Effect of Nozzle Geometry on Flow Characteristic of Jet from Expansion Pipe Nozzle

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Abstract
The flow characteristic of jet from expansion nozzle was investigated by using flow visualization and numerical simulation technique. The effect of nozzle geometry on flow characteristic was also studied. The experiment was conducted for the free jet from round pipe with installing collar at jet exit. The inner diameter of round pipe nozzle was D=17.2 mm for generating jet. The collar was installed at pipe nozzle exit to form an expansion pipe or chamber. The jet outlet-to-collar outlet distances of 2D, 4D, 6D, 8D and the collar diameters or nozzle expansion of 1.3D, 2D, 4D, 6D were examined. The comparison of flow characteristic of jet for different nozzle geometry was based on the constant jet mass flow rate (Re=2,300 for water jet, Re=20,000 for air jet). The flow visualization was studied in water tank by mixing dye within jet flow. The numerical simulation was employed to predict velocity field and turbulent kinetic energy for case of air jet by using commercial software (ANSYS ver. 12.0, Fluent). The results show that the jet spreading rate of pipe nozzle with collar is not different from the conventional jet (pipe nozzle without collar), but the fluctuation or turbulent kinetic energy of jet from pipe nozzle with collar is larger than conventional jet. The numerical results also show that there is reverse flow of ambient fluid into the chamber for the pipe nozzle with collar.

Keywords: Jet flow, Expansion pipe nozzle, Flow visualization, Numerical simulation

1. Introduction
The characteristics of jets such as entrainment, mixing and diffusion are closely related to the motions of vortices evolved in jets. In circular jets, large-scale axisymmetric and stream-wise vortices are important factors to entrain ambient fluid into the jet flow. There are many passive methods to enhance the entrainment, mixing and diffusion such as addition tabs and modification at the jet outlet [1, 2], generation of swirling and processing jet flow [3, 4].

Processing jet is a simple method for increasing the entrainment, mixing and diffusion of jet by extended jet outlet. Fig. 1 shows the flow visualization and schematic flow of processing jet.

From the Fig.1, there are flow phenomena such a reattaching flow, recirculation flow and swirling flow within the chamber and exiting jet deflected across the axis of chamber at a large angle [5]. It should be noted that the increasing of the entrainment, mixing and diffusion of jet also increase turbulent intensity of it.

Usually, the processing jet is used for enhancing of a jet mixing or combustion in industrial applications. It is also possible to employ processing jet for increasing heat transfer of impinging jet. A main concept to enhance the heat transfer that has been discussed in previous works is to increase a turbulent intensity into the jet flow [6-8]. So, applying the processing jet flow into jet impingement may be increased the heat transfer on impinged surface.
The aim of this research is to study the flow characteristics of jet from different geometry of expansion pipe nozzle. The effect of jet outlet-to-collar outlet distances and collar diameters were examined. The flow characteristics were investigated by using flow visualization and numerical simulation technique. The flow visualization was studied by mixing dye in water jet flow. The numerical simulation was also employed by using commercial software (ANSYS ver. 12.0, Fluent).

2. Experimental Model and Parameter

The experimental model using in this study is shown in Fig.2. The round collar was assembled at the pipe nozzle exit. An origin of the Cartesian coordinate was located at the centre of jet outlet. The X-axis is identical direction to the jet axial, and Y-, Z-axes are normal to the jet axial as show in Fig.2.

The experiment was conducted for the free jet from round pipe nozzle with collar at jet outlet. The inner diameter of round pipe was D=17.2 mm. The geometry of collar was varied. The jet outlet-to-collar outlet distances at 2D, 4D, 6D, 8D and the collar diameters at 1.3D, 2D, 4D, 6D were examined. The conventional pipe (pipe without collar) was also studied to compare the results of the jet with collar. The comparison of flow characteristics was based on the constant jet mass flow rate (Re=2,300 for water jet, Re=20,000 for air jet). To adjust the jet outlet-to-collar outlet distance, the pipe nozzle was fixed, and the collar was moved along X-axis.

3. Experimental setup and method

Schematic diagram of the experimental apparatus is shown in Fig. 3. A 0.5-HP pump sucks and accelerates the water mixing with magenta dye from bottom tank through a flow meter. The flow rate of jet was controlled by main and by pass valves that mounted after pump outlet. The dye water enters to a jet chamber then discharge from pipe nozzle into clear water. The turbulent jet discharges from round pipe that has inner diameter of D=17.2 mm and length of 300 mm. The length of pipe nozzle was sufficient to ensure that the velocity profile at the exit of jet became fully developed. The jet flow pattern was recorded by digital camera.

4. Numerical simulation

The flow characteristic was illustrated by using 3-D numerical simulation (ANSYS ver.12.0). The model of numerical simulation is same the experimental model in dimension as shows in Fig. 4. The air jet was fixed at constant jet Reynolds number of Re=20,000. The numerical computation was carried out by solving the governing equations with boundary condition. The standard k-ε turbulent model with general wall-function mode was used for solving numerical simulation problems. A non-uniform grid system was finely generated at jet outlet in collar and near collar outlet. A wall inflation function was used for 5 layers with smooth transition option before contacting a surface grid. A solution method was based on SIMPLE algorithm with second order upwind for all spatial discretization. The solution was considered to be converged when the normalized residual of the algebraic equation was less than a prescribed value of 1x10^-4.
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Fig. 5. Flow visualization of jet (water jet at Re=2,300)

5. Results and discussion

5.1 Experimental results

The flow visualization of jet spreading is shown in Fig. 5. The spreading of jet can be observed by discharging of color water jet in to the water. The jet is more grow when distance from jet outlet (X/D=0) increase. The jet growing rate of pipe nozzle with collar isn't quite different when compare with the conventional jet (Fig. 5 (q)). However, the votexes (eddies) of jet from the case of some of pipe nozzle with collar are larger than the case of conventional jet such as in Fig. 5 (a), (e), (f), (i), (j), (k) and (l).
Due to limitation of flow visualization technique, the experiment was conducted at low jet Reynolds number at Re=2,300. The jet spreading rate for case of pipe nozzle with collar is not different from the conventional jet, but the fluctuation of jet from pipe nozzle with collar is larger than conventional jet. From this results, the tendency of increasing of fluctuation in jet flow might increase a turbulent intensity and mixing of jet for case of high Reynolds number in the next study.

Fig. 5 shows the variation of jet width (W) at each of jet cross section along X-axis that measure from Fig. 4. The results can be obviously illustrated that the spreading rate of jet width for d=1.3D and L=2D is higher than the case of conventional jet. For other parameters, the spreading rate of jet with collar is not different from the case of conventional jet. Moreover, it is lower than conventional jet for some of parameters, especially, in the case of d=1.3 and L≥4D.

In the case of smallest collar diameter d=1.3D (Fig. 6 (a)), the spreading rate of jet width decrease with increasing L. The increasing of L in the case of d=1.3D is quite different to the other parameters. The spreading rate of jet width for d=1.3D decrease rapidly corresponding to the increasing L while other parameters, it small decreases and small different comparing to the case of conventional jets.

5.2 Numerical results

The vectors and contour of velocity are shown in Fig. 7, and contours of turbulence kinetic energy are shown in Fig. 8. Both figures are derived from numerical results that was simulated for case of using air jet at Re=20,000.

In the case of conventional pipe (Fig. 7 (g)) and pipe with collar d=1.3D and L=2D (Fig. 7 (a)), the direction of vectors is straight from upstream to downstream direction. However, the vectors at around jet outlet with collar d=1.3D and L=2D (Fig. 7 (a)) are larger and longer than of the case conventional pipe (Fig. 7 (g)). This result can be observed that ambient air in the case of d=1.3D with L=2D is more entrain into the jet flow than of conventional pipe. The area of high turbulence kinetic energy of pipe with collar d=1.3D and L=2D (Fig. 8 (a)) decreases rapidly when compare with the case of conventional pipe (Fig. 8 (g)). However, in region around jet flow, turbulence kinetic energy of pipe with collar d=1.3D with L=2D (Fig. 8 (a)) is higher than the case of conventional pipe (Fig. 8 (g)).

When collar diameter increases as d=4D and 6D with L=2D (Fig. 7 (c) and (e)), the air flow at ambient flow reverse into the collar chamber. The turbulence kinetic energy of this condition is also high at jet outlet due to this reverse flow from ambient air (Fig. 8 (c) and (e)). In the case of large L (Fig. 7 (d) and (f)), the distance of mixing between ambient air and jet is larger. So, the mixing between jet and ambient increase, and the region of high axial velocity is smaller (when compare with the case of conventional jet (Fig. 7 (g)) and the case of small L (Fig. 7 (c) and (e)).

![Fig. 6. Spreading rate of jet width at each cross section along X-axis (water jet at Re=2,300)](image)

5. Conclusions

In this study, the effect of jet outlet-to-collar outlet distances and collar diameters were experimentally and numerically investigated. The main results show that:

1. The spreading rate of jet width for d=1.3D and L=2D is higher than the case of conventional jet. For other parameters, the spreading rate of jet with collar is not quite different from the case of conventional jet.

2. The jet spreading rate of pipe nozzle with collar is not different from the conventional jet, but
the fluctuation of jet from pipe nozzle with collar is stronger than conventional jet.

3. The numerical results show that the flow of ambient air flow reverse into the chamber for pipe with collar at d=4D and 6D with L=2D. When the jet outlet-to-collar outlet distances increases as L=8D, the mixing between jet and ambient air within chamber increases.

Acknowledgments

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References


Fig. 7. Vectors and contour of velocity for CFD results (air jet at Re=20,000)

Fig. 8. Contour of turbulence kinetic energy (air jet at Re=20,000)