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EXPERIMENTAL STUDY OF THERMALLY STRATIFIED CO-AXIAL JETS WITH TRIP RING EXCITATION

M. A. T. Ali and Sukanta Bhattacharjee

Dept. of Mechanical Engineering, Bangladesh University of Engineering & Technology,
Dhaka, Bangladesh

ABSTRACT

The experimental investigation of thermally stratified coaxial jet with trip ring excitation is presented. Isothermal as well as thermally stratified or non-isothermal co-axial jet flows are developed by issuing two jets with different unidirectional velocities from a concentric compound nozzle. Enhanced mixing of coaxial free jets of different temperature and different velocity ratio is achieved with the help of vortex generation influenced by inner and outer trip ring placed around the central nozzle. The spatio-temporal velocity fields along with the temperature of the jets are studied by a pitot-static tube with an embedded thermocouple and a high-resolution pressure transducer. The inner dynamic and thermal potential core lengths become much shorter, and mixing between the inner and the outer fields is markedly enhanced by the wake produced after introducing the trip rings. Among the different combinations inner trip ring is found most efficient in mixing non-isothermal co-axial jets.

Keywords: Non-Isothermal, Coaxial Jets, Trip Ring, Potential Core.

1. INTRODUCTION

Jet flow is one of the basic flow configurations that are found both in nature and in industrial applications. Most of the jets encountered in our daily life are turbulent in nature. Simple flow cases are relatively easy to handle and solve theoretically but when it involves two or more turbulent fluid streams then the flow structure becomes too complicated to solve theoretically. Therefore, experimental investigation is the best option to know about the flow field of interacting flows. Experimental investigation of the mean flow characteristics of velocity field as well as thermal field of thermally stratified trip ring excited co-axial jets have been carried out for different initial conditions. The hot central jet comes out form a 19 mm central nozzle while the annular ambient jet is emitted through the annular space between the outer and the central nozzle. Outer nozzles having inner diameter of 63mm is used that results in the area ratio of annular to central jet as 3.57. Four outer to inner jet velocity ratios ranging from 0.0 to 0.75 have been considered for each nozzle configuration. The temperature of the central jet is varied to establish different temperature gradient between the central jet and the annular jet by varying supply voltage to the heater placed upstream of the central nozzle. Three different values of temperature ratio of the annular jet to the central jet have been considered as 1.0, 0.974 and 0.925 on the basis of absolute temperature scale. The excitation is made by two trip rings. One placed outside the inner nozzle, trips the flow of annular jet is called outer trip ring and the other placed inside of the inner nozzle, trips the flow of the central jet is called inner trip ring. Measurements of mean velocity and mean temperature in the mixing zone of these two jets are taken with the help of a pitot-static tube with embedded thermocouple.

2. FLOW STRUCTURE OF CO-AXIAL FREE JETS

As represented in figure 2 the initial region of co-axial jets consist of two potential cores separated by an annular mixing region. In the streamwise direction the central jet interacts only with the annular jet but the later interacts with both the central jet and the ambient room air at the boundary. Thus, near the exit of co-axial jets two distinct potential cores exist, one at the center and the other along the mean circumference of the annular jet forming a wedge shaped ring. Of the two mixing regions, one is between the central and inner boundary of the annular jet and the other is between the ambient room air and the outer boundary of the annular jet. As the flow proceeds, the width of each core decreases approximately linearly. This zone is in a state of intense mixing and afterward it becomes fully turbulent in its developed state. In the developing stage, the inner mixing layer spreads towards the outward direction more rapidly to meet the outer one and further in the downstream distance, the co-axial jets produce a velocity profile identical to that produced by a single axisymmetric one indicating the complete mixing and fully developed flow condition. The characteristics of flow properties in this region become self-preserving.

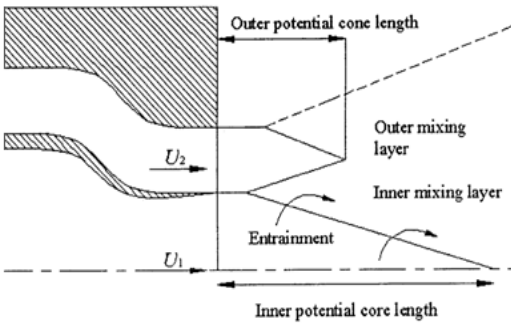

Fig 1. Schematic Diagram of the Mixing Layers in the Near Field of Co-axial Free Jets

3. EXPERIMENTAL SET UP

The experimental study has been carried out by using the circular co-axial air jet facility as shown in the figures 2 and 3. To make the flow of hot central jet to produce non isothermal single jet as well as thermally stratified co-axial jets, a series of heaters are installed in the upstream of the central jet. The overall length of the flow facility (Fig. 2) is 8.1 m. It has axial flow fan unit, two settling chambers, two diffusers a silencer and a flow nozzle. The fan unit consists of three Woods Aerofoil fans of the same series. The fan unit receives air through the butterfly valve and discharges it into the silencer of the flow duct. Flow from the silencer passes on to the settling chamber through a diffuser. At the discharge, side of this chamber there is a flow straighter and wire screen of 12 meshes to straighten the flow and to breakdown large eddies present in the air stream. Air from this chamber then flows to the second settling chamber through a nozzle and second diffuser. The flow straighter and wire screens are used here to ensure a uniform axial flow free of large eddies which may be present in the upstream side of the flow. The flow from the second settling chamber then enters the 100 mm long and 80 mm diameter circular nozzle. At the farthest end the diameter of the flow facility is reduced from 475 mm to 80 mm where the experimental nozzle is fitted. A centrifugal blower is placed below the main flow system to supply air to the central nozzle. A 100 mm discharge line of the blower is connected to the heating/settling chamber. A 62 mm PVC pipe is connected to the delivery side of this chamber and enters radially into the 2nd settling chamber of the main flow system placed concentrically with the 475 mm diameter main flow set up by means of four pin centralizers in three different locations. The distances between the three consecutives centralizers are 520 mm and 460 mm respectively. In between the centralizers, a 100 mm PVC pipe having length of 520 mm is placed and it is connected to the 62 mm radial pipe insertion through a 62 mm×100 mm diffuser. The outlet of the 100 mm PVC pipe is connected with a 29 mm steel pipe acting as the central nozzle via another diffuser. This 100 mm PVC pipe acts as a plenum chamber with two pairs of wire screens of 24×24 mesh inside it. These wire screens are placed at the entry and exit of this 100 mm PVC pipe to break the big eddies created in the upstream side and thereby to produce smooth uniform flow with low levels of turbulent intensity.

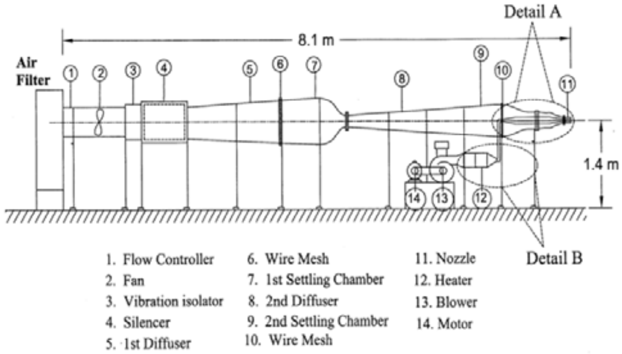

Fig 2. Schematic diagram of the jet flow facility

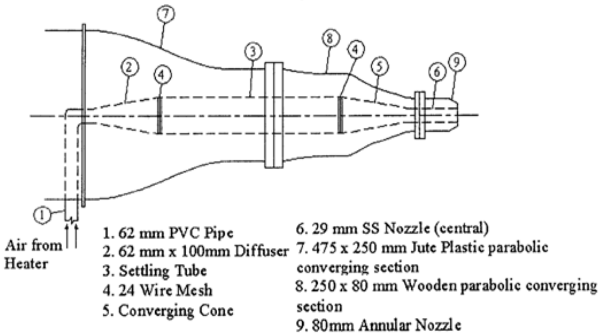

Fig 3. Enlarged View of Co-axial Flow System

The heating system has a capacity of 3 kW and consisted of four different sections as divergent entry section, heater section, settling chamber and convergent exit section. Air from the centrifugal blower comes to the heater section through the divergent entry section. There are six heating elements in the heater section that are made of electric resistance wire and mica sheet and placed to ensure uniform heating to the flowing air throughout the section. After passing over the heaters, the hot air enters into the settling chamber where the temperature of the hot air attains more uniformity because of intermixing. The whole air heating system is insulated with asbestos cloth and glass wool to prevent the heat loss to the surrounding from the hot air. Finally, the hot air is passed to the co-axial jet flow system through the exit section. The flow through the central nozzle is regulated by controlling the supply frequency to the centrifugal blower whereas airflow through the annular nozzle is controlled by the butterfly valve and/or by regulating the speed of the fan units. The temperature of the central jet is regulated by controlling the supply voltage to the heaters by means of a variac. The whole setup is mounted on rigid frames of M.S. pipes and plates and these frames are securely fixed with the ground so that any possible unwanted vibration of the system may be reduced to a minimum. To avoid the effect of ground shear, the set is installed at an elevation of 1.4 m from the ground. For the present investigation, an outer nozzle of 63 mm diameter is used. The diameter of the central nozzle jet is kept fixed at 29 mm, which makes the area ratio of 3.57. The trip rings used for the excitation is made of nylon and are placed at the exit of the co-axial nozzle. The outer trip ring is attached around the outside periphery of the central nozzle, which has an inner diameter of 29.2 mm and outer diameter of 39 mm. The inner trip ring is attached with the inner side of the central nozzle, which has an outer diameter of 29mm, inner diameter of 19mm. Each trip ring has a wedge shaped edge and is 4mm thick.

4. CENTERLINE VELOCITY

The fundamental axis of any jet flow is its centerline. Different important aspects of flow field such as the potential core length, momentum transfer amongst fluid streams; virtual origin etc. can be identified from the flow characteristics along the centerline of a jet. In figure 4 the effect of different types of excitation for the same velocity ratio is shown. For the velocity ratio of 0.25 the unexcited jet has a core length of 6d and that of for outer trip ring excitation is 4d and inner trip ring excitation is 2d. The inner trip ring also decrease the centerline velocity of the central jet at a very faster rate. For the velocity ratio of 0.50 there is a clear indication that inner trip ring tends to accelerate the fluid at lower x/d value while external trip ring decelerates it. For higher velocity ratio this effect is increased initially for excited jets. However, for inner and outer trip ring excited co-axial jets the decrease of change of velocity occurs in the same manner.

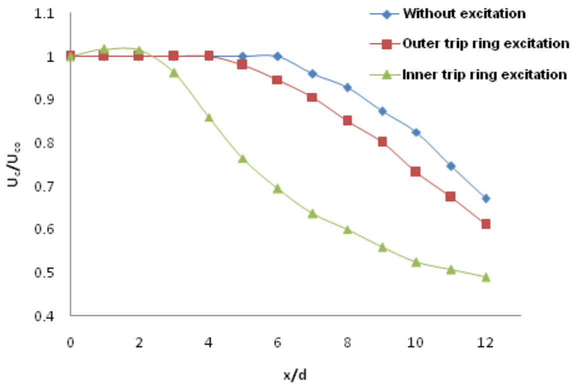

Fig 4. Non-dimensional centerline velocity profiles of isothermal co-axial jet with a velocity ratio (U_2/U_1) of 0.25 at different excitation method

5. EXIT VELOCITY

Figure 5 present a comparative study between the non dimensional exit velocity profiles of isothermal co-axial jets for different excitation at a velocity ratio of 0.75. There is a negative pressure zone in the exit velocity profile of the excited jets, created by both outer and inner rings. This reverse flow creates some wakes indicated by the dotted line in the graphs. In case of the outer ring excitation the region is formed around 0.6d to 0.7d and in case of the inner ring excitation the region is fromed around 0.4d to 0.5d. At lower velocity ratio the velocity profiles at the annular jet region is like top hat shape and as the velocity ratio increases the shape changes to parabolic shape gradually.

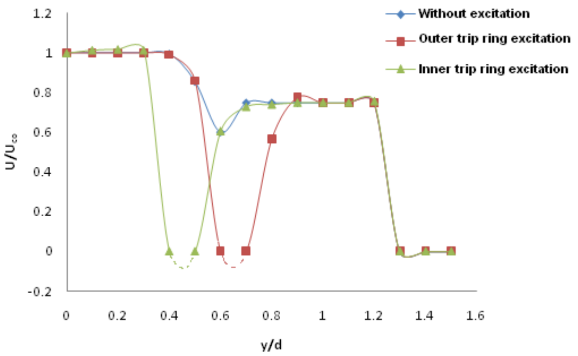

Fig. 5: Non-dimensional exit velocity profiles of isothermal co-axial jets (Re= $3.72\text{x}10^4$) at velocity ratio (U_2/U_1) of 0.75 with different excitation method

6. EXIT TEMPERATURES

In figure 6 the effect of different types of excitation is shown. It is clearly visible that the temperature gradient is more prominent in unexcited co-axial jets than the excited ones. This is due to the enhanced mixing by the wake produced by the excitation rings.

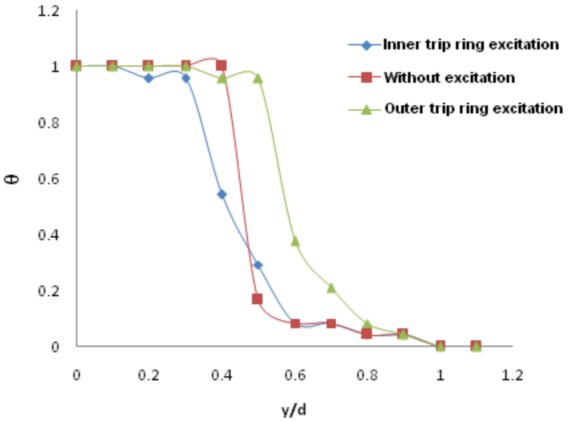

Fig 6. Non-dimensional exit temperature profiles of Non-isothermal co-axial jet (Re= $3.72\text{x}10^4$) at temperature ratio (T_2/T_1) of 0.925 and velocity ratio (U_2/U_1) of 0.25 with different type of excitation

Moreover, the thermal potential core for outer trip ring excited jets is longer than that of inner trip ring excited or unexcited jets. This is caused by the convex nature of the outer trip ring, which gives an expanding effect on the cooler outer jet and prevents the hot jet from the central nozzle to mix with it. While in inner trip ring excited co-axial jets the inner ring tends to compress the jet due to its concave nature.

7. CENTERLINE TEMPERATURE

The centerline mean temperature of non-isothermal jet flows is one of the most important parameters that reveal different important aspects of the thermal field of non-isothermal jets like thermal core length, diffusion mixing amongst the fluid streams etc. In the current investigation the centerline temperature of the jet is expressed as:

$$\theta_c = \frac{T_c - T_2}{T_1 - T_2} \qquad (1)$$

For both of the temperature ratios (T2/T1 = 0.974 and 0.925) thermal potential core is found to be of length 4d for unexcited non-isothermal co-axial jets. It is also observed that, the centerline temperature of non-isothermal single jet decreases more rapidly at lower temperature ratio. The fluctuation of temperature is found to be more prominent at its lower range than that in the higher one. It indicates that the instability of temperature is more at lower value of temperature ratio.

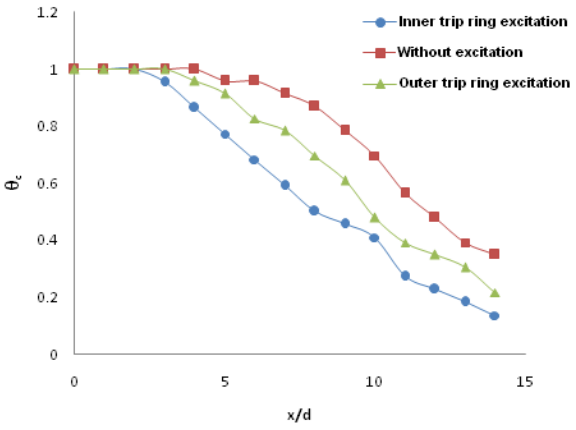

Fig 7. Centerline temperature profile of co-axial jets at velocity ratio of 0.75 and temperature ratio of 0.925 with different type of excitation

It is evident that the centerline temperature at lower velocity ratio of unexcited and outer trip ring excited co-axial jets follows the same path. With the increase of velocity ratio the difference of centerline temperature profiles between them is increasing. In the present investigation the inner trip ring excited co-axial jets have the shortest thermal potential core and the rate of change of temperature is also greater than other two cases i.e. without excitation and outer trip ring excitation.

8. CONCLUSIONS

From the study of trip ring excited non-isothermal co-axial jets it is found that inner trip ring is most efficient in mixing co-axial jets. The lengths of both dynamical and thermal potential core are shorter than that of outer trip ring excited or unexcited co-axial jets. In the case of dynamical potential core it is less than 3d and for thermal potential core it is less than 2d for most of the cases. However, outer trip ring excited co-axial jets and unexcited co-axial jets have almost the same thermal potential core length in lower velocity. Temperature gradient is more prominent in unexcited non-isothermal co-axial jets than the excited ones.

In trip ring excited co-axial jets a negative pressure zone is created at the exit of the jets due to formation of wake and reverse flow in the place between the central and annular jets. The place of the wake depends on the thickness of the trip ring and the type of the ring i.e. outer or inner.

9. REFERENCES

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10. NOMENCLATURE

Symbol	Meaning	Unit
d	Central jet diameter	(mm)
D_2	Annular jet diameter	(mm)
T	Local mean temperature	(K)
T_1	Mean temperature of inner jet	(K)
T_2	Mean temperature of outer jet	(K)
T_c	Centerline temperature	(K)
U	Mean jet velocity	(m/s)
U_1	Central mean jet velocity	(m/s)
U_2	Annular mean jet velocity	(m/s)
θ	Non-dimensional temperature	(m/s)

11. MAILING ADDRESS

M. A. T. Ali
Dept. of Mechanical Engineering,
Bangladesh University of Engineering & Technology,
Dhaka, Bangladesh.