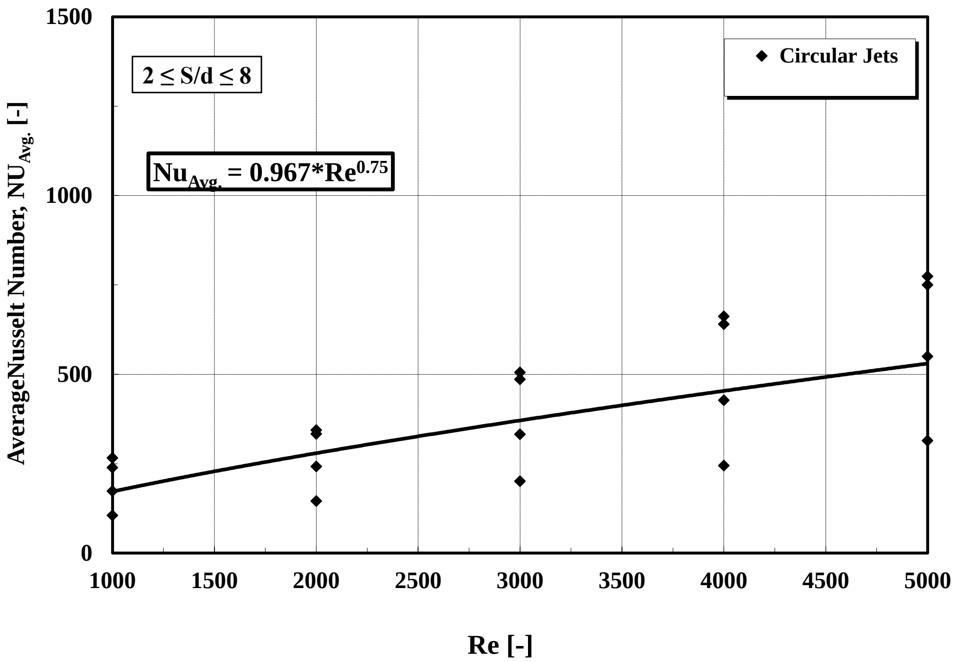


Figure 6: Average Nusselt number distribution with Reynolds number for two rectangular jets

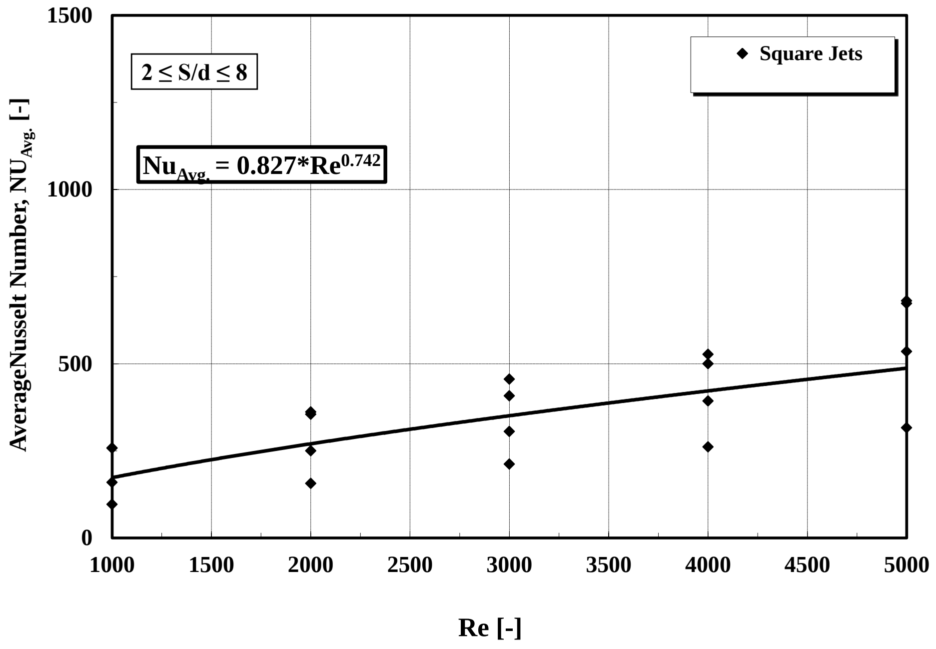


Figure 7: Average Nusselt number distribution with Reynolds number for two squar

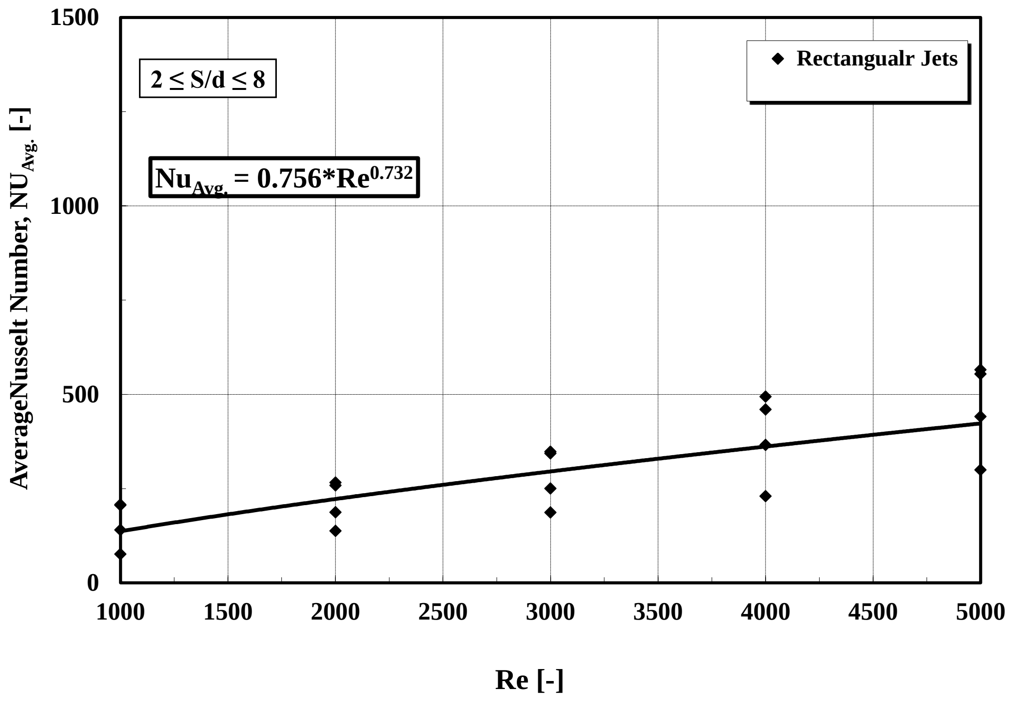


Figure 8: Average Nusselt number distribution with Reynolds number for two rectangular jets

Finally the correlation equations are developed through this study.

For Circular Two Jets

$$Nu_{avg} = 0.969 * Re^{0.75}$$

For Square Two Jets

$$Nu_{avg} = 0.827 * Re^{0.742}$$

For Rectangular Two Jets

$$Nu_{avg} = 0.756 * Re^{0.732}$$

The last three equations are valid at the flowing conditions:

1000e ≥ 5000, 2 ≥ S/dh ≥ 8, and $H/d_h = 2$.

4. Conclusions

The main conclusions from this study can be summarized as the flowing:

- The heat transfer rate enhancement with increase of Reynolds number for all three jets types.
- For case of circular and square jets, the two jets at low spacing distance (S/dh = 2) is considered one jet. While for case of rectangular jets at the same spacing distance (S/dh = 2), the local Nusselt number have two peaks (Two stagnation point) and one valley (interaction between two jets).
- At spacing distance greater than 2 (S/dh > 2), the local Nusselt number distribution have two peaks and one valley for all three configurations.
- The stagnation Nusselt number increase with increase of Reynolds number. And it is better value founded for circular jets than other two types.
- The average Nusselt number is found enhancement with circular two jets by 3.76% and 8.8 % for square and rectangular jets respectively.

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