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Research Article

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Experimental Study of Heat Transfer for Three Circular Air Jets

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Abstract Heat transfer from three circular jets arranged in-line and staggered has been investigated experimentally. The inner diameters of jet is 10 mm and with length of 40 cm. the distance between jets and target plate as well as between jets are considered 1 and 8 respectively. The Reynolds number varied between 9400 to 1400. The results showed that, the temperature distribution over line I is more uniformity than line II in both arrays in-line and triangle. In general, the cooling process is better for in-line than triangle array.

Keywords in-line, triangle, temperature distribution, Nusselt number

Introduction

Jet impingement cooling is an extremely effective cooling method to achieve high heat transfer rates. In the steel making industry, water-cooling technologies are widy used for controlling the steel plate temperature. The study of three jets impingement cooling is very important because controlling the cooling rate and uniformity can improve the microstructure and mechanical properties of the steel plate and strip [1-8].

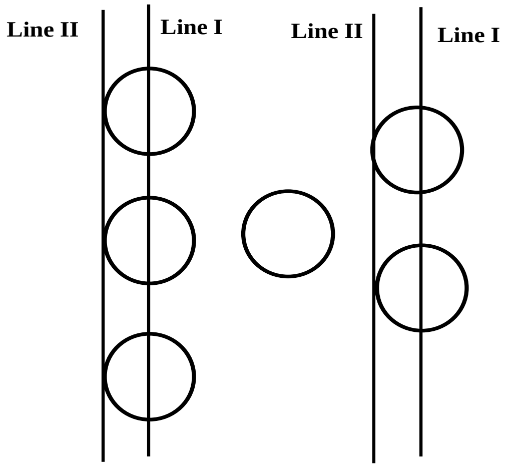
Arrays of impinging jets are applied in, for instance, steel and glass quenching, textile drying, paper processing, baking. Due to the high temperatures in gas turbines the blades are subject to high stresses that can cause severe damage to the blades. Huber and Viskanta [7] studied the effects of jet-jet spacing (X,/D), low nozzle-plate spacing (H/D = 0.25, 1.0 and 6.0) and spent air exits located between the jet orifices for confined 3 x 3 square arrays of air jets impinging normally to a heated surface. Attalla and Specht [4-6] conducted an experimental investigation of the convective heat transfer on a flat surface in a multiple-jet system is described. Varied parameters were the jet Reynolds number in the range from 1,400 to 41,400, the normalized distance nozzle to sheet H/d from 1 to 10, and the normalized nozzle spacing S/d from 2 to 10. A geometrical arrangement of nine nozzle in-line arrays was tested. The results show that the multiple jet system enhances the local and average heat transfer in comparison with that of a single nozzle. A maximum of the heat transfer was found for the normalized spacing S/d = 6.0. The normalized distance H/d has nearly no effect on the heat transfer in the range 2 B H/d B 4. The maximum average Nusselt number was correlated as a function of the jet Reynolds number. Wen, He and Ma [15] investigated the effects of nozzle arrangement on the convective heat transfer uniformity of multiple impinging jets. A simplified physical model with the size of 200 mm ×200 mm ×50 mm is built and the shear-stress transport (SST) k-ω turbulence model is used in the calculation. The nozzle quantity is varied from 8 ×8 to 32 ×32 for uniform nozzle arrays with a fixed total area of the nozzles. The corresponding numerical results of uniform nozzle arrangements are analysed in details. Based on the 16 ×16 uniform arrangement results, the effects of diameter varying nozzle arrangements on heat transfer uniformity are further examined.

Ozmen and Ipek [9] investigated the cooling performance of multiple impinging jets with different nozzle arrangements. Three nozzle arrangements with different nozzle numbers and the same total area are used. Due to the complicated interactions caused by the multiple jets, nozzle arrangement is found to determine the basic flow field and cooling performances of different nozzle arrangements are greatly dependent on tank pressure and nozzle height conditions. Finally, an overall performance evaluation indictor RU ratio is proposed. RU ratio is flexible in weighing both the cooling rate and cooling uniformity. Based on the evaluation result, the N-4 nozzle arrangements proves to be the best when nozzle height H=5cm and H=7.5cm while the N-16 arrangement is the optimum when H=3.5cm. It's also found that additional information of controlling strategies can be obtained by using the RU ratio to evaluate performances of nozzle arrangements under different working conditions [10].

This paper carried out to investigate the effect of three impinging jets with in-line and triangle arrays. The spacing and separation distance are considered constant and equal to 8 and 2 respectively. The Reynolds number is varied from 9400 to 1400 for two arrays.

Experimental set-up

The two arrays are shown in Fig. 1. Where line I through the centre of three jets and line II through for distance of d/2 of in case of in-line array. In case of triangle, the line I through in centre of two jets and line II through a distance of d/2 as shown in Fig. 1. The IR-camera used to measure the temperature over the impinging plate.



(A) In-line Array (B) Triangle Array

Figure 1: Three Jets Arrays

Data Reduction

The local temperatures distribution is measured by using the IR-Camera (TROTEC- IC120LV) that is placed under the plate surface. The local heat transfer coefficient is determined from the surface temperature of the plate measured with IR-camera by applying the Newton law [9-12];

$$q_{conv} = h.\left(T_{w-}T_j\right) \quad (1)$$

The heat transfer coefficient (h), the exit jet temperature, wall temperature, and air thermal conductivity are expressed in a dimensionless form by Nasselt number (Nu) [13-15];

$$Nu_L = h.d/k_a \quad (2)$$

Where d is inner diameter of jet and k_a is the air thermal conductivity. In the current study, the Reynolds number is defined an basis of the inner jet diameter to maintain mass flow rate and is calculated as the flowing;

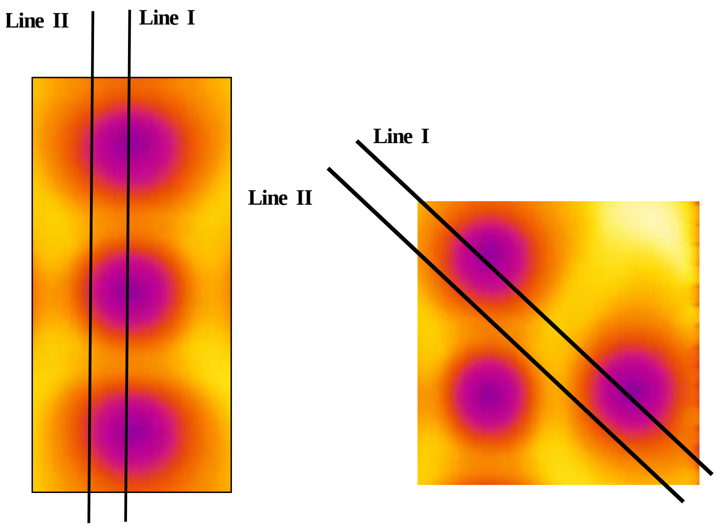
$$Re = 4\dot{m}/\pi.d.\mu \quad (3)$$

Results and Discussion

Temperature Distribution

Triangle Array

Fig. 2 shows the IR-camera temperature contours over impinging plate through the line I and Line II. Fig. 3 a and b are shown the temperature distributions over line I and II for triangle arrays. It observed that, the temperature increased with decreases of Reynolds number. This cases the turbulence intensity is weakness with decreases of Reynolds number. Where the maximum temperature is 475 C at center of plate with Reynolds number of 1400 on other hand the value of temperature is lower to 110 C for high Reynolds number of Re = 9400.



(a) In-line Array (b) Triangle Array

Figure 2: IR-Camera Photo with Line I and II

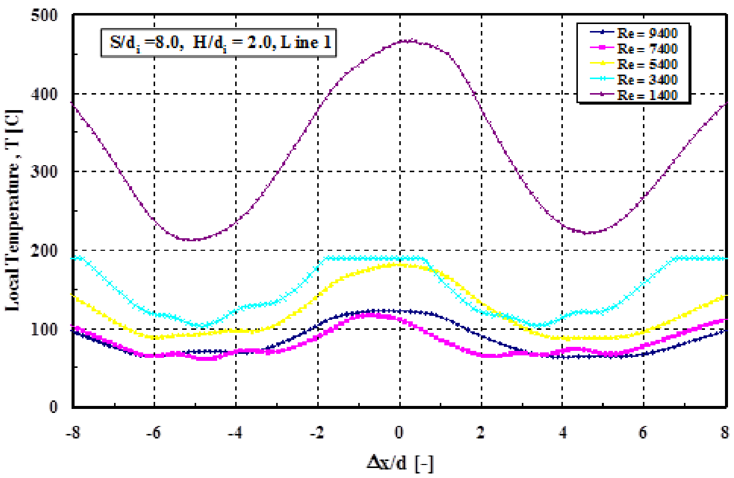


Figure 3a: Temperature distribution in triangle array over line I

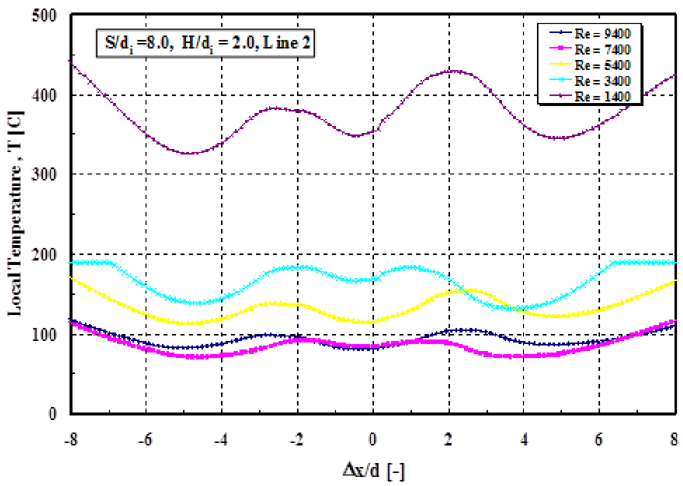


Figure 3b: Temperature distribution in triangle array over line II

In-Line Array

Fig. 4 a and b are shown the temperature distributions over line 1 and 2 for triangle arrays. It observed that, the temperature increased with decreases of Reynolds number. This cases the turbulence intensity is weakness with decreases of Reynolds number. Where the maximum temperature is 285 °C at center of plate with Reynolds number of 1400 on other hand the value of temperature is lower to 90 C for high Reynolds number of Re = 9400.

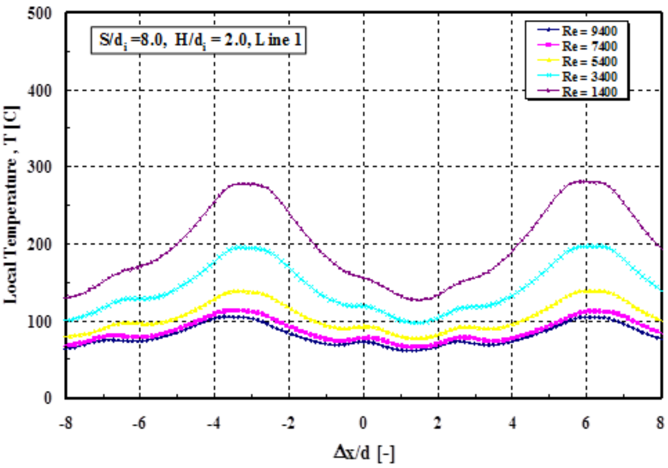


Figure 4a: Temperature distribution in-line array over line I

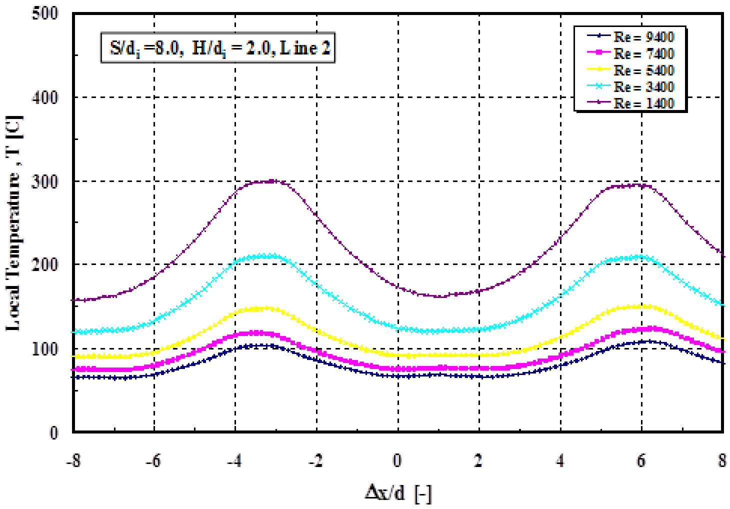


Figure 4b: Temperature distribution in-line array over line II

Conclusions

This study carry out to investigated the effect of different array (in-line and triangle) under spacing distance of S/d = 8 and h/d = 2. The Reynolds numbers are varied between 9400 and 1400. The local Nusselt numbers are taken over line I and line II for two cases (in-line and triangle). The temperature distribution and local Nusselt number over two lines a two array are considered in this study. The compassion between two arrays is considered also through this study. The main conclusion from this study is following:

- The temperature distribution over line 1 for triangle array is better in-line array.
- Over line 2 the temperature is lower that line 1 for two arrays (in-line and triangle).

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