Study of the Flow Characteristics of Swirling Confined Jet

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***Abstract*:- Axial mean velocity is the primary criteria of most of the flow field. In the present investigation, the mixing of swirling jet within the solid boundary and the wake position memory as it came out of the solid boundary was studied. Extension tubes of 105mm, 210mm and 315m length were fitted to 30 degree and 60 degree swirling nozzle which were made by fitting triangular shaped double start wedge shaped helical right hand thread inside the pipe nozzle. Height of these wedges were 27.5mm, leaving a clear opening of 25mm diameter in the central zone of the 80mm diameter pipe nozzle. Data of axial mean velocity at the exit of the extension tubes were recorded at Reynolds number 5.3e4.**

***Keywords*—swirling, wedge-shaped, sinusoidal, helix, saddle-shaped, central.**

I. INTRODUCTION

Both in nature and engineering fields one confronts with various types of flow situation viz boundary layer flows, free shear layer flows, wake flows, flow around bluff and streamline bodies, flow through pipes and ducts, flow through turbo-machines, jet flows and many others. Again, each of the flow types may confront with varieties and free jet. These jets may be without swirl and with swirl.

While the jets are used extensively to create thrust of aircraft and rocket engines, the swirling jets are used as a means of controlling flames in combustion chambers and have also found applications in various types of spray guns, burners, heat exchangers, cyclone separators mixing process etc. In turbulent swirling jet the tangential velocity components combine with the axial one making the flow field complex in nature and enhance the mixing of different flow particles present in the flow field.

Swirling jet may be produced by various methods. Due to the complex and unpredictable formation of the swirling flow field, study of swirling flow is considered as the foremost subject in the past and still it is one of the top issue of scientific research. Literature review reveals that the formation of flow field mostly depends on the boundary conditions and the flow fields display different dynamic features. Researchers used various kinds of methods to generate swirl. Sheen et al. [1] studied the recirculation zones of both unconfined and confined swirling jets with a center body of blockage ratio 0.23. Escudier and keller [2] studied a confined swirling flow which went across a large cylindrical center body with blockage ratio of 0.25 and 0.39. The work was done to justify Benjamin's theory of vortex breakdown phenomenon [8]. Tom and Auriault [3] investigated the small amplitude wave modes inside a duct with compressible swirling flow. Lai [4] investigated the predictive capability of the Reynolds stress transport turbulence model for a confined swirling flow with the presence of a swirl induced flow reversal at the centerline. Naughton et al.[5] experimentally investigated the mixing of compressible jets with different levels of swirl and compressibility. Feyedelom and Sarpkaya [6] studied the turbulent flow field created by a round swirling jet issuing form a nozzle. Kitoh's [7] investigation of free vortex tube swirling flow was introduced in a long straight circular pipe.

In the present study swirling jet is generated by using wedge shaped helical pipe nozzle having internal threads. Swirl strength in this case was varied by varying the pitch of the thread.

II. EXPERIMENTAL SETUP

Experimental study was conducted in the circular air jet facility which had an overall length of 8.1m. The experimental setup consisted of an axial flow fan, flow controller, two settling chambers, two diffusers, wire mesh screen and finally the flow nozzle as shown in Fig. 1. A silencer was fitted at the discharge of the fan unit through a vibration isolator to reduce the transmission of noise and vibration of the fan to the downstream direction. Flow form the second settling chamber passed through two reducers which reduced pipe diameter from 230mm to 80mm. The reducer has the bell mouth profile to reduce pressure loss during the reduction of pipe diameters. Finally air entered the 80mm diameter circular swirling pipe nozzle. All these steps had been taken to ensure stable flow at the swirling nozzle entry.

To measure and collect data at different axial (x) and vertical (y) locations of the jet a five-hole yaw meter was used. Pressure transducer were used as the sensing device while data loggers along with computer were used for recording and data processing. A two-coordinate traversing mechanism was used for mounting and positioning the probe at different x-y locations of the jet.

In the experiment two swirling nozzles of 30 degree and 60 degree swirl were used with extension tubes of 105mm, 210mm and 315mm length. Swirling flow thus came out from the extension tube had been studied in this investigation. The nozzles setup used in this experiment is shown in Fig. 2(a, b) and Fig. 3(a, b, c).

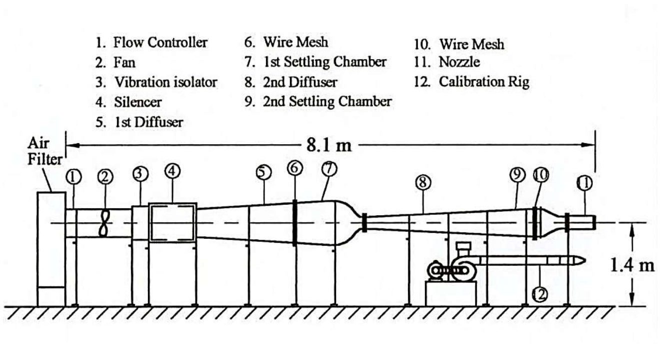
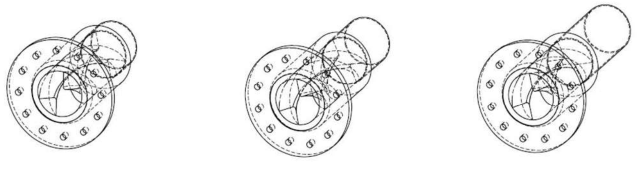


Fig. 1. Experimental setup

(a) (b)

Fig. 2. Swirling nozzles; (a) 30 Degree Swirling Nozzle, (b) 60 Degree Swirling Nozzle



(a) (b) (c)

Fig. 3. Swirling nozzles with extension tube; (a) with 105mm extension tube, (b) with 210nn extension tube, (c) with 315mm extension tube

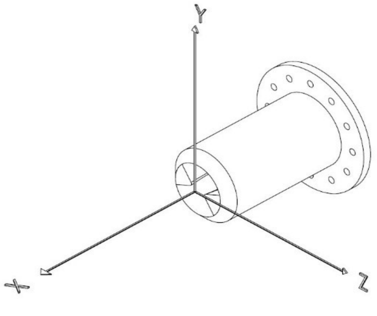
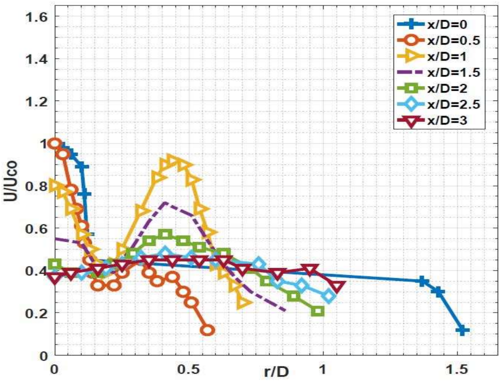


Fig. 4. Co-ordinate system

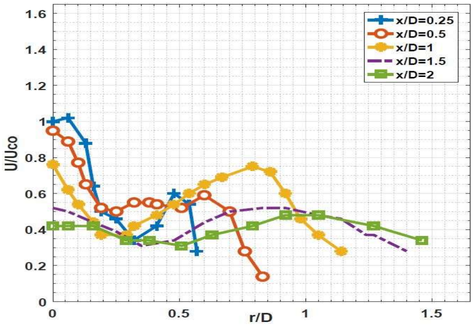
III. RESULTS AND DISCUSSION

In the swirling jet flow field, the main flow direction was taken as the x-axis, the vertical direction as the y-axis, the direction perpendicular to the x-y plane as the z-axis and the center of the nozzle exit is taken as the origin. The co-ordinate system is shown in Fig. 4. Before taking readings the yaw-meter was properly calibrated. Before taking measurements the symmetry of the swirling jet flow was checked. Flow velocity at different downstream locations were taken in the x-y plane and at the positive y-direction only. In the measurements Reynolds number were based on nozzle exit diameter, exit velocity and air properties at standard atmospheric condition.

Velocity profiles in figures 5(a) and 5(b) for 30 degree and 60 degree swirling nozzle show that, the swirl generated the centrifugal force on the flow field which drives away the centerline fluid in the radial direction creating high velocity field near the periphery of the nozzle. Flow beyond the clear opening of the central zone behind the solid obstacle of the wedge shaped thread formed the wake in the zone which maintains, low velocity field near the exit. However, further in the downstream direction, the effect of swirl becomes prominent and shifts the velocity maxima towards the nozzle boundary conforming the influence of increased swirl on mean axial velocity. For 60 degree swirling nozzle the presence of strong swirl increases the centrifugal force that creates the velocity peaks beyond the nozzle boundary. Profiles of the figures 6(a) and 6(b) show that the introduction of 105mm extension tube on the exit of 30 degree and 60 degree swirling nozzles enhance the mixing inside the tube before the jet discharge out. For the lower pitch angle (30 degree) the velocity profiles in the downstream direction spread out indicating their loss of strength. However, for high pitch angle (60 degree) the effect of swirl is found to exist. From the figures 7(a) and 7(b) for 210mm extension tube it is observed that the velocity maxima increase and occur at the periphery. The hump shape profile which found near the exit, dies out in the downstream locations forming usual velocity profiles. Figures 8(a) and 8(b) show the profiles for 315mm extension tube. Long length of the extension tube facilitates intense mixing resulting in uniform velocity across the section at the discharge for the lower pitch. For higher pitch angle the discharge velocity maxima of hump shaped profile are observed but they decrease quickly in the downstream direction. Centerline velocity profiles in figure 9 show that the jet dissipates approximately at x/D=2. Thus x/D=0 to 2 is considered as the mixing zone.

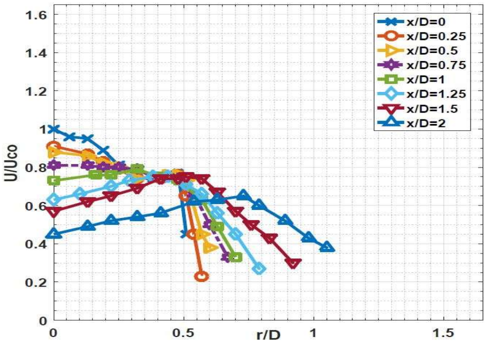


(a)

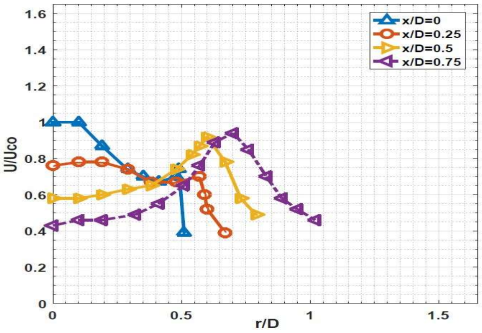


(b)

Fig. 5. Profiles of Axial Mean Velocity in the vertical plane, (a) for 30 Degree Swirling Nozzle, (b) for 60 Degree Swirling Nozzle

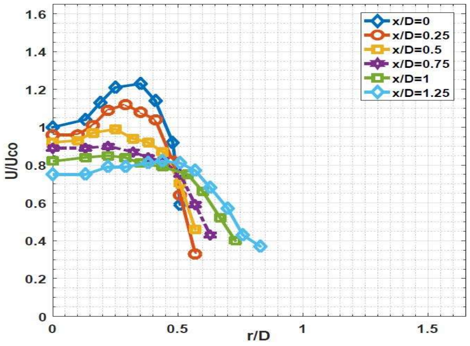


(a)

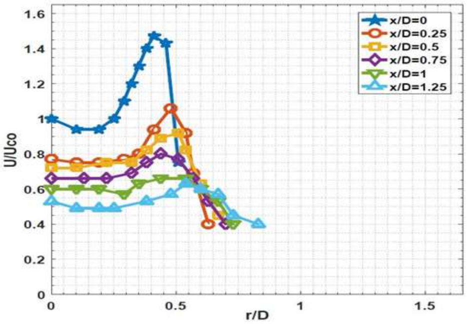


(b)

Fig. 6. Profiles of Axial Mean Velocity in the vertical plane with 105mm Extension Tube, (a) for 30 Degree Swirling Nozzle, (b) for 60 Degree Swirling Nozzle

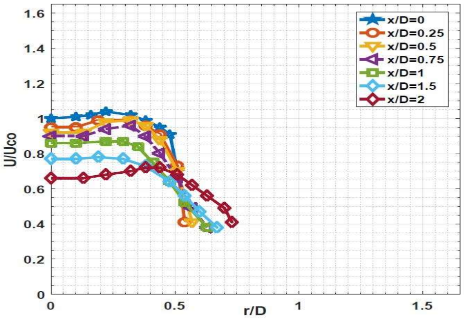


(a)

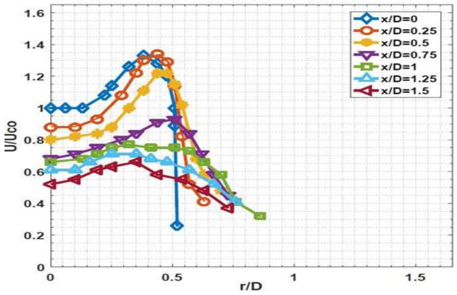


(b)

Fig. 7. Profiles of Axial Mean Velocity in the vertical plane with 210mm Extension Tube, (a) for 30 Degree Swirling Nozzle, (b) for 60 Degree Swirling Nozzle



(a)



(b)

Fig. 8. Profiles of Axial Mean Velocity in the vertical plane with 315mm Extension Tube, (a) for 30 Degree Swirling Nozzle, (b) for 60 Degree Swirling Nozzle

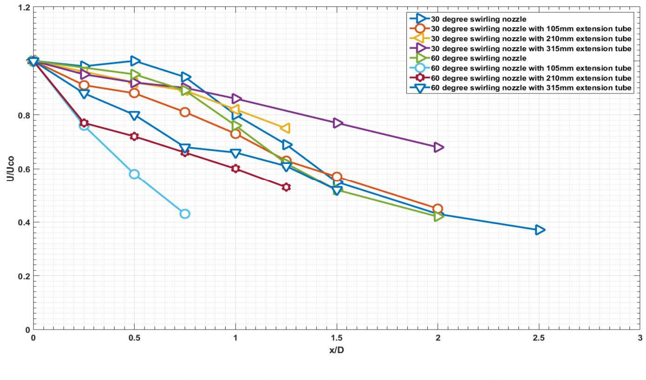


Fig. 9. Comparison of Decay of Centerline Velocities Profiles in the vertical plane

IV. CONCLUSIONS

Experimental investigation has been carried out on swirling jet issued from nozzles having double start helical thread with and without extension tube at the discharge of the nozzle at Reynolds number of 5.3e4. The swirling jet of the present investigation behaves as a composite twin jet interacting with a common centerline core at the exit of the nozzle. The jet dissipates approximately at x/D=2, which indicates that the mixing zone exist up to x/D=2. As the swirl pitch increases the intensity of mixing increases. With the introduction of extension tube the flow mixing zone formed at the exit of the swirling nozzle lose their identity very quickly due to its interaction inside the confined flow area and the flow found in the extension tube exit to be more organized.

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