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EFFECT OF VELOCITY AND AREA RATIOS ON MIXING OF COAXIAL FREE JET

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ABSTRACT

The present study deals with the experimental investigation of mixing of two circular coaxial free jets. Coaxial flow arrangement has been made by issuing two concentric jets at different velocities from a compound nozzle. The central jet is emitted through the inner nozzle of 42 mm diameter while annular jet is produced by passing flow through the space between the outer and the inner nozzle. Three outer nozzles of 80, 63 and 52.5 mm diameter are used to get the different area ratios. Measurements of velocity have been taken with 1.6 mm OD Pitot - static tube for Reynolds number ranging from 1.04×10^4 to 4×10^4. From the measurements, exit velocity profile, spread of shear layer, and self- preservation variable in the mixing zone of these jets have been investigated for three different area ratios (0.56, 1.25, 2.61) with four values of velocity ratios of outer to inner jet ranging from 0.10 to 0.90. In the study, spread rate of the jets has also been observed.

Keywords: Free jet, potential core, shear layer, self-preserving variable.

1. INTRODUCTION

Jet flow is a common flow field occurring both in nature and in many engineering application and most of the jets are turbulent in nature. Considering its various use, extensive research have been done on turbulent jet flow into a still air or a secondary stream and their essential features have been explored. The simple flows are well understood and can be handled theoretically but when flow pattern becomes complicated by the interaction of two or more turbulent jets it becomes impossible to handle theoretically. Therefore, to know about the flow characteristics of interacting jet flows experimental investigation is required to be carried out to know about the nature of flow field.

2. LITARATURE REVIEW

Over decades, jet flow has become the subject of many investigators and both experimental and numerical works have been performed on free jets by previous researchers.

Morton [1] studied experimentally the complicated flow structure of coaxial jet, where more than one miscible streams are emitted from neighboring sources. Elbanna and Sabbagh [2] found that during the interaction of two parallel jets, the flow field is greatly influenced by the velocity of jet. Villermaux and Rehab [3] worked on the mixing in the coaxial jet with large annular to inner velocity ratio. They reported that the mixing in coaxial jets is contemplated according to the evolution of interface generated between the mixing streams. Antonia and Bilger [4] made an experimental study on an axisymmetric jet in a co-flowing air stream. Ahmed and Sharma [5] investigated the turbulent mixing of coaxial jets having low annular to core area ratio with chute mixture. Lau [6] carried out his experimental study on coaxial jet with heated core jet. He found that temperature ratio as well as density ratio influences the spread of shear layer i.e. mixing in coaxial jet.

3. EXPERIMENTAL SET UP AND METHODOLOY

3.1 Co-axial Jet Flow System

A schematic diagram of co-axial jet flow system is illustrated in the figs: [1-2]. The co-axial jet flow system has been developed by adding a central circular air flow system in the existing jet flow facility in the laboratory. The jet flow facility has overall length of 8.0 m having 80 mm diameter exit nozzle. In the delivery side of the flow facility the diameter of pipe is reduced in two stages from 475 mm to 80 mm where the experimental nozzle is fitted. A 62 mm PVC line is taken out from the delivery of another blower, which has been placed just below the jet flow facility. In order to place the central nozzle along the central axis of 80 mm nozzle 3 sets of centralizers have been placed been in three different locations. Finally, the exit diameter of the central nozzle is reduced to 42 mm through 100 mm×42 mm reducer. The flow straightener and wire screens are present in both jets to straighten the flow and break down large eddies present in the air flow. To minimize the effect of any boundary on the jet flow, the nozzle centerline is set at 1400 mm above the ground.

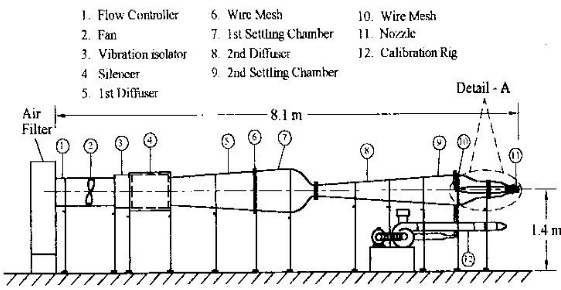

Fig 1: Schematic diagram of the jet flow facility and calibration rig

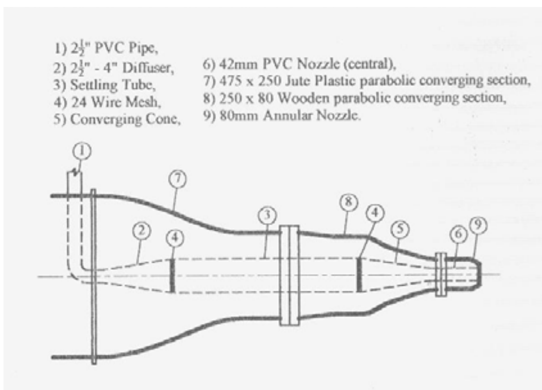

Fig 2: Detail-A

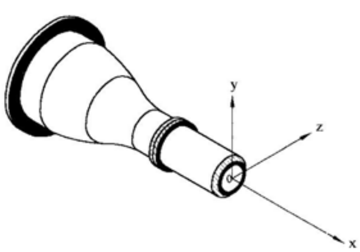

Fig 3: Co-ordinate system of nozzle

3.2 Co-ordinate System

In the present investigation, nozzle exit center is taken as the origin. The center line of the nozzle in the direction of flow is taken as positive x-axis and radial distance pointing upwards as positive y-axis and the axis 90° anticlockwise from positive x-axis is considered as the positive z-axis [fig: 3].

3.3 Traversing Mechanism and Probe Setting

The pitot static tube is traversed in the air stream with the help of a Mitutoyo (Japan) coordinate measuring machine (type: CS 652) with ranges X co-ordinate 800 mm, Y co-ordinate 500 mm and Z co-ordinate 400 mm. This traversing mechanism is placed on a hydraulically operated table, which 900 mm away from the nozzle axis to avoid any possible disturbances.

3.4 Velocity Measurement

The mean velocities are measured by United Sensor (USA) pitot static tube of 1.6 mm outside diameter with a furnace Control Ltd. (UK) pressure transducer. (model: MDC FC001) with a data logger (Cathley, USA). Before starting the experiment, the pressure transducer is calibrated with a inclined tube manometer for its different ranges.

4. RESULTS AND DISCUSSION

Flow characteristics of coaxial jet have been investigated by varying the velocity ratio of the annular jet to central jet as well as the area ratio of the annular to inner nozzle. Four values of velocity ratio (U_2/U_1) in each co-axial nozzle configuration have been studied.. Values are found in the range 0.10< U_2/U_1<0.90. The values of area ratios (A_2/A_1) are 2.61, 1.25 and 0.56. The summary of this experimental work are explained below.   .

4.1 Effect of Velocity Ratio on Exit Velocity Profile

Effect of velocity ratio on exit velocity at different area ratios are shown in figs. [4-6]. From fig. 4 it is found that with the increase of velocity ratio the nature of the central jet velocity profile is changed from saddle shape to parabolic form. Therefore, near the central nozzle boundary, velocity decreases with the increase of velocity ratio. For annular jet, with the increase of velocity ratio, the profile is converted to asymmetric shape from its symmetric nature. i.e. as the velocity ratio increases, the velocity towards the outer wall increases relative to its inner wall. This may be the consequence of differential curvature effect of the nozzle. Same configuration is observed in fig. 5 for area ratio 1.25 but the curvature effect is less due to small annular space.

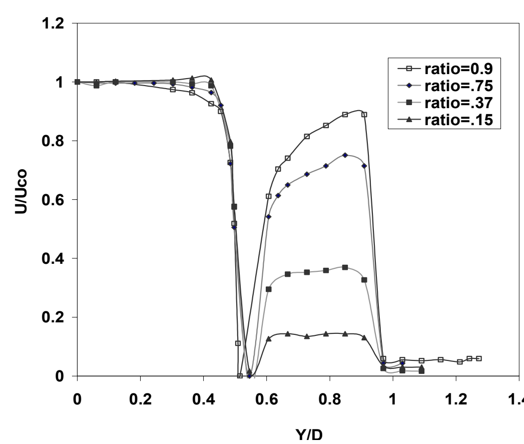

Fig 4: Effects of Velocity Ratio on Exit (X/D=0.0) Velocity Profiles of Co-axial Jets at A_2/A_1=2.61 and Re=2.69 X 10^4

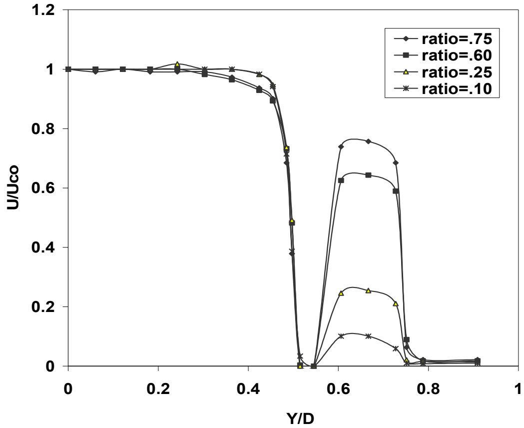

Fig 5: Effect of Velocity Ratio on Exit (X/D=0.0) Velocity Profiles for Co-axial jets at A2/A1=1.25 and $Re=4x10^4$

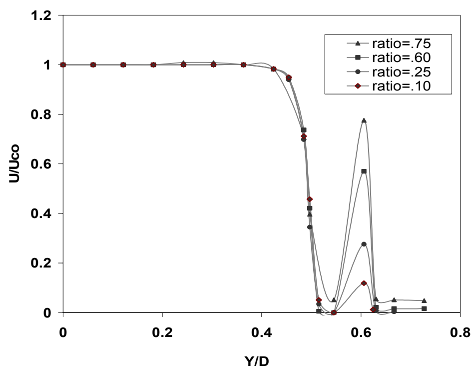

Fig 6: Effect of Velocity Ratio on Exit (X/D=0.0) Velocity Profile of Co-axial Jets at A2/A1=0.56 and $Re=4X10^4$

4.2 Effect of Area Ratio on Exit Velocity Profile

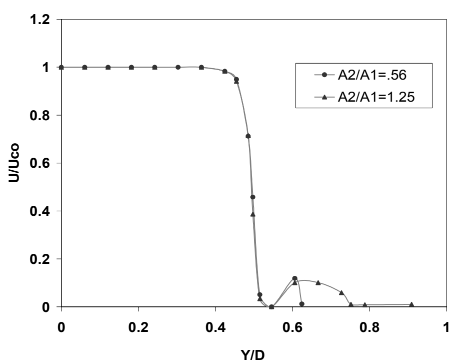

Fig 7: Effect of Area Ratio (A2/A1) on Exit (X/D=0.0) Velocity Profiles at U2/U1=.10 and $Re=4X10^4$

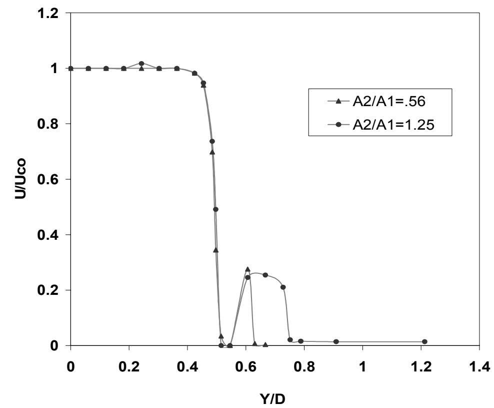

Fig 8: Effect of Area ratio (A_2/A_1) on Exit (X/D=0.0) Velocity Profiles at U2/U1=0.25 and $Re=4X10^4$

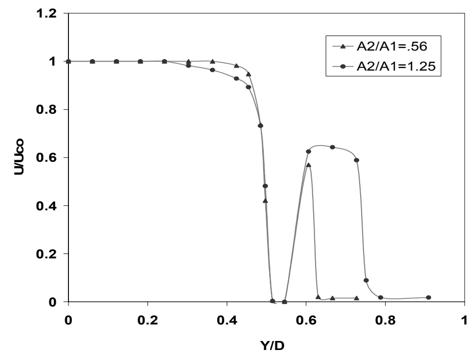

Fig 9: Effect of Area ratio (A_2/A_1) on Exit(X/D=0.0) Velocity Profiles at U_2/U_1 =0.60 and $Re=4X10^4$

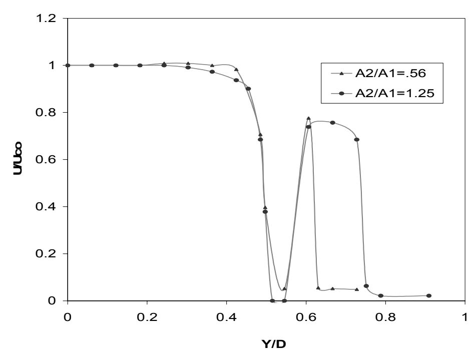

Fig 10: Effect of Area ratio (A_2/A_1) on Exit (X/D=0.0) Velocity Profile at U_2/U_1=0.75 and $Re=4X10^4$

Effect of area ratio on exit velocity at different velocity ratio and $R_e=4\times10^4$ are shown in figs.[7-10]. For velocity ratio 0.10 and 0.25 the effect of area ratio for central jet is zero but for velocity ratio 0.60 shows that with the increase of area ratio the nature of the velocity profile of the central jet changes near the inner nozzle boundary. There, the velocity decreases thereby decreasing the potential core region. Near the outer wall boundary, the velocity decreases asymptotically to its zero velocity.

4.3 Effect of Velocity Ratio and Area Ratio on Centerline Velocity

The centerline velocity profiles of the jet for different area and velocity ratios are presented in figs. [11-15]

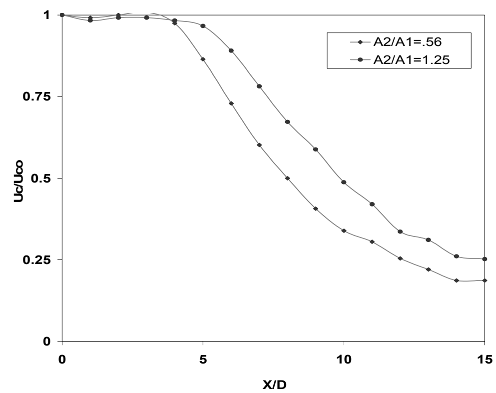

Fig 11: Effect of Area ratio (A_2/A_1) on Centerline Velocity Profile of Coaxial Jets at U_2/U_1=0.10 and Re=4X10^4

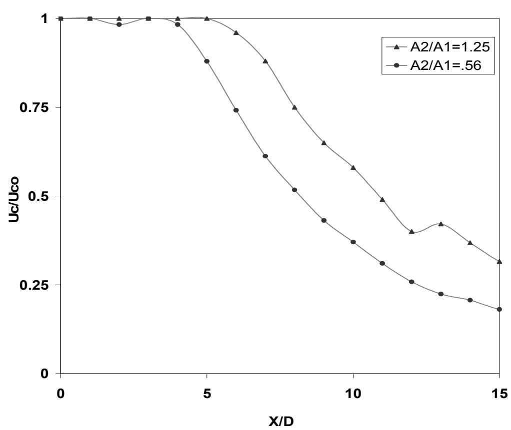

Fig 12: Effects of Area Ratio (A_2/A_1) on Centerline Velocity Profiles of Coaxial Jets at U_2/U_1=0.25 and Re=4X10^4

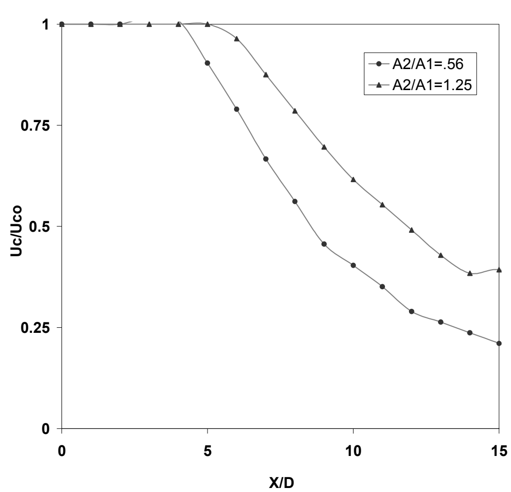

Fig 13: Effects of Area Ratio (A_2/A_1) on Centerline Velocity Profiles of Coaxial Jets at U_2/U_1=0.60 and Re=4X10^4

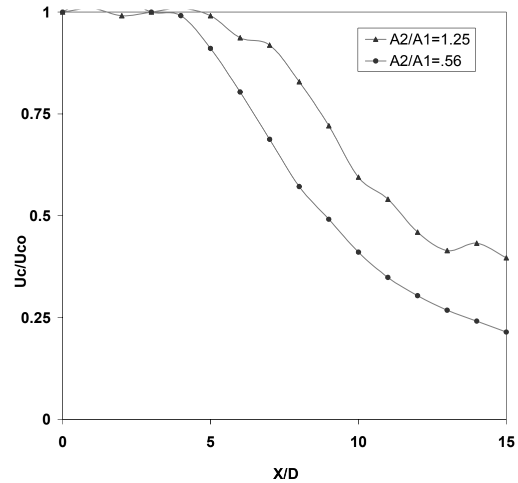

Fig 14: Effects of Area Ratio (A_2/A_1) on Centerline Velocity Profile of Coaxial Jets at U_2/U_1=0.75 and Re=4X10^4

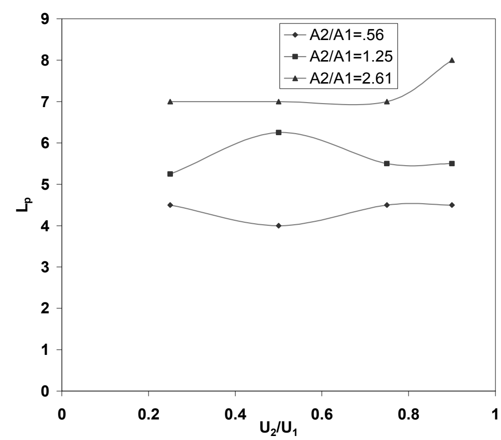

Fig 15: Length of Potential Core as a Function of the Velocity Ratio (U_2/U_1)

at $R_e=4\times10^4$. From these figure it is evident that, for certain area ratio, the length of potential core remains more or less constant with different velocity ratios. However, for a particular velocity ratio, the length of potential core increases as the area ratio increases.

4.4 Effect of Area Ratio on Spread of the Shear Layer

The shear layer of the free jet is bounded by iso-velocity lines with U/Uco values 0.10 and 0.95. The variation of shear layer width, b with downstream distance is the manifestation of spread rate of the shear layer. Fig. [16] shows the effect of area ratio on iso-velocity lines at $R_e=4\times10^4$ and it is found that all the iso-velocity lines spread outward in the strem wise direction. This spread rate is more with A_2/A_1=0.56 than that for A_2/A_1=1.25. The effect of area ratio on the shear layer width is shown in fig. [17]. It can be said that the shear layer width of coaxial jet decreases as the area ratio increases.

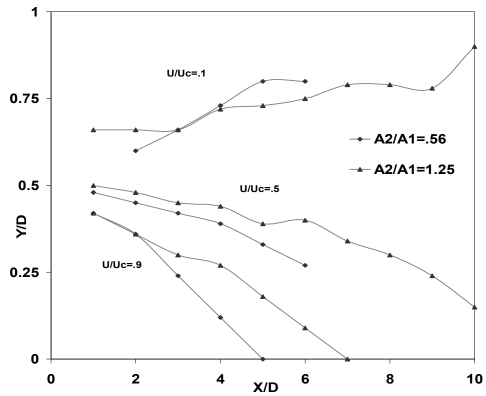

Fig 16: Effect of Area Ratio (A_2/A_1) on Iso-Velocity Lines at Re=4X10^4

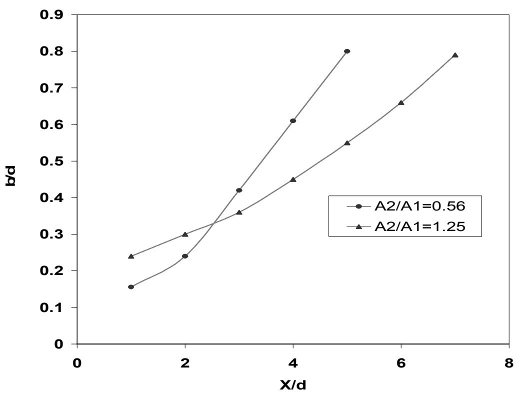

Fig 17: Effect of Area ratio (A_2/A_1) on Shear Layer Width at Re=4x10^4

4.5 Effect of Area Ratio Self-preservation Profiles

Actual self-preservation zone of a jet is occurred when all of its mean and turbulent components are in equilibrium, which is in the fully developed region of a jet. Another self-preservation is observed in the potential core region called partial self-preservation region. The self-preservation variable for mean velocity taken in the present study as $(Y-Y_{0.5})/X$.

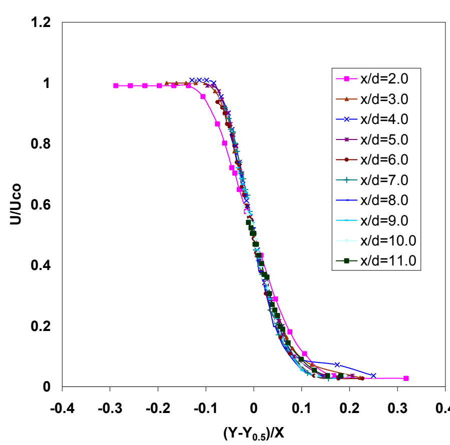

Fig 18: Self-Preservation of Velocity Profiles of Co-axial Jets of Area ratio (A_2/A_1) =1.25 at U_2/U_1=0.75 and at Re=4x10^4

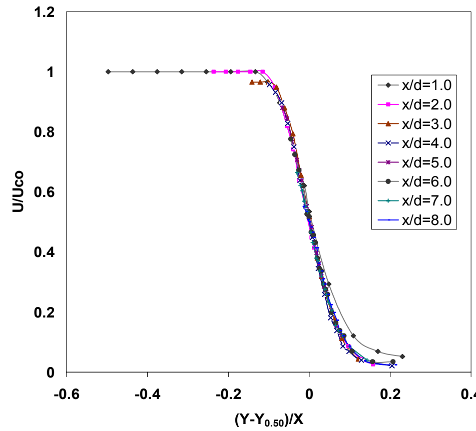

Fig 19: Self-Preservation of Velocity Profiles of Co-axial Jets of Area ratio (A_2/A_1) =1.25 at U_2/U_1=0.75 and at Re=4x10^4

From figs. [18-19] presents the self-preservation profiles for area ratios (A_2/A_1) 1.25 and 0.56 at velocity ratio (U_2/U_1) 0.75 and at $R_e=4\times10^4$. These figures indicate that at lower area ratio jet attains stability earlier.

5. CONCLUSIONS

Experimental investigations have been performed to study the effect of velocity ratios and area ratios on the velocity distributions of coaxial free jets. From the measurements and subsequent analysis, it is found that at higher velocity ratio, velocity of the central jet at the exit plane decreases earlier and the effect of area ratio on exit velocity profile is negligible for velocity ratio (U_2/U_1) 0.10 and 0.25 but for velocity ratio (U_2/U_1) 0.60 and 0.75 exit velocity decreases earlier at higher area ratio.

The Length of potential core increases with increase of area ratio at a certain velocity ratio. Shear layer width of coaxial jet increases prominently with area ratio and Self-preservation profile is attained earlier at low area ratio.

6. REFERENCES

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7. NOMENCLATURE

Symbol	Meaning
D_i, d	Diameter of inner nozzle
D_O, D_2	Diameter of outer nozzle
R_e	Reynolds number
G_{xy}	In-plane shear modulus in the x-y plane
U	Axial mean velocity
V	Transverse mean velocity
U_1	Central jet velocity
U_2	Annular jet velocity
U_c	Centerline velocity
$A_1 = (\pi d^2/4)$	Area of inner nozzle
$A_2 = (\pi(Do^2 - d^2))/4$	Area of annular nozzle
L_p	Length of potential core
$Y_{0.10}$	Outer edge of the shesr layer
$Y_{0.50}$	Half width of the shesr layer
$Y_{0.90}$	Inner edge of the shesr layer