Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2019, 6(3):105-111

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Study of Heat transfer Cooling Process of Flat Surface Using Array of Free Impinging Air Jets

Fayez S. M. M. M. Almutairi[1]*, Hussein M. Maghrabie[2], M. Attalla[2], Hamada Mohasab[2]

[1]General Authority for Applied Education and Training, Kuwait - Kuwait
[2]Department of Mechanical Engineering, Faculty of Engineering, South Valley University, Qena 83521, Egypt
*Corresponding Author: Fayez S. M. M. M. Almutairi

Abstract The present study examined the heat transfer performance of circular jets arranged in-line array. This result carried out under different conditions such as, Reynolds number varied from 2000, 4000, 6000, 8000, and 10000. Four jets are array inline circular cross section. The spacing distance between jets are considered constant of (S/d = 6). The separation distance (H/d = 2, 4, 6, and 8). The result showed that, the cooling process enhancement with increase of Reynolds number.

Keywords cooling Jets, Circular jets, Heat Transfer

1. Introduction

Impingement with high velocity gas jets has become an established method of convectively cooling or heating surfaces in a wide variety of process and thermal control applications. Examples include cooling of gas turbine air- foils and electronic equipment, drying of paper and textiles or other thin layers of films, annealing of metals, and glass tempering operations. The most commonly used jet openings are slots and circular holes. For applications requiring highly localized heating or cooling a single circular jet may suffice. For long, but very narrow areas a single row of circular jets or a single slot jet may be appropriate [4]. The single row or slot may also be adequate, in some cases, for treating sheets of material which can be moved continuously past the row or slot. However, where all portions of a surface of larger expanse must be continuously heated or cooled, multiple slot jets or two-dimensional arrays of jet orifices are required [1-6].

In addition to the increased heat rates attainable relative to non-impinging flows, the jet array provides the designer with potential for a high degree of control of the distribution of surface heat transfer characteristics [4-5]. By varying the flow and geometric parameters, including the number, size, and spacing of the jet orifices as well as the nozzle-to-target plate height, the potential exists for adjustment of the heat transfer coefficients to achieve a specified distribution in surface temperature or heat flux [7-10].

The collision of wall jets leads to an interesting flow feature. [11] presents an investigation of three impinging jets related to the operation of the aircraft. He identified the existence of an upwash flow between two adjacent impinging jets. A schematic of such a flow is given in Figure 1. The upwash flow is a result of the above mentioned collision of wall jets. It affects the entrainment of the impinging jets and provides two mechanisms for the discharge of exhaust air. Part of the exhaust air in the upwash flow is entrained into the adjacent jets, while the other part is discharged along the nozzle plate, avoiding the adjacent jets.

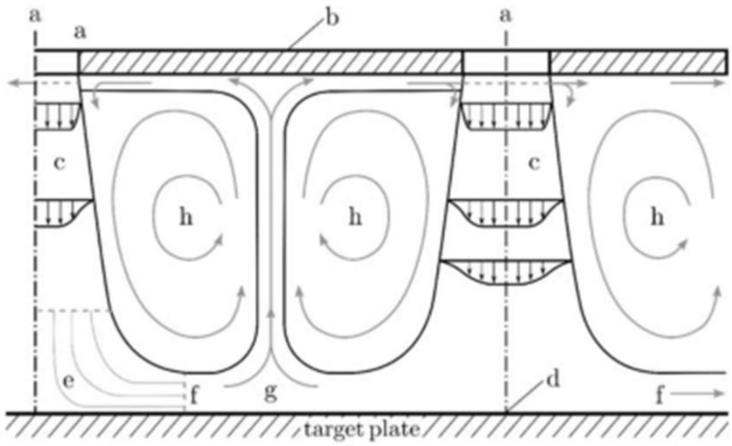

Figure 1: Flow characteristics and interactions of multiple jet impingements [11]

Wen, He and Ma, [12] 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.

He and Wen [7] 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.

A. Sarkar, N. Nitin, M.V. Karwe [1] have investigated the physical characteristics of impinging jets, such as turbulent mixing in the free jet region, stagnation, boundary-layer formation, recirculation, and their interactions on heat and mass transfer. The discussion includes experimental methods used for measurement of heat and mass transfer for single and multiple slot and circular jets. Procedures used for measurement of heat-transfer coefficient such as lumped sensor method, micro-calorimetric approach, and use of flux sensors are presented. Typical qualitative and quantitative flow field studies using planar visualization and laser Doppler anemometry have been reviewed. Numerical modelling of air impingement systems is discussed with special consideration of problems arising in food- processing systems.

Wae-Hayee, Tekasakul and Nuntadusitb [13] investigated the effect of jet arrangements on flow and heat transfer characteristics was experimentally and numerically investigated for arrays of impinging jets. The air jets discharge from round orifices and perpendicularly impinge on a surface within a rectangular duct. Both the in-line and staggered arrangements, which have an array of 6×4 nozzles, were examined. A jet-to- plate distance (H) and jet-to-jet distance (S) were fixed at H=2D and S=3D, respectively (where D is the round orifice diameter). The experiments were carried out at jet Reynolds number Re=5,000, 7,500 and 13,400. The results revealed that the effect of crossflow on the impinging jets for the staggered arrangement is stronger than that in the case of in-line arrangement. In the latter case of in- line arrangement, the crossflow could pass throughout the passage between the rows of jets, whereas in the former case the crossflow was hampered by the downstream jets. The average Nusselt number of the in-line arrangement is higher than that of the staggered arrangement by approx. 13-20% in this study.

The main objective of this study is to examine the heat transfer of heat transfer of circular as well as square nozzles, arranged to form an in-line array. To achieve this goal, the characteristics of heat transfer over impinging plate will be studied therefore the local heat transfer will be estimated. This result carried out under different conditions such as, Reynolds number varied from 2000, 4000, 6000, 8000, and 10000. Four jets are array inline circular and square cross section. The spacing distance between jets are considered constant of (S/d = 6). The separation distance (H/d = 2, 4, 6, and 8).

2. Experimental Set-Up

The experimental set-up sketched in Fig. 2 was constructed to determine the heat transfer from a flat plate sheet with multiple jets arrays. This includes the air supply section, heating section, distribution box, multiple jets system, impingement sheet and Infrared thermo camera.

The metal sheet was made up of the nickel basis alloy Inconel 600 of size

200 mm x 100 mm. It is being cooled on one side (top side) by the air multiple jets system, while on the other side (bottom side) the surface temperature was measured by an infrared thermo camera. Because of the small thickness of 0.1 mm, the temperature difference between both sides was always lower than 0.065 K, therefore the temperature of both sides could be assumed to be equal, as will be explained later.

The metal sheet was clamped lengthwise between two copper blocks. These copper blocks conduce to the fixation of the plate and in addition to the consistent conduction of electricity. To generate a constant electric transition, a conductive paste of copper basis was used between the copper blocks and the metal sheet. Bar electrodes were embedded in the copper blocks which run from the flexible copper cable to the power source. The power supply was made up of DC transformer (400 A, 7 V) which was controlled by a PC. The amperage was to be assumed and the voltage was adjusted according to the total drag of the current path.

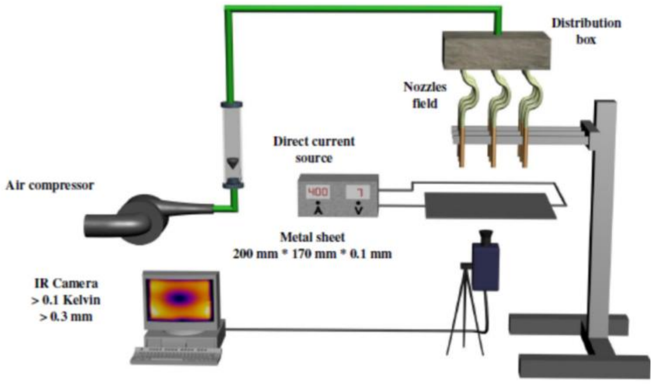

Figure 2: Experimental Set-Up

3. Data Reduction

In the present study the heat losses from the impinging plat by free convection is very small compared to heat flux [9].

The local convective heat transfer coefficient of the target surface is estimated based on the following equations.

Heat transfer coefficient:

$$h = \frac{q_{con}}{T_s - T_j} \quad (1)$$

Where: Ts = Surface temperature (K); jr = jet temperature (K),

$$q_{con} = q_{ele} - q_{loss} \quad (2)$$

Where

$$q_{ele} = q_{rad} - q_{nat} \quad (3)$$

$$q_{ele} = VI \quad (4)$$

Where: V= Supply voltage (V); I = Supply current (Amp)

The Nusslet number could be estimated by the following equation:

$$Nu = \frac{h.d}{k} \quad (5)$$

The Reynolds number could be calculate by the following equation

$$\mathrm{Re} = 4\dot{m}/\pi.\mathrm{d}.\mu. \quad (6)$$

4. Results and Discussion

4.1 Distribution of Surface Temperature

Nusselt number contours for circular and square nozzles for spacing and separation distances equal to 6 and 2 for different values of Reynolds number (2000, 6000, 8000, and 10,000) are presented in Fig. 3. It is observed that the color of contours is brighter with decreasing the Reynolds number for circular nozzle. This due to the increase of the momentum of the jet with increasing the Reynolds number [14]. In addition, the colour patterns for circular and square nozzles are symmetrical in x and y directions due to the symmetric geometric structure of the circular and square nozzles in x and y directions. Moreover, the contour colour is darker at the center of nozzle for all cases. On other hand, the colour brightness increases sharply between the impingement points due to decreasing the radial wall jet velocity with increasing the distance from the jet impingement point and the heating of air [14]. In addition, the contours colour for the circular nozzles is slightly darker than those for the square nozzles. This may be attributed to the decay in axial velocity in the square nozzle as reported in [15].

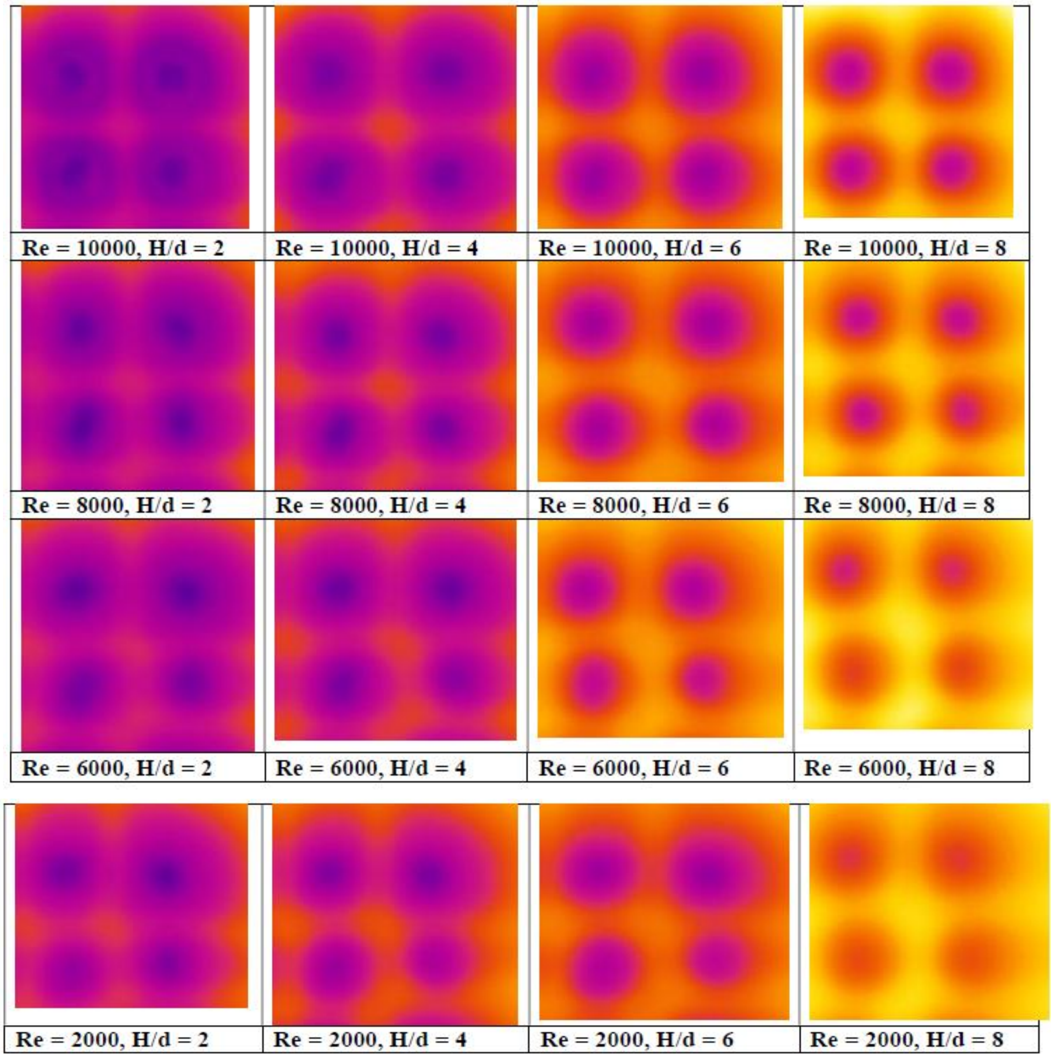

Figure 3: Temperature contours for Circular Jets

4.2 Local Nusselt Number

The radial distribution of local Nusselt number for the circular and squaer- line array is presented in Figs. 4a-d for all Reynolds numbers (10000, 8000. 6000, 4000 and 2000). The separation distance H/d was chosen in the range from 1 to 8. The distributions of the heat transfer for S/d = 8 is shown in Figs. 4a-d and. Examination of the Nusselt number values of Figs. 4a-d clearly shows the presence of secondary region or peak. This is because the spacing distance between adjacent jets is large and can consider each jet as single nozzle. In this case, the maximum Nusselt number occurs at the stagnation point as observed with larger separation distances. The secondary peak is ring around the stagnation point. This ring occurs at $X/d \approx 0.5$ and $X/d \approx 1.8$. The peaks which occurred at $X/d \approx 1.8$, is attributed to both the fluid accelerating out of the stagnation region which thins the local boundary layer and the influence of the shear layer generated turbulence around the circumference of the jet. This peak also caused by the transition to turbulent flow in the boundary layer. Thus, as Reynolds number increases, the peak in the local Nusselt number becomes more pronounced. This peak becomes less pronounced as the Reynolds number is reduced and the separation distance is increased. A decrease in Reynolds number and an increase or the separation distance appears to promote an earlier boundary layer transition from laminar to turbulent flow, because the location of this peak moves toward the stagnation point when either of these two parameters are varied appropriately [14].

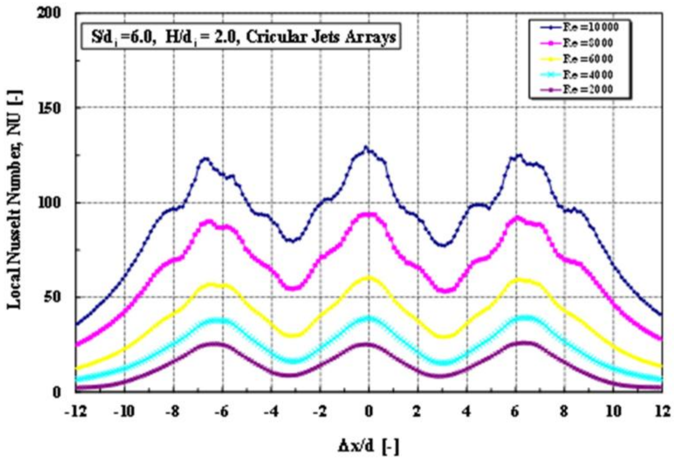

Figure 4a: Radial Local Nussle number Distribution for Circular Array at H/d = 2

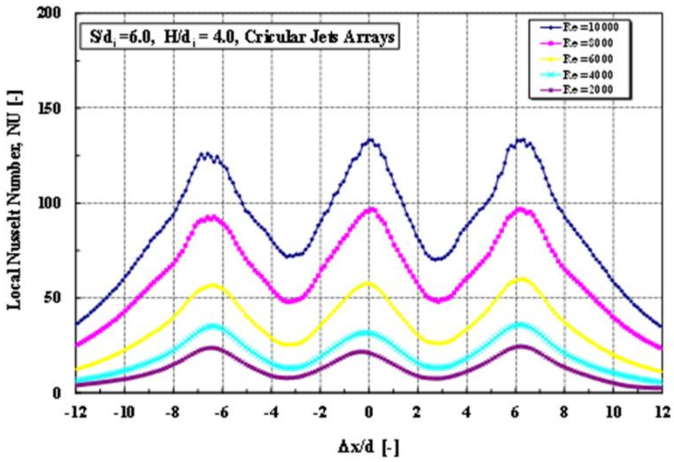

Figure 4b: Radial Local Nussle number Distribution for Circular Array at H/d = 4

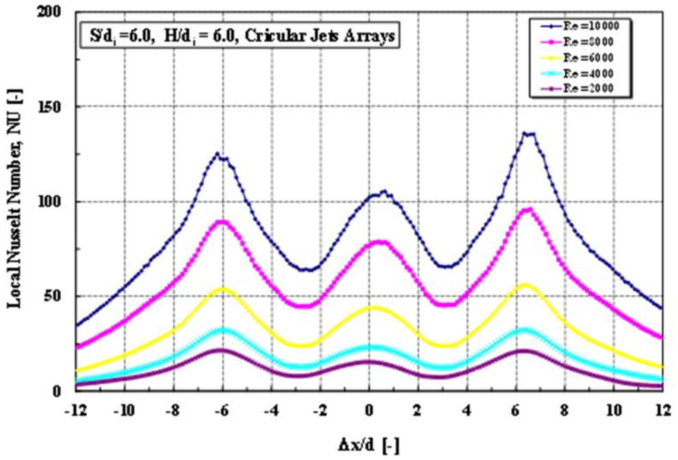

Figure 4c: Radial Local Nussle number Distribution for Circular Array at H/d = 6

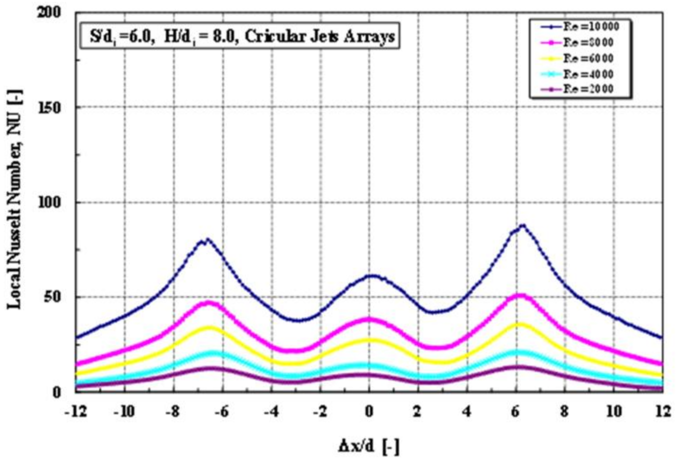

Figure 4d: Radial Local Nussle number Distribution for Circular Array at H/d = 8

5. Conclusions

The main conclusion as the following:

- The second peak is shown in the redial distance x/d = 1.87, for all values of Reynolds number.
- The local Nusslet numbers are increase with increase on flow rate of air goes out from the nozzle. This results because the turbulent intensity in more effect than laminar flow.
- The local Nusselt number in nearly constant the separation distance ranged from $H/d \leq 4$. In this case the nozzle is optional core length, therefore the velocity profile is not change through this region.

References

[1]. A. Sarkar, N. Nitin, M.V. Karwe, A. R. P. S. (2004) 'Fluid Flow and Heat Transfer in Air Jet', Journal of Food Science CRH113, 69(4), pp. 113–122.

[2]. Attalla, M. (2015) 'Stagnation Region Heat Transfer for Circular Jets Impinging on a Flat Plate', Experimental Heat Transfer: A Journal of Thermal Energy Generation, Transport, Storage, and Conversion, 28(2), pp. 139–155.

[3]. Attalla, M. and Specht, E. (2009) 'Heat transfer characteristics from in-line arrays of free impinging jets', Heat and Mass Transfer/Waerme- und Stoffuebertragung. doi: 10.1007/s00231-008-0452-y.

[4]. Berry, R. D. (1978) Heat Transfer from Arrays a impinging Jets with Large Jet- to-Jet. Available at: http://heattransfer.asmedigitalcollection.asme.org/.

[5]. Crispo, C. M., Greco, C. S. and Cardone, G. (2018) 'Convective heat transfer in circular and chevron impinging synthetic jets', International Journal of Heat and Mass Transfer. doi: 10.1016/j.ijheatmasstransfer.2018.06.062.
[6]. Gao, L. and Tong, S. J. (1998) Effect of Jet Hole Arrays Arrangement on Impingement Heat Transfer.
[7]. He, Y. L. and Wen, Z. X. (2017) 'Experimental study on cooling performance of multiple impinging jets with different nozzle arrangements in a ground fast cooling simulation device', Applied Thermal Engineering. doi: 10.1016/j.applthermaleng.2016.11.091.
[8]. Huber, A. M. and Viskanta, R. (1994) 'Effect of jet-jet spacing on convective heat transfer to confined, impinging arrays of axisymmetric air jets', International Journal of Heat and Mass Transfer. doi: 10.1016/0017-9310(94)90340-9.
[9]. James Guzlntner, by W. et al. (1970) N A S A T E C H N I C A L N O T E N A S A Tn D-5652 C F I L E C O P Y Survey Of Literature On Flow Characteristics Of A Single Turbulent Jet Impinging On A Flat'plate Survey of Literature On Flow Characteristics Of A Single Turbulent Jet Impinging On A Fl. Available at: https://ntrs.nasa.gov/search.jsp?R=19700009658.
[10]. Ozmen, Y. and Ipek, G. (2016) 'Investigation of flow structure and heat transfer characteristics in an array of impinging slot jets', Heat and Mass Transfer. Springer Berlin Heidelberg, 52(4), pp. 773–787. doi: 10.1007/s00231-015-1598-z.
[11]. San, J. Y. and Chen, J. J. (2014) 'Effects of jet-to-jet spacing and jet height on heat transfer characteristics of an impinging jet array', International Journal of Heat and Mass Transfer, 71, pp. 8–17. doi: 10.1016/j.ijheatmasstransfer.2013.11.079.
[12]. Wen, Z. X., He, Y. L. and Ma, Z. (2018) 'Effects of nozzle arrangement on uniformity of multiple impinging jets heat transfer in a fast cooling simulation device', Computers and Fluids. doi: 10.1016/j.compfluid.2017.05.012.
[13]. Wae-Hayee, M., Tekasakul, P. and Nuntadusit, C. (2013) 'Influence of nozzle arrangement on flow and heat transfer characteristics of arrays of circular impinging jets', J. Sci. Technol, 35(2), pp. 203–212. Available at: http://www.sjst.psu.ac.th.
[14]. Wang, B. et al. (2018) 'Local Heat Transfer Characteristics of Multi Jet Impingement on High Temperature Plate Surfaces', ISIJ International. doi: 10.2355/isijinternational.ISIJINT-2017-154.
[15]. Roy, S. and Patel, P. (2003) 'Study of heat transfer for a pair of rectangular jets impinging on an inclined surface', International Journal of Heat and Mass Transfer. doi: 10.1016/S0017-9310(02)00295-8.