Effects of Reynolds Number on Twin Circular Jets at a Small Space Ratio

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Abstract: **A twin circular jet of diameter 20 mm is investigated experimentally for a small space ratio of 1.2 and how Reynolds number affects the flow field is analyzed for three different Reynolds number (Re = 16300, 34400 and 49200). The experiment is carried out in an air jet facility and pressure probe method is used to measure and calculate the position dependent data. Mean velocity profiles along the longitudinal, transverse and lateral directions are studied where an impact of varying Re is evident. Static pressure and mean kinetic energy distributions are also investigated where an enormous influence of Re is found. With the increase of Re, interaction of two jets is enhanced and ample amount of energy and mass transfer occur between the shear layers of the twin jets.**

Keywords- **twin jets, mean velocity, static pressure, kinetic energy, flow field, shear layer.**

I. INTRODUCTION

Twin jets are produced when flow exerted from a nozzle having two orifices. This two orifices can be symmetric, asymmetric or of different shapes. Various advantages have been unfolded for a twin jet over a single jet regarding its mixing characteristics, noise generation level and other phenomena while applying in gas turbine combustion system, mixing in boiler, burner, chemical reactor and so on.

Twin jets have been studied from last few decades where many researchers came up with various results. For example, Tanaka [1], [2] was one of the earliest researchers to study two dimensional parallel jets where he found three regions in the downstream of the flow named converging, transition and combined regions respectively shown in Fig. 1. According to him the region from jet exit to point where inner shear layers merge is called converging region, from merge point to combined point is called transition region and from combined point to onward is called combined region. Elbana et al. [3] experimentally observed the interaction between two plane parallel jets and found that mean velocity profile behaves like a single jet after combined point. Lin and Sheu [4], [5] investigated two parallel plane jets by hot wire anemometry where their result shows that in combined region entrainment and spreading rate are greater in twin jet than single jet. Pandey and Kumar [6] numerically analyzed twin jet flow at a fixed space ratio of 9 and different Mach numbers. They noticed that jet width and merging length increases with Mach number. Behavior of twin axisymmetric free jet at various nozzle spacing was investigated by Azim [7] where he found the mixing in the merging region reduces as nozzle spacing increases. He also observed that converging and combining points shift forward with the increase of nozzle spacing. Most recently, Philippov et al. [8] experimentally studied the interactions of two parallel jets at different space ratio and Reynolds number by using Laser-Doppler Anemometry. They came to a conclusion that increase of Reynolds number and space ratio weaken the interaction between the jets. Nozzle spacing effects were also studied by Laban et al. [9] where they carried out an experiment by PIV method and found a significant rise of streamwise as well as transverse turbulence intensity along the centerline with the decrease of jet spacing. Furthermore, interaction of inner shear layers is enhanced by reducing jet spacing. A comparative study of symmetrical and asymmetrical twin jets was experimentally done by Muthuram et al. [10] for a fixed space ratio at low Mach numbers. Their result shows that an asymmetric twin jet exhibits better mixing over a symmetric twin jet.

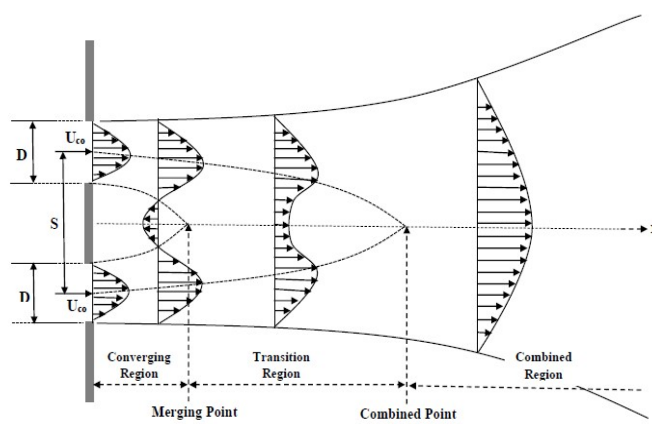


Fig. 1 A twin jet flow field

Zheng et al [11] analyzed the nearfield mixing of parallel dual round jets by both numerical and experimental method. They found that merging of the jets is affected by jet spacing almost linearly. Two jets deflect towards the central plane and degree of deflection is characterized by pressure ratio and turbulence intensity. Mohapatra [12] predicted the turbulent flow in two parallel jets by using k-ε model where existence of both negative and positive static pressure was identified on both sides of merging point. Effects of Reynolds number on both single and twin surface jets were investigated by Rahman and Tachie [13]. They observed that jet attachment point to the surface is sensitive to lower Reynolds number (Re ≤ 3890) and attachment length is nearly independent of higher Reynolds number. They also found that, Reynolds number has no significant influence on velocity decay, spread rate and merging point of twin surface jet. Bell et al. [14] studied twin supersonic jet by using PIV method and noticed a strong near field standing wave at increased nozzle pressure ratio. Some other researchers [15], [16] carried out research on twin jet flow field at different conditions.

Although twin jet was studied extensively in previous time both numerically and experimentally, very few researchers worked with small space ratio and Reynolds number effects on it. So, the aim of this experiment is to investigate the flow field characteristics of twin jets having a small space ratio with varying Reynolds number which is expected to contribute to the field of jet flow research.

II. EXPERIMENTAL DETAILS

The experiment was carried out in a circular air jet facility which is shown in Fig. 2. It has an inlet diameter of 300 mm followed by an axial fan unit (with two axial fans), settling chamber, reducer, flow straightener and a discharge nozzle which consists of an axially symmetric twin jet of diameter D = 20 mm with space ratio S/D = 1.2. Geometry of the twin jet nozzle has been shown in Fig. 3. This air jet facility is able to produce maximum flow velocity of 36 m/s at the exit of the discharge nozzle. A flow controller is installed at the inlet of the nozzle to control the flow velocity. The experiment was conducted for three different Reynolds numbers (Re = 16300, 34400 and 49200) at a fixed jet space ratio. Pressure probe method [17] was used to measure and calculate the position dependent mean flow velocity, static pressure as well as mean kinetic energy by using a calibrated three hole wedge shape yaw meter and three identical dual input differential pressure transducer. Each of the pressure transducers has the range of +/- 13.79 kPa with 0.01 resolution and +/- 0.3% accuracy. Three dimensional traversing mechanism was used to mount and move the probe at various longitudinal (x), transverse (y) and lateral (z) directions. Co-ordinate system is shown for the nozzle in Fig. 4. Non-dimensional data are used for plotting only in the positive directions of all three axis due to symmetrical properties of twin jet. Exit mean velocity (U_{co}), dynamic pressure (P_d) and kinetic energy at jet exit (K_o) are used to non-dimensionalize streamwise mean velocity (U_x), static pressure (P_s) and mean kinetic energy (K) respectively. Room temperature, air density and pressure were continuously monitored and recorded during the experiment.

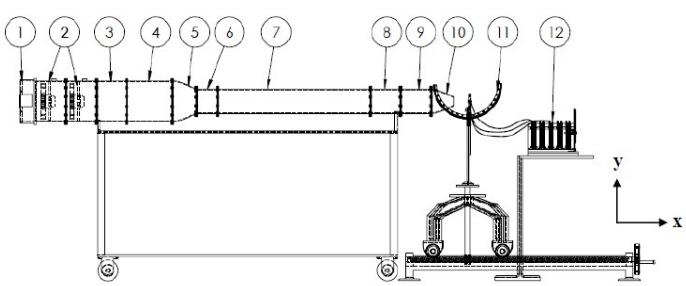


Fig. 2 Air jet nozzle setup; (1) Flow Controller (2) Fan Unit (3) Guide Vane (4) Settling Chamber (5) Reducer (6) Flow Straightener (7) Stabilizer Pipe (8) Vortex Breaker (9) Discharge Pipe (10) Nozzle (11) Traversing Mechanism (12) Pressure Transducer.

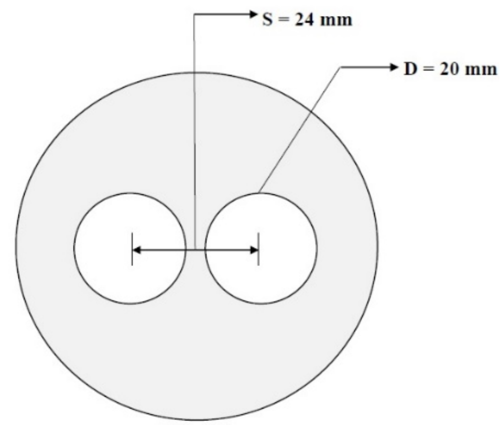


Fig. 3 Geometry of twin jet nozzle

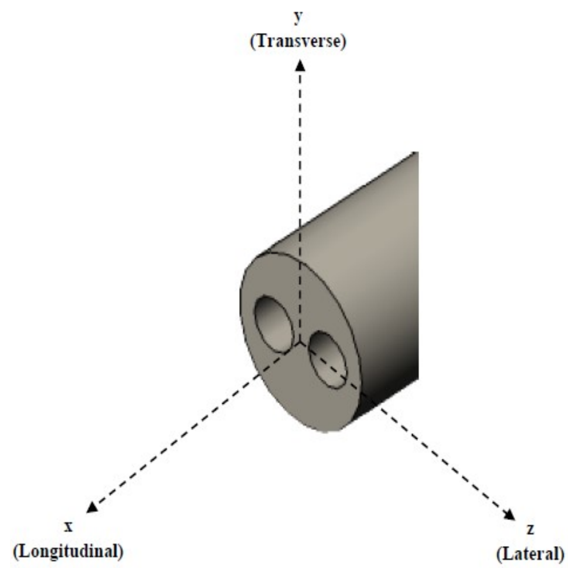


Fig. 4 Co-ordinate system

III. RESULTS AND DISCUSSION

A. Centerline Mean Velocity Decay

Fig. 5 represents centerline mean velocity decay at three different Reynolds number (Re = 16300, 34400 and 49200). It is observed from the experiment that mean velocity increases rapidly in the downstream upto X/D = 5 for all Re and starts decaying in the further downstream where it resembles the properties of single jet. But absence of negative velocity is noticed at the immediate exit of the nozzle where Tanaka [1] found negative velocity at higher space ratio (S/D = 8.5). For lower Re, mean velocity increases at lower rate but decays faster than higher Re after X/D = 5; furthermore maximum velocity attained in the centerline is higher as Re increases. Hence, entrainment of surrounding air happens faster in outer shear layer of the jet at low Re.

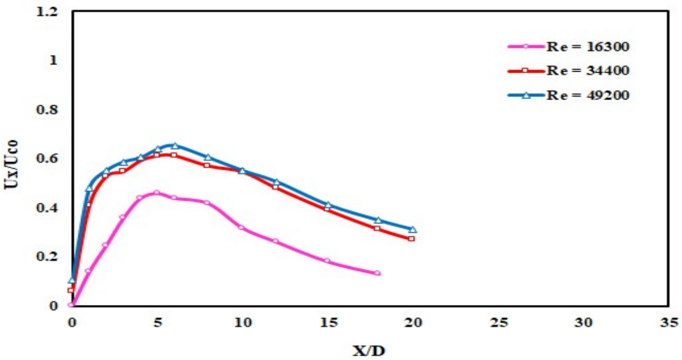
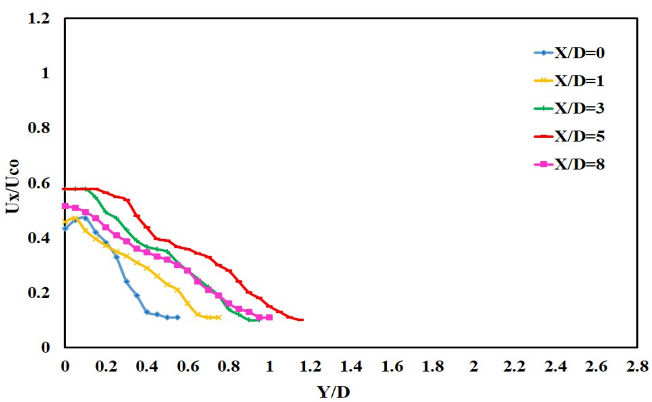


Fig.5 Centerline mean velocity decay

B. Mean velocity Profile in Transverse Direction

Mean velocity variation in transverse direction is shown in Fig. 6 for all three Reynolds number where velocity gradient is faster for low Re and as Re increases, mean velocity decreases at slower rate along the downstream. It indicates that lower Re permits the surrounding air to enter into the outer shear layer of the jets more quickly than that of higher Re. There is also evident of increase of mean velocity up to certain level and a quick decrease in the near field for Re = 16300. As the Re increases, this elevation of the mean velocity starts to supersede.



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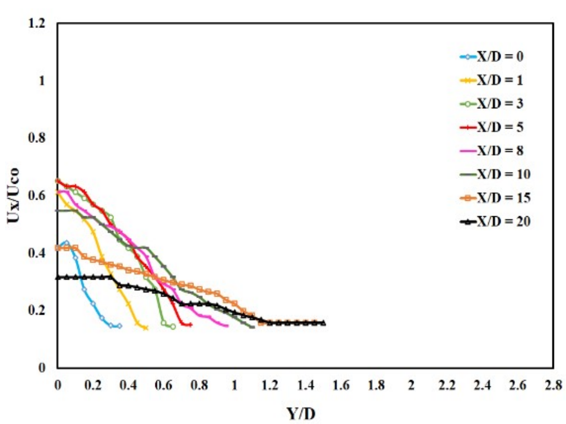

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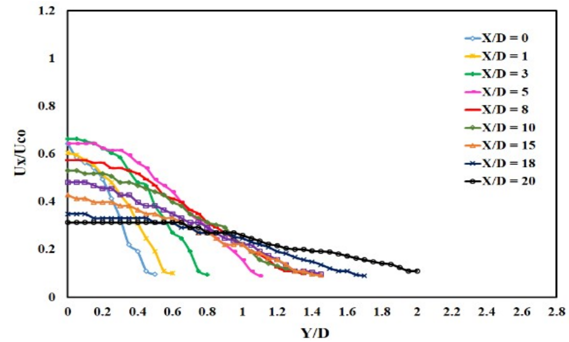

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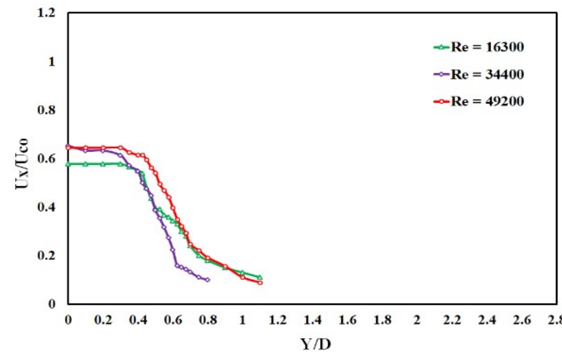
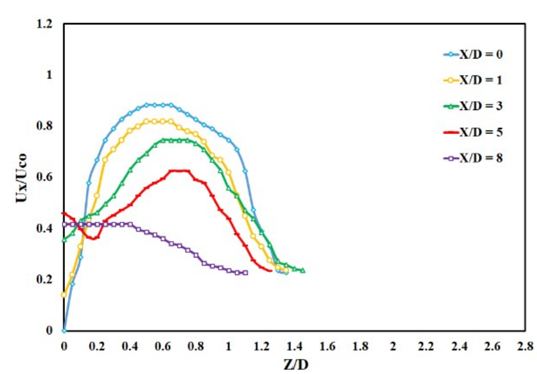


(d)

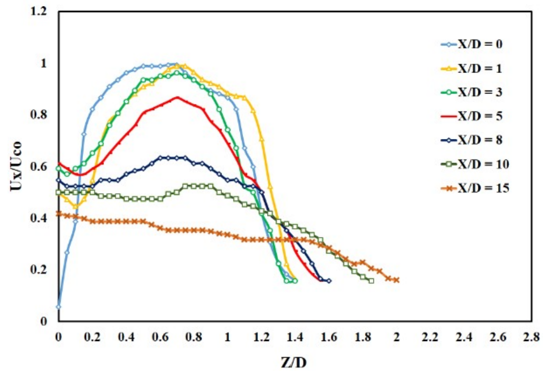
Fig. 6 Mean velocity profile in transverse direction at (a) Re = 16300 (b) Re = 34400 (c) Re = 49200 (d) different Re for X/D = 5

C. Mean Velocity Profile in Lateral Direction

Fig. 7 shows mean velocity profile in lateral direction for all the Reynolds number considered where they exhibit symmetrical profile with respect to x-y plane. In the near field up to X/D = 5 (approx.) sharp decrease and increase of mean velocity is evident for all Re due to interaction between inner shear layers. As Re increases pick value also increases. In the further downstream jets interact with each other and behave like a single jet. At low Re, surrounding fluids enter the flow field via outer shear layer more quickly and hence mean velocity decays faster than high Re. As previously discussed that recirculation region is not present for twin jet at S/D = 1.2, negative velocity is rarely existent at the immediate exit of the nozzle in the near field.



(a)



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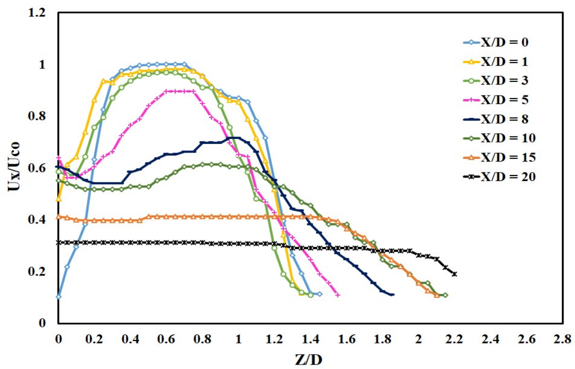

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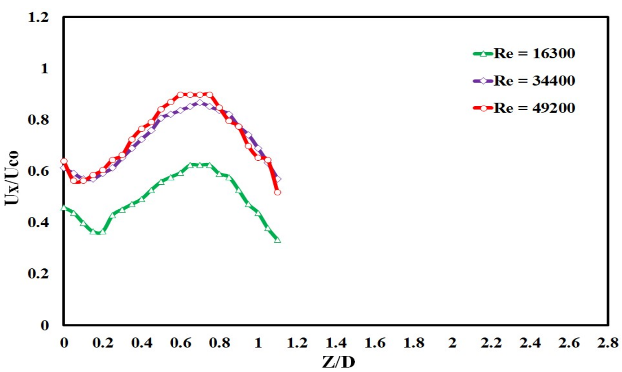

(d)

Fig. 7 Mean velocity profile in lateral direction at (a) Re = 16300 (b) Re = 34400 (c) Re = 49200 (d) different Re for X/D = 5.

D. Static Pressure Distribution

In twin jet, existence of negative static pressure (P_s) is found in the upstream region up to X/D = 1 which is shown in Fig. 8. A sudden rise of static pressure with deliberate decrease towards atmosphere in the further downstream is observed. Higher the Re more the magnitude of static pressure in the flow field. Furthermore, at Re = 16300, substantially small negative static pressure is evident up to X/D = 10 (approx.) which indicates that lower Re has greater turbulent instability in case of twin jet at space ratio of 1.2. Even rate of increment of static pressure at immediate exit of the nozzle is greater for higher Re.

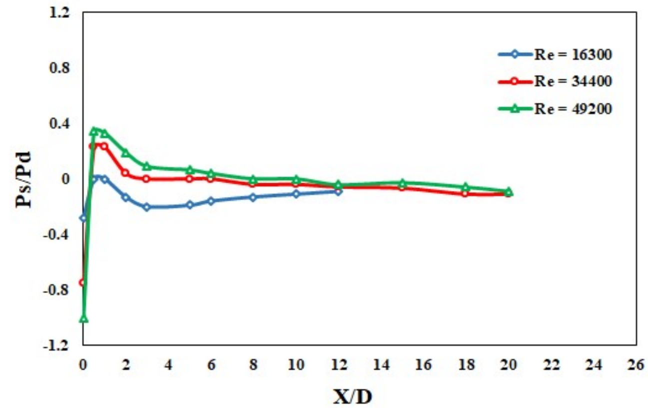

Fig. 8 Static pressure distribution along the centerline

E. *Mean Kinetic Energy Distribution*

Mean kinetic energy (K) distribution along the centerline is shown in Fig. 9 where energy increases at steeper rate upto X/D = 5 (approx.). It indicates that due to merging of inner shear layers of the jets, there is huge energy and mass transfer occurs at near field. In the further downstream, kinetic energy dissipates at exponential rate for all Re. But it is noticeable that as Re increases, kinetic energy increases in the near field and dissipates slowly in the far field which implies that energy transfer is greater for higher Re.

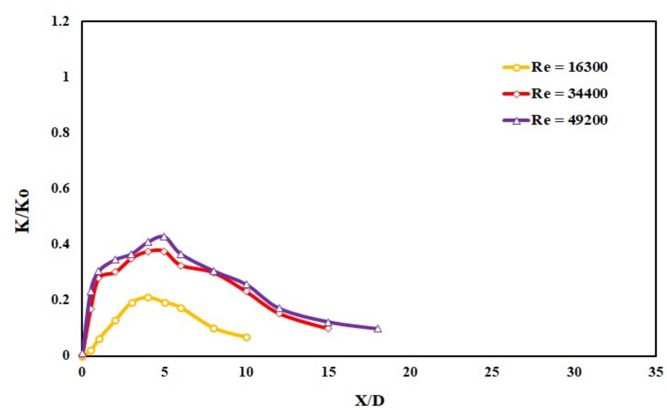

Fig. 9 Mean kinetic energy distribution along the centerline

IV. CONCLUSIONS

Effects of Reynolds number on twin circular jets for small space ratio 1.2 are studied in this experiment where three Reynolds number (Re = 16300, 34400 and 49200) were considered. Results show that it has large influence on twin jet with small space ratio. No negative velocity is existent for any of the Re considered. Mean velocity increases rapidly and decay at slower rate for higher Re whereas opposite phenomena is observed for lower Re. Mean velocity profile in both transverse and lateral direction was analyzed. At low Re mean velocity gradient is faster than higher Re which indicates quick entrainment of surrounding air in the flow field at lower Re in transverse direction. On the other hand, sharp decrease and increase of mean velocity is noticed at near field for lateral direction and this pick value increases as Re increases. The interaction between the jets cause bending of the inner shear layers towards symmetry plane. In the far field after X/D = 5, jet behaves like a single jet. Static pressure distribution is also investigated and sudden increase of pressure was evident at immediate exit of the jet along the centerline for all Re. the magnitude of the static pressure is more for higher Re but a small value of negative static pressure is existent up to X/D = 10 (approx.) for Re = 16300. If mean kinetic energy distribution is inquired, it is found that energy transfer is greater for higher Re.

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