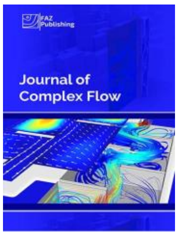
JCF

Journal of Complex Flow, Vol. 3 No. 2 (2021) p. 7-11

Journal of Complex Flow

Journal homepage : www.fazpublishing.com/jcf

e-ISSN : 2672-7374



2-Dimensional Numerical Study of Multiple Slot Jet Impingement on Flat Surfaces

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Received 23 April 2021;
Accepted 16 June 2021;
Available online 30 Oct. 2021

Abstract: Convectional The results of the numerical simulations carried out in this research is for the modeling of jet impingement cooling systems. To develop a more effective jet impingement cooling system, numerous ways were tested. This thesis investigates the effect of multiple slotted jet impingement where the distance between nozzle's pitch is manipulated to determine the heat transfer relationship. This research also factors in the investigation of the spacing distance between the nozzle inlets to the impinge flat surface. This research is carried out in ANSYS Fluent for the Computer Fluid and Dynamics software approach. The result of this research is generated and analyses with comparison data from the previous studies that had been conducted and validated. These investigations are required in addition to the current research efforts for future cooling system development in global industries. They are three primary factors that are varied in the experiment such as the nozzle-to-nozzle width ($X_n/B = 8, 16, 24$), the distance between the nozzle and the flat surface ($Z_n/B = 5, 8,16$), and the Reynolds number involved in this study is 500, 1000, 2000, 10000, 20000. The heat source or heated plate is about 400k and cooled down by the flow of air jets from the nozzle. The heated plate is then measured after the cooling to find out the heat transfer coefficient. The effect shows the discovery of the relationship of the nozzle-to-nozzle width of the jet impinging on a flat surface. The most noticeable configuration is where the width of the nozzle to nozzle is at $X_n/B = 24$ and the distance from the nozzle to heated flat plate is at $Z_n/B = 5$. Moreover, it is also shown that a high Nusselt number is produced by a high Reynolds number and a small distance between the nozzle edges and the impingement surface, implying that the systems will be cooled effectively.

Keywords: CFD, numerical analysis, jet impingement, fluent

1. Introduction

Heat Impinging jets have received considerable attention due to their inherent characteristics of high rates of heat transfer besides having simple geometry. Various industrial processes on apply impinging jets. Few industrial processes which employ impinging jets are drying food products, textiles, films, and papers on processing of some metals and glass, cooling gas turbines blades and outer wall of the combustion chamber, cooling electronic equipment [1]. The nozzle effect in the case of impinging jets is affected by various parameters like Reynolds number, jet to plate spacing, duty cycle, nozzle geometry, and others parameters [2].

Jet impinging cooling with a suitable fluid medium is widely preferred where high rates of heat transfer are desired. It gives better local heat transfer performance as compared to parallel flow cooling, such as duct flow. When jet impinges on a heated plate, a thin boundary layer formed over it results in a higher convective heat transfer coefficient. Due to this advantage, the jet impingement cooling technique is widely used in the cooling of gas turbine components, freezing of tissue in cryosurgery, drying of textiles products and paper, electronics cooling, glass tempering, metals cooling, etc. [3-5]. There have been many researchers who reported the investigations of the heat transfer characteristic of impinging jets in the past decades. Jambunathan *et al*. [6] reviewed the heat transfer characteristics of a single circular jet impinging on a flat surface. It depends on the parameters such as Reynolds number, nozzle to plate spacing, radial distance, Prandtl number, the turbulent intensity at a nozzle exit, confinement of jet, and nozzle geometries [7].

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A lot of equipment or appliances need to have a high heat transfer performance to guarantee the quality and to increase the capability; old cooling systems cannot be used anymore as it does not cool sufficiently. This makes it necessary to develop new techniques to meet the demand, so researchers are moving towards the technology of jet impingement cooling systems. In the design of an impinging-jet system for a given thermal application, a large number of geometric and flow parameters like jet type (round/slot) [8], nozzle to target spacing, angle of impingement, nozzle design, jet-inlet Reynolds number, etc. are involved. So, a purely experimental approach to the problem is unlikely to lead to a satisfactory solution at a reasonable cost and time. With the availability of computers and robust numerical techniques a properly validated numerical study can enhance our understanding of the jet impingement flow and heat transfer phenomena with much less cost and time.

For this study, several objectives have been laid out which are to investigate the characteristic of thermal and flow fields on flat surfaces caused by multiple slot jet impingement. Besides that, this study also aims to obtain a correlation between flow geometries and the thermal performance of multiple jet impingement cooling. This study only simulates for steady-state flow only, by using Ansys fluent software package to run the simulation. The simulation only for 2-dimensional submerged jet flow with the angles of jet impingement will be set at 90°. This study focuses on multiple jets from slot nozzles impinging on a flat surface and nozzle tip to impingement surface distance is ranging from 0.5 to 20 times the nozzle width. The jet-to-jet distance is ranging from 10 to 40 times the nozzle width while the Reynolds number is between 500 to 20000.

This study is essential to acquire the result of the analyzed data of multiple impinging jets on a flat surface. Jet impingement study is important because of its various applications in different industries [9-12], ranging from school sensitive electronic equipment and drying of paper and the cooling of turbine blades, and to de-ice aircraft wings in severe weather, so advanced approach yields low cost and accurate prediction of heat transfer process on a flat surface by impinging jet, which may help the design of above applications, with relative ease.

2. Methodology

The flowchart of the simulation flow for this study has been developed as shown in Fig. 1 below to achieve the objectives of this study. For simulation case of the jet impingement, the basic geometry shown in Fig. 2 while Fig. 3 described the boundary condition for the simulation model.

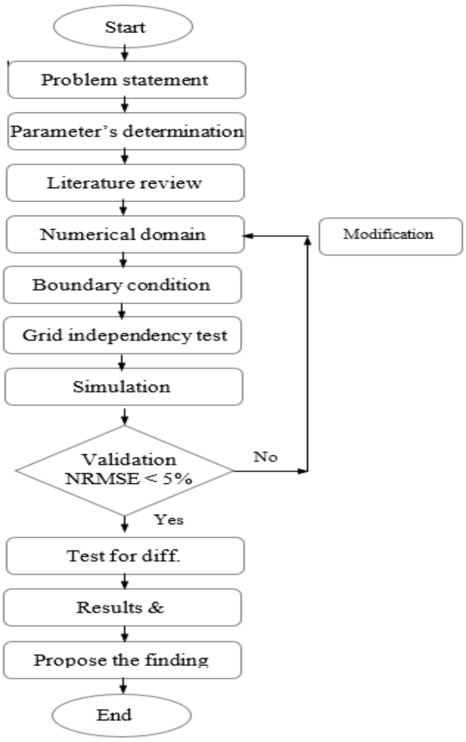

Fig. 1 – Process flow for the study

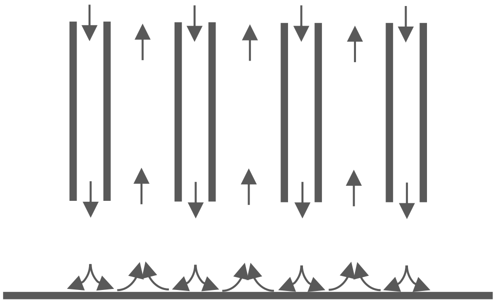

Fig. 2 – Basic geometry of the jet impingement

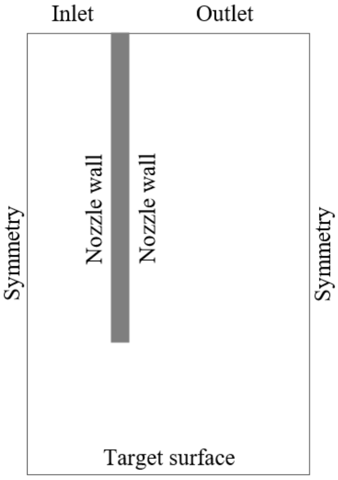

Fig. 3 – Computational domain of the jet impingement

2.1 Meshing

Meshing is a process where it refines (smaller cells) for high solution gradients and fine geometric detail [13, 14]. This process gives accuracy and stability deteriorate as mesh cell deviates from its ideal shape. Global mesh controls are used to make global adjustments in the meshing strategy, which includes sizing functions, inflation, smoothing, defeaturing, parameter inputs, and assembly meshing inputs. Minimal inputs automatically calculate global element sizes based on the smallest geometric entity. The smart defaults are chosen based on physics preference. Global mesh controls make global adjustments for the required level of mesh refinement. The advanced size functions are used for resolving regions with curvatures and proximity of surfaces. In the present study, verification process and Grid Independent Test, element sizing in a global mesh is adjusted until it is relevant with the mesh quality check.

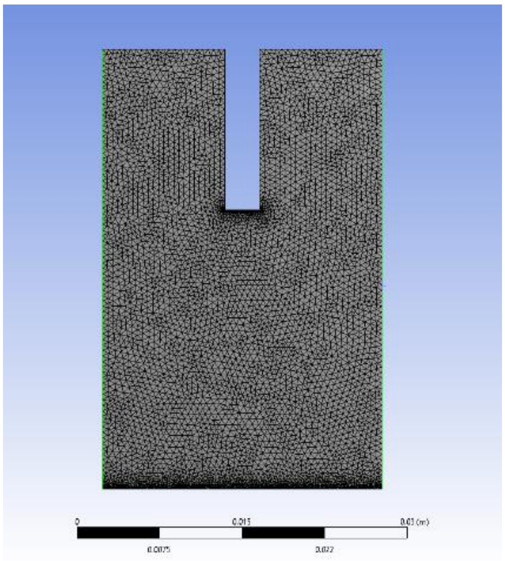

Fig. 4 – Meshing of the computational domain

3. Results and Discussion

In this chapter, an elaboration of graphical data and numerical data on the effect of the characteristic of thermal and flow fields on the flat surface caused by multiple slot jet impingement results is presented. The parameter that is taken to show the thermal and flow characteristics in the jet impingement on a flat surface is the surface heat transfer coefficient, velocity, and turbulent kinetic energy. This chapter discussed the explanation of methodology that was used to complete the simulation study on the effect of slotted jet impingement on a flat surface.

3.1 Data Verification

For verification purposes, a study by Robert Gardon & J. Cahit Akfirat, [15], graphical data are used to verify the new simulation. In the study, they indicated that four regimes of heat transfer can readily be recognized, correspondingly, respectively, to low and high Reynolds number and to the small and large nozzle to plate spacings. Which is in the nozzle size, B, nozzle to plate spacing, Zn. To compare the simulation result, a graph of surface heat transfer against the X/B position of the heated plate is plotted. The journal graph numerical data is obtained with the usage of a digitizer web application. In this simulation, the value of 1×10^{-5} is specified for the residual continuity and 10000 iterations are requested in the initialization. Hybrid initialization is used to initialize the flow field and simulation is calculated.

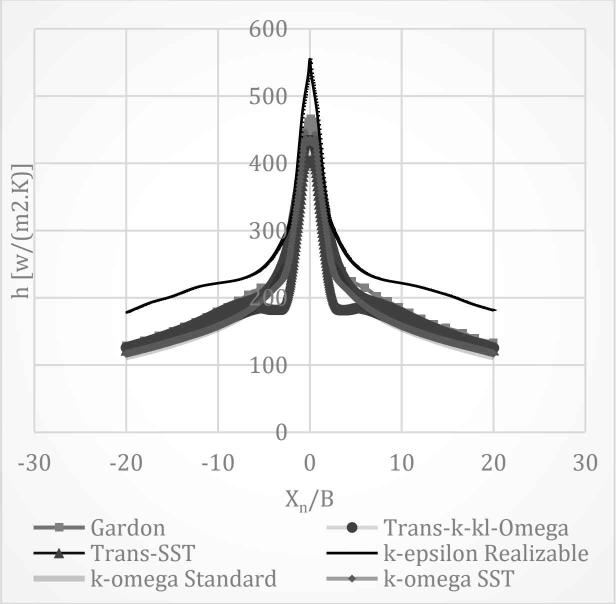

Fig. 5 - Comparison of data for NRSME from different turbulence model

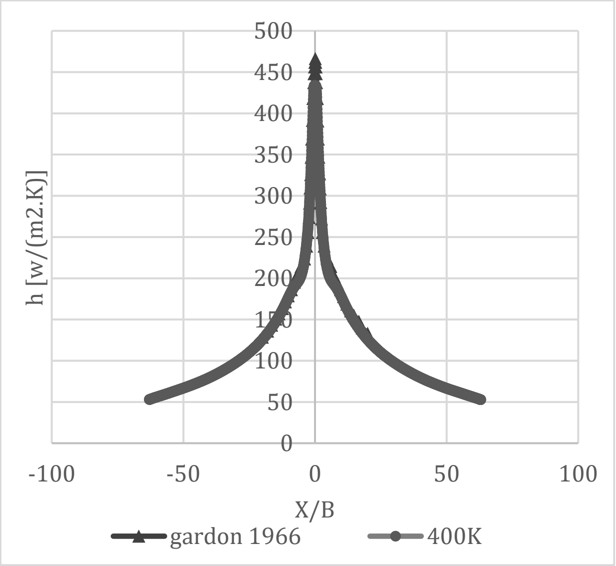

Fig. 6 - Comparison of current results with Gardon [11]

From the figures above, it shows that the comparison for simulation results with a different turbulent model and the comparison with the experimental data from Gordon. As mentioned previously the experimental data known as the reference data. Thus, the turbulence model Trans-k-kl-omega has the best characteristic like the reference line. It is also shown in the Table 1.

Table 1 – Different turbulent model by using NRSME

	NRMSE	NRMSE %
Trans-k-kl-Omega	0.024994	2.499446
Trans-SST	0.095944	9.594441
k-epsilon-Realizable	0.128405	12.84052
k-omega-Standard	0.068659	6.865857
k-omega-SST	0.060164	6.016375

3.2 Summary of the Results

Table 2 – Average heat transfer coefficient for $X_n/B = 8$

X_n/B	X_n (m)	Z_n/B	Z_n (m)	Re	V_{inlet} (m/s)	h (W/m^{2}K)
8	0.0254	5	0.0158	500	23.0037	157.8726
				1000	46.0074	273.3247
				2000	92.0147	403.8083
				10000	460.073	1621.426
				20000	920.147	2728.224
		8	0.0254	500	23.0037	136.7618
				1000	46.0073	235.4183
				2000	92.0147	1713.634
				10000	460.073	1689.84
				20000	920.147	2452.82
		16	0.0508	500	23.0037	47.6434
				1000	46.0073	86.89307
				2000	92.0147	153.552
				10000	460.073	597.9906
				20000	920.147	707.1944

Table 3 – Average heat transfer coefficient for $X_n/B = 16$

X_n/B	X_n (m)	Z_n/B	Z_n (m)	Re	V_{inlet} (m/s)	h (W/m^{2}K)
16	0.0508	5	0.0158	500	23.0037	138.9238
				1000	46.0074	225.3813
				2000	92.0148	340.1379
				10000	460.074	1545.373
				20000	920.148	2761.737
		8	0.0254	500	23.0037	115.7713
				1000	46.0074	203.3639
				2000	92.0148	363.6582
				10000	460.074	931.6882
				20000	920.148	2864.744
		16	0.0508	500	23.0037	92.48665
				1000	46.0074	159.539
				2000	92.0148	274.8305
				10000	460.074	934.7566
				20000	920.148	1632.669

Table 4 – Average heat transfer coefficient for $X_n/B = 24$

X_n/B	X_n (m)	Z_n/B	Z_n (m)	Re	V_{inlet} (m/s)	h (W/m^{2}K)
24	0.0762	5	0.0158	500	23.0037	128.8588
				1000	46.0074	206.1087
				2000	92.0148	328.1101
				10000	460.074	1449.842
				20000	920.148	2896.931
		8	0.0254	500	23.0037	109.8526
				1000	46.0074	189.3781
				2000	92.0148	344.5248
				10000	460.074	1767.612
				20000	920.148	2852.919
		16	0.0508	500	23.0037	90.60558
				1000	46.0074	153.2547
				2000	92.0148	269.7944
				10000	460.074	1024.558
				20000	920.148	1824.632

4. Conclusion

In conclusion, the simulation done based on the heat transfer coefficient of the slot jet impingement on a target flat surface was validated. In this research, three parameters will affect the heat transfer coefficient of the multiple slot jet impingement. The distance between nozzle and flat surface, or we can say the ratio of the jet to surface distance and the nozzle width. We can see that as the ratio increases, the heat transfer coefficient shows a noticeable decrease. Secondly, it is the Reynolds number. This can be observed in the Average heat transfer table where when we increase the velocity inlet at the nozzle, the Reynolds number can be controlled. As the Reynolds number increases so do the Heat transfer Coefficient. Next, it is the distance between nozzle-to-nozzle width. When we increase the nozzle-to-nozzle width it can be observed that the heat transfer coefficient leads to an increase only up to a certain Reynolds number. For the future reference, it suggested to try with transient rather than steady state to get more meaningful result for study the multiple slot jet impingement on flat surfaces.

Acknowledgement

The author would also like to thank the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, and Flow Analysis, Simulation and Turbulence Research Group (FASTREG) for its support.

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