ANALYSIS O F JET-JET INTERACTION OF MULTIPLE IMPINGING JET USING DNS

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Abstract Impinging jet is widely used for cooling of industrial applications such as electric device, blades of gas turbine, hot steel and so on, since it possesses high performance of heat transfer rate and is easier to implement into various system. A single impinging jet produces a high heat transfer rate around an impinging position on an impinging wall, while the heat transfer performance decays increasing the distance from the impinging position. Thus in order to overcome the shortcoming of single impinging jet, the occurrence of both inhomogeneous heat distribution on the wall and the narrow heating area, multiple impinging jets (MIJ) are generally introduced in industrial applications. Thus far it is well-known that each jet of MIJ interact with each other, producing the complex flow field[1], in addition the heat transfer performance is significantly influenced with their interaction. Therefore to predict an optimum heat transfer performance, the influence of geometrical arrangement of jets, $i.e.$, the separation length between jets, the arrangement pattern, should be investigated. In order to make clear the effect of these parameter, we conduct the DNS (direct numerical simulation) of four round impinging jet arranged at an inflow of flow field. As control parameters, both the geometrical arrangements of jets and the separation between each jet are varied. From view of instantaneous vortical structures and time-averaged velocity distribution, it reveals that the generation of vortical structures are enhanced due to an interaction between each jet, compared to that of a single impinging jet, and that various type of upward flow which does not exist in the single one, appears according to the control parameter.

RESULTS

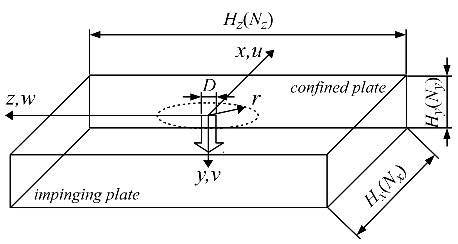


Figure 1. Coordinate system and computational domain

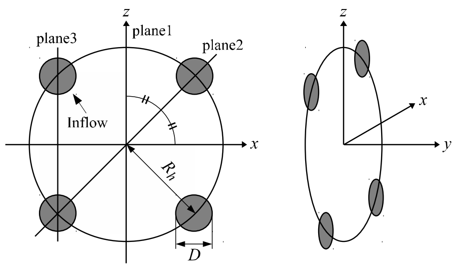


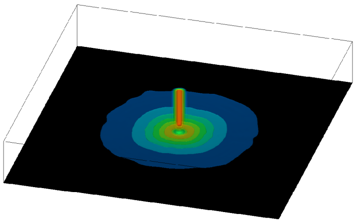
Figure 2. Geometrical arrangements of nozzles

Numerical procedure

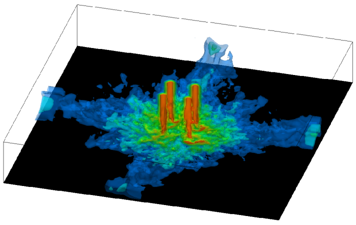
The flow is assumed to be incompressible. Thus, the governing equations are the continuity, momentum and energy equations. The Cartesian coordinate system is employed[2]. Computational conditions such as the size of the computational domain, grid number, and Reynolds number are $(H_x, H_y, H_z) = (24D, 4D, 24D)$, where D is the nozzle diameter, $(L_x, L_y, L_z) = (128, 100, 128)$, Reynolds number $Re = 1500$, respectively. The spatial discretization involves a sine or cosine series expansion in the x and z directions and sixth-order compact scheme [3] in the streamwise direction. A top-hat profile of velocity is imposed as an inflow boundary condition of each jet. Figure 1 is schematic drawing of the flow field. Figure 2 shows the geometrical arrangement of the multiple jet. In the present study, four jets are placed on the inflow plane, and the separation length R_h is varied as $R_h/D = 1.5 \sim 5.0$ (eight cases are conducted).

Flow field

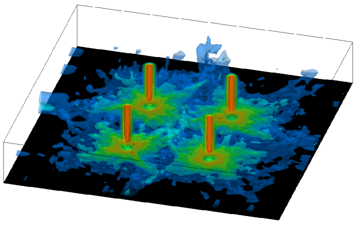
In order to investigate the flow field of the multiple jets, the instantaneous contour of velocity magnitude for the single and multiple (at $R_h/D = 1.5$ and 5.0) jets are visualized in Fig. 3 . Although the single jet uniformly spreads over the impinging wall, as shown in Fig., for the multiple jets the jet-jet interaction markedly disturb the flow field. Compared to the case of $R_h/D = 1.5$ and 5.0, in particular, in Fig.3(b) blue-colored region corresponding to the strong blow-out flows markedly appear according to the separation length. In order to compare the details of the influence of separation length, the velocity contour on the plane2 (in Fig. 2) are shown in Fig.5. In the most narrower case, $R_h/D = 1.5$, the intense fluctuation due to the interaction with each jet appears in the center of computational area, while in the most wider case, $R_h/D = 5.0$, the fluctuation disappear in the center area and the profile of each jet is almost similar to that of single jet. In order to show the instantaneous vortex structures, the iso-surfaces of second invariant velocity gradient tensor,Q ($Q = 0.1$) are visualized in Fig. 4. From Fig. 4(a), the vortex structures of single jet monotonically spread outward as well as the velocity field, while the structure of multiple jets in Fig. 4(b)(c) densely distribute compared to the single jet. Corresponding to the flow field of MIJ, in the case of $R_h/D = 1.5$, the cluster of vortical structures are formed around



(a) single nozzle jet

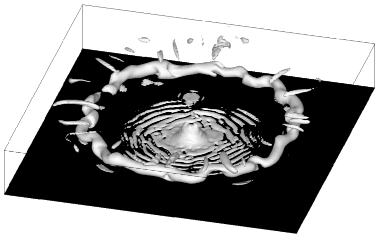


(b) $R_h/D = 1.5$

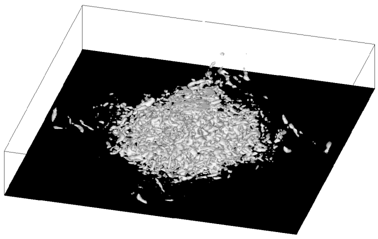


(c) $R_h/D = 5.0$

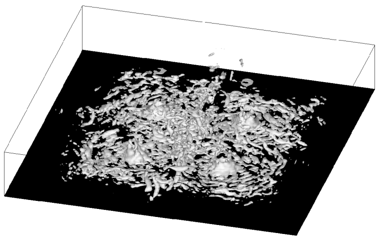
Figure 3. Instantaneous contour of velocity structure



(a) single nozzle jet

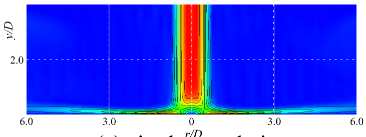


(b) $R_h/D = 1.5$

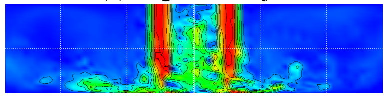


(c) $R_h/D = 5.0$

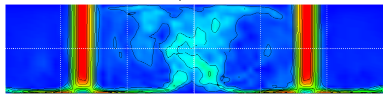
Figure 4. Instantaneous vortex structures



(a) single nozzle jet

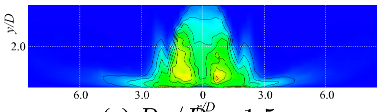


(b) $R_h/D = 1.5$

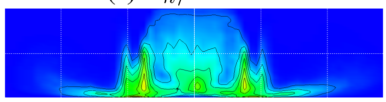


(c) $R_h/D = 5.0$

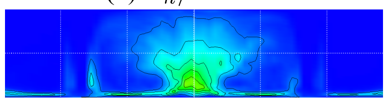
Figure 5. Instantaneous contour of velocity magnitude on the plane2



(a) $R_h/D = 1.5$



(b) $R_h/D = 2.5$



(c) $R_h/D = 5.0$

Figure 6. Contour of turbulent kinetic energy on the plane2

center of impinging wall. In the case of $R_h/D = 5.0$, the vortical structures are formed around the impinging point of each jet. Figures 6 show the contour of turbulent kinetic energy (TKE) of multiple jet ($R_h/D = 1.5, 2.5$ and 5.0) on the plane2. In the most narrower case, $R_h/D = 1.5$, the peak value of TKE appears the area where the outer-edge of each jet interacts with the upwash flow. In the case of $R_h/D = 2.5$, the peak appears both the outer-edge of each jet and the center area in where the wall jet issued from each jet collide with each other. In the most wide case $R_h/D = 5.0$, the peaks around the outer-edge of jet disappear, but the peaks around collision point of two-wall jet only appears. From these findings, it is demonstrated that the interaction of upwash flow and jet is dominant in the case of narrow separation length, however, as increasing the separation length, the interaction weakens, and the collision of wall jet is relatively dominant.

Conclusions

1. From the instantaneous flow structures, for the single impinging jet , the flow is issued from the nozzle and impinges to the wall and then become wall jet on the wall. As the peculiar feature for multiple jets,it is demonstrated that, the promptly break-down of jet core ; decreasing of velocity around the outer edge of jet,; the wall jets from each jet collides with each other; the formation of recirculation region due to the interaction of upwash flow and each jet.

2. From the turbulent kinetic energy, it is demonstrated that multiple jet produce fairly strong turbulence compared to the single jet, and that the spatial pattern of turbulence production depends on the separation length between each jet.

References

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[3] Lele, S. K., 1992, Compact finite difference schemes with spectral-like resolution, *J. of Comp. Phys.* **103**, pp.16–42.