

PAPER • OPEN ACCESS

Heat Transfer Characteristics of Twin Circular Jet Impingement Cooling on the Strip Surface after Rolling

To cite this article: Jianhui Shi *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **472** 012042

View the [article online](#) for updates and enhancements.

Heat Transfer Characteristics of Twin Circular Jet Impingement Cooling on the Strip Surface after Rolling

Jianhui Shi*, Liping Bian, Ruquan Liang and Song Xiao

School of Mechanical and Vehicle Engineering, Linyi University, Linyi 276000, China

*Corresponding author

Email:sjh051208@126.com

Abstract. The heat transfer characteristics of the strip surface due to the twin circular jet impingement were numerically investigated by a three-dimensional finite element program. Systematic parametric research is conducted by varying the jet velocity of nozzle exit of 7.5 m/s, nozzle to the steel plate surface distance ($H=6.7, 11.7, 16.7$), and the nozzle to nozzle centre spacing ($W=10, 15$). The general trend of the distribution of the local Nusselt number and the average Nusselt number variation on the impingement surface of strip was obtained under the various parameters. The results show that, the heat transfer capacity of the strip surface perpendicular to the centre of the two jets decreases with the increase of the nozzle to nozzle centre spacing. The average Nusselt number increases by about 2%-20% with the increase of nozzle to the steel plate surface distance from 6.7 to 11.7 for the nozzle to the steel plate surface distance of 100mm and 200mm, while the average Nusselt number decreases by about 11%-25% with the increase of nozzle to the steel plate surface distance from 11.7 to 16.7.

1. 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 widely used for controlling the steel plate temperature. For the steel plate and strip, heat transfer of jet impinging is the key process of the ultra-fast cooling after rolling and it affects the cooling rate and uniformity of them. The study on twin and multi jet 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.

Xu et al. [1] carried out a numerical investigation on two-dimensional heat transfer behavior in the impingement zone under single circular water jet. Dou et al. [2] experimentally investigated the heat transfer characteristics of a circular water jet impingement on high-temperature steel plate. They found that increasing the surface roughness can provide better heat transfer in the stagnation region. The experimental and numerical study on the transient heat-transfer characteristics of circular air-jet impingement on a flat plate have been carried out by Guo et al. [3]. The study was performed for the inner diameter of circular nozzle of 6 mm and the Reynolds number of 14,000 -53,000. Shi et al. [4] conducted a numerical investigation on the heat transfer symmetry of a single group oblique slot jet impingement for high temperature strip after hot rolling. They reported that the functional relationship between the systematic parameters and the discrepancy of the average Nusselt number or the coordinate values of the stagnation point. Wang et al. [5] investigated the effect of the initial surface temperature, water temperature, and jet velocity on the heat transfer characteristics during the cooling process of a water jet impinging on a hot plate surface. They observed that the wetting delay time was extended by the superheat increase and the sub-cooling and jet velocity decrease.



Frosell et al. [6] investigated the dynamics of the impingement region of a circular turbulent jet for the nozzle diameter of 6.4mm, the distance from the nozzle to the impingement surface of 2.5-8.5 and the Reynolds number of 71,000 -142,000. Their results showed that the size and the movement of the impingement region are observed to increase linearly with the standoff distance of the nozzle, while the size of the impingement region is independent of the fluid velocity at the nozzle. Brian et al. [7] experimentally studied the effects of volumetric quality (0-0.9) on the hydraulic jump radius, local Nusselt number and the pressure at the stagnation point for air-assistant circular water jet impinging. Their results showed that the dimensionless hydraulic jump radius increased with volumetric quality, attained a maximum value at around 0.8 of the volumetric quality, and then decreased. A few studies on the circular jet impingement cooling of the circular cylinder have been presented by Lee [8], Wang [9], Amirhosein [10] and Dushyant [11].

The object of the above studies is single circular jet impinging cooling, while a few studies on two or multi jet impingement cooling were carried out. Abdel [12] conducted experimental and numerical studies on the two dimensional impinging twin circular air jet flow with no-cross flow. The parametric was carried out for Reynolds number of 95,000-224,000, nozzle to plate spacing (h/d) of 3-12, nozzle to nozzle centerline spacing (l/d) of 3, 5 and 8, and jet angle of 0-20°. It was observed that the spreading of jet decreases by increasing nozzle to plate spacing, the intensity of re-circulation zone between two jets decreases by increasing of h/d and jet angle, and the increase of turbulence kinetic energy occurs within high gradient velocity. Greco et al. [13] experimentally study the behavior of impinging single and twin circular synthetic jets in phase opposition. Dushyant et al. [14] carried out an experimental and numerical investigation on flow and heat transfer characteristics of double circular air jet impingement cooling of a heated circular cylinder. They reported that the average Nusselt number over the cylinder surface increased with the increase in non-dimensional distance between double the jets and the confinement at the bottom of the cylinder increases heat transfer.

Christopher [15]2016 carried out a numerical investigation on convective heat transfer of multiple impinging circular jets for a horizontal circular cylinder. They reported that movement away from the cylinder axis, increased axial spacing and lateral offset all lead to degradation of heat transfer from the cylinder for jet-to-cylinder ratios of the jet-to-cylinder diameter ratio great than or equal to 0.23. Satyanand [16]2018 investigated the effectiveness distribution measurements for a row of heated circular jets impinging on a cylindrical convex surface at different inclinations.

2. Numerical Procedures

2.1. Governing Equations

Reynolds averaged equations can be written using mass Eq. (1), momentum Eq. (2) and energy Eq. (3) for the steady incompressible flow.

$$\frac{\partial u_i}{\partial x_i} = 0 \quad (1)$$

$$\rho u_j \frac{\partial u_i}{\partial x_j} = \frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j} \left[\mu \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) - \overline{\rho u'_i u'_j} \right] \quad (2)$$

$$\rho u_j \frac{\partial T}{\partial x_j} = \frac{\partial}{\partial x_j} \left[\frac{\mu}{Pr} \frac{\partial T}{\partial x_j} - \overline{\rho T' u'_j} \right] \quad (3)$$

Where, P is the mean pressure, T is the mean temperature, T' is the fluctuating temperature, u_i and u_j are the mean velocity, u'_i and u'_j are the fluctuating velocity, x_i and x_j are the coordinate direction, ρ , μ and Pr are the fluid density, the dynamic viscosity, and the Prandtl number, respectively.

2.2. Boundary Conditions and Initialization

Fig. 1 shows the three-dimensional simplified model of the circular jet impinging on the hot rolling strip. The shaded region in the bottom of the model is the section of the strip, and the other cylindrical areas (ABCD) above the shaded region are the fluid calculation regions. The initial medium of fluid calculation regions is static air and the medium of jet is incompressible cooling water. The inlet jet velocity (V_0) of the circular jet is uniform. The diameter of the fluid inlet is d and r is the radius. The distances of the circular jet outlet to the strip surface is H ($H = h/r$), and h is the actual distance of the circular jet outlet to the strip surface. The distance between the centre of two circles jet is W ($W = w/r$), and w is the actual distance between the centre lines of two circular jet flows. The initial temperature of the cooling water is maintained at 300 K. The velocity component of the wall is zero. The normal pressure gradient of the outlet boundary is zero. The initial temperature of strip is evenly distributed (1123 K). The surface of the strip is specified as isothermal wall.

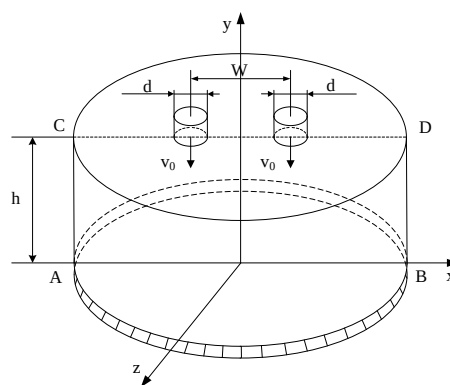


Figure1. The three-dimensional simplified model of the twin circular impinging jet

3. Simulation results and Analysis

Numerical investigations were carried out, and the parameters are the jet inlet velocity ($V=7.5\text{m/s}$), the nozzle to the steel plate surface distance ($H=6.7, 11.7, 16.7$), and the nozzle to nozzle centre spacing ($W=10, 15$) and the diameter of the fluid inlet ($d=6\text{mm}$). The Nusselt numbers of the X-axis and Z-axis on the steel plate surface were obtained under the various parameters. The X-axis is parallel to the centre of the two jets, and the Y-axis is perpendicular to the centre of the two jets.

3.1. Local Nusselt Number Distribution Along the Strip Surface

In order to study the heat transfer features of the twin circular jet impingement cooling processes, the distribution of the local Nusselt number on the strip surface of the strip for X-axis and Z-axis is plotted in Fig. 2 to Fig. 3. These plots are shown for a length of the heat transfer surface of 200mm from the symmetry plane ($x = 0$ or $z=0$).

In Fig.2, the overall distribution trend of the local Nusselt number on strip heat transfer surface is that the valley value of the Nusselt number appears at the symmetry point for X-axis, and two peak values of the Nusselt number form near the stagnation point. The valley value of the Nusselt number decreases with the increase of the nozzle to nozzle centre spacing from 10 to 15, and the two peaks near the stagnation point also change from steep to gentle. While the range of the heat transfer surface of the strip gradually increased with the increase of the nozzle to nozzle centre spacing.

In Fig.3, the overall distribution trend of the local Nusselt number for Z-axis is that the multiple peak values of the Nusselt number appear at strip heat transfer surface. When the non-dimensional domain of the two nozzles centre is 10, the general trend of the valley value near stagnation point is closed to the X-axis. As the two jets are relatively close, the main heat transfer region still appears at the middle area. The Nusselt number of the heat transfer surface for X-axis became more uniform with the increase of the non-dimensional domain of the two nozzles centre, and multiple small peaks form along the heat transfer surface, and the peak values decreased. It indicates that the heat transfer

capacity of the strip surface perpendicular to the centre of the two jets decreases with the increase of the nozzle to nozzle centre spacing.

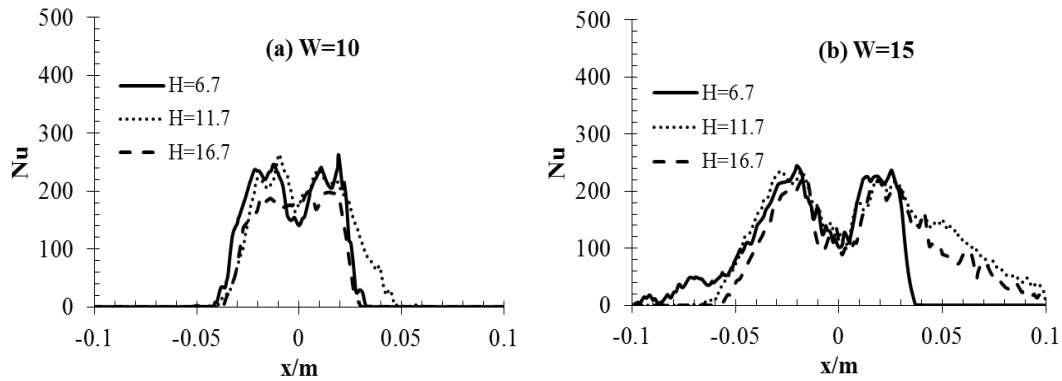


Figure 2. Local Nusselt number distribution along the strip surface with jet velocity of 7.5m/s for x

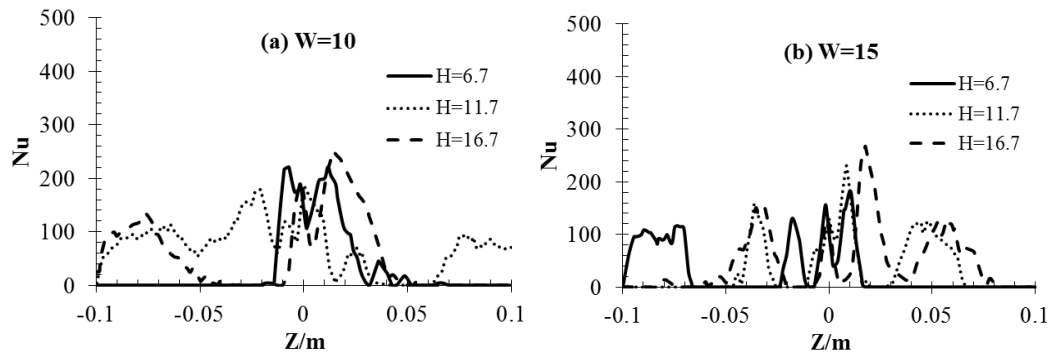


Figure 3. Local Nusselt number distribution along the strip surface with jet velocity of 7.5m/s for z

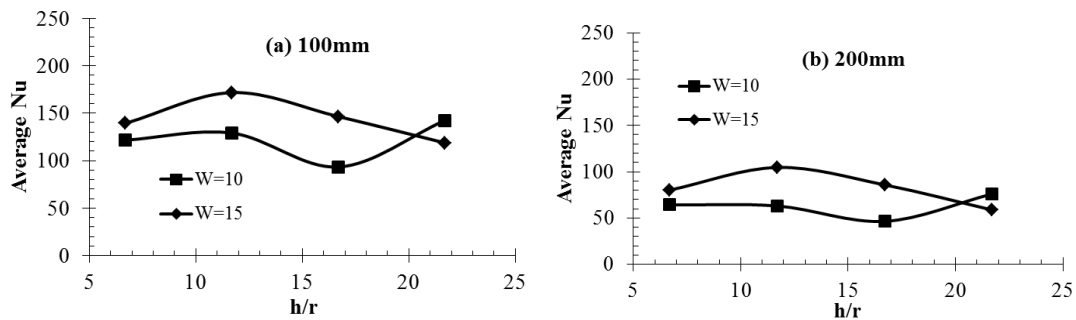


Figure 4. Average Nusselt number variation along the strip surface of 7.5m/s for x axis

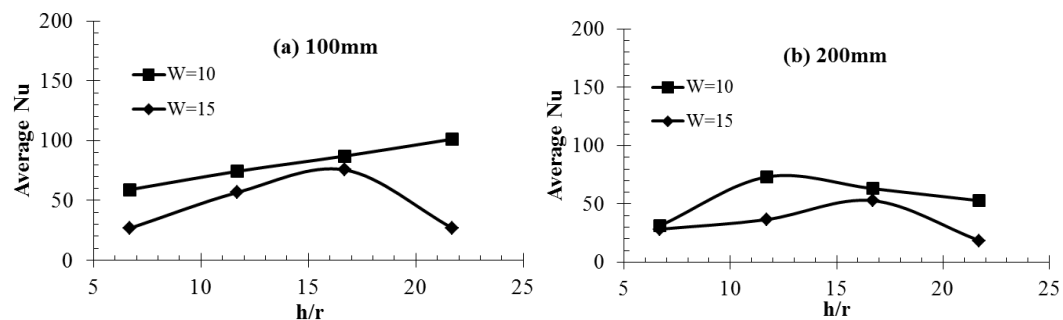


Figure 5. Average Nusselt number variation along the strip surface of 7.5m/s for z axis

3.2. Average Nusselt Number Variation along the Strip Surface

Fig. 4 and Fig. 5 show the average Nusselt number variation of the heat transfer surface with the effect of various parameters for X-axis and Z-axis. The analysis length of strip surface is 100mm (-50mm to 50mm) in Fig. 4 (a), and it is 200mm (-100mm to 100mm) in Fig. 4 (b). It is noticed that the average Nusselt number of the strip surface for X-axis increases with the increase of the nozzle to the steel plate surface distance for H of 6.7 to 11.7. In addition to some irregularities of the average Nusselt number, the general trend is that the average Nusselt number increases by about 6%-15% with the increase of H for the nozzle to the steel plate surface distance of 100mm, and it increases by about 2%-20% for the nozzle to the steel plate surface distance of 200mm. while the average Nusselt number of the strip surface for X-axis decreases with the increase of the nozzle to the steel plate surface distance for H of 11.7 to 16.7. The average Nusselt number decreases by about 11%-22% with the increase of H for the nozzle to the steel plate surface distance of 100mm, and it decreases by about 15%-25% for the nozzle to the steel plate surface distance of 200mm.

4. Conclusions

The heat transfer characteristics of the twin circle jet impingement for the parameter of nozzle to the steel plate surface distance and the nozzle to nozzle centerline spacing is investigated numerically using the ANSYS Fluent. The ratio of the the steel plate surface distance is varied from 6.7 to 16.7, and the nozzle to nozzle centerline spacing is forced from 10 to 15. The distribution of the local Nusselt number on the strip surface for X-axis and Z-axis were obtained. The average Nusselt number variation of the heat transfer surface with the effect of various parameters for the analysis length of 100mm to 200mm was investigated. The valley value of the Nusselt number decreases with the increase of the nozzle to nozzle centre spacing from 10 to 15, and the two peaks near the stagnation point also change from steep to gentle. The average Nusselt number increases by about 2%-20% with the increase of H from 6.7 to 11.7 for the nozzle to the steel plate surface distance of 100mm and 200mm. while the average Nusselt number decreases by about 11%-25% with the increase of H from 11.7 to 16.7.

Acknowledgments

This work is supported by the Shandong Provincial Natural Science Foundation of China (Grant NO. ZR2018PEE004).

References

- [1] Xu F C, Gadala M S, Heat transfer behavior in the impingement zone under circular water jet 2006, *Int. J. Heat Mass Transf.* **49** 3785-3799.
- [2] Dou R F, Wen Z, Zhou G, Liu X L and Feng X H, Experimental study on heat-transfer characteristics of circular water jet impinging on high-temperature stainless steel plate 2014, *App. Therm. Eng.* **62** 738-746.
- [3] Guo Q, Wen Z and Dou R F, Experimental and numerical study on the transient heat-transfer characteristics of circular air-jet impingement on a flat plate 2017, *Int. J. Heat Mass Transf.* **104** 1177-1188.
- [4] Shi J H, Yuan G, Jiang L Y, Li Z L, Zhao K and Wang G D, Heat transfer symmetry of the strip surface due to a group oblique slot jet impingement after hot rolling 2015, *Steel Res. Int.* **86** 1548-1557.
- [5] Wang B X, Lin D, Xie Q, Wang Z D and Wang G D, Heat transfer characteristics during jet impingement on a high-temperature plate surface 2016, *App. Therm. Eng.* **100** 902-910.
- [6] Frosell T, Fripp M and Gutmark E, Dynamics of the impingement region of a circular turbulent jet 2018, *Exp. Therm. Fluid Sci.* **91** 399-409.
- [7] Brian K F, Tamira D F, Aspen W G and Kyosung C, Experimental study of the hydrodynamic and heat transfer of air-assisted circular water jet impinging a flat circular disk 2017, *Int. J. Heat Mass Transf.* **106** 804-809.
- [8] Lee D H, Chung Y S and Kim D S, Turbulent flow and heat transfer measurements on a curved surface with a fully developed round impinging jet 1997, *Int. J. Heat Fluid Fl.* **18** 160-169.

- [9] Wang X L, Motala D, Lu T J, Song S J and Kim T, Heat transfer of a circular impinging jet on a circular cylinder in crossflow 2014, *Int. J. Therm. Sci.* **78** 1-8.
- [10] Amirhosein H, Mehran R Z, Heat transfer and flow characteristics of impinging jet on a concave surface at small nozzle to surface distances 2018, *App. Therm. Eng.* **138** 534-541.
- [11] Dushyant S, Premachandran B and Sangeeta K, Circular air jet impingement cooling of a circular cylinder with flow confinement 2015, *Int. J. Heat Mass Transf.* **91** 969-989.
- [12] Abdel F A, Numerical and experimental study of turbulent impinging twin-jet flow 2007, *Exp. Therm. Fluid Sci.* **31** 1061-1072.
- [13] Greco C S, Castrillo G, Crispo C M, Astarita T Cardone G, Investigation of impinging single and twin circular synthetic jets flow field 2016, *Exp. Therm. Fluid Sci.* **74** 354-367.
- [14] Dushyant S, Premachandran B and Kohli S, Double circular air jet impingement cooling of a heated circular cylinder 2017, *Int. J. Heat Mass Transf.* **109** 619-646.
- [15] Christopher C, Anthony G S, Forced convective heat transfer on a horizontal circular cylinder due to multiple impinging circular jets 2016, *App. Therm. Eng.* **105** 290-303.
- [16] Satyanand A, Rajendra P V, Effectiveness distribution measurements for a row of heated circular jets impinging on a cylindrical convex surface at different inclinations 2017, *Int. J. Heat Fluid Fl.* **69** 210-223.