HOMOGENEOUS FLUID CONCEPT APPLIED TO JET THEORY

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ABSTRACT

Understanding the fluid mechanics of high density particle jet ribbons ("particle ropes") and the physical reasons for their formation, persistence and eventual break is important in providing data which can be used to design better pulverised fuel burners which will have high efficiencies and better flame characteristics which will limit the production of NOX and SOX gases that are known to harm the environment.

This study has shown that for a given particle loading and background velocity, the particle jet behaves just like the single phase jet. The centre line velocity of the jet decreases with increasing issuing jet velocity - almost linearly. For a given velocity, the jet dispersion and acceleration decreases for increasing particle loading. Also, the higher the dispersion, the greater is the rate of acceleration of the jet and the more uniform the cross sectional velocity profile.

INTRODUCTION

The concept of the air-particle mixture behaving as a homogeneous fluid has been applied to air-particle jets before e.g. by Soo (1967). In the laminar flow case, if both the particle diameter and the loading (concentration) is small, the spread of the particles in the jet is due to fluid motion and as the particle cloud is slowed down, its concentration increases and eventually settles down, the overall momenta of the system is conserved as in a jet of single phase fluid but the momenta of the particles is not as they are dispersed.

When the flow is turbulent, the particles, in addition to experiencing the behaviour of other particles, via particle-wake interactions, experience region of air-flow recirculation with a consequence of significantly reducing the fluid turbulent shear stress. This reduction is enhanced by the dissipating effects of the particles; accompanied by the decrease in the turbulent Kinetic energy. Particles dispersion, however, depends strongly in Aerodynamic response time, $t^* = \frac{\rho d^2}{18\mu}$, and as such large particles cannot be expected to follow the rapid fluctuations of the air phase, t^* is the particle relaxation time, ρ is the particle density, d is the particle diameter and μ is the fluid viscosity.

Some previous studies of "particle ropes" (McCluskey et. al.) suggest that particle ropes", once formed, maintain their coherence. When particle-jets go over a right angle bend, normally from vertical to horizontal, the jets separates into regions, the high density particle jet region, termed as the "particle rope" and the less dense region consisting of mainly air. Clearly the fluid dynamics of the process needs to be understood more in order to asses why this is the case. The figure shows, schematic diagram of a small wind tunnel utilised to study the particle jet dispersion. This study was aimed at finding the behaviour of a particle and compare it with that of a known single phase jet.

EXPERIMENTAL SET-UP

The Fig.1, shows a schematic diagram of a small wind tunnel utilised to study the particle jet dispersion. The particle jets were generated by means of a stream of air from a fan picking up the particles from the outlet of dust hopper with a screw feeder. The speed of both the screw feeder of the dust hopper and the fan were variable so that the injection velocity and particle loading of the jet could be controlled independently.

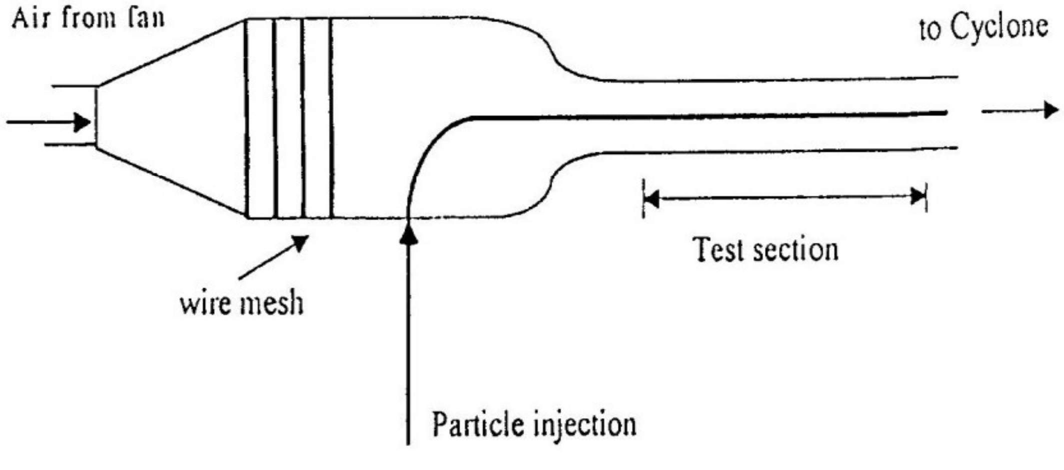

Fig. 1: Schematic Diagram of Wind Tunnel Rig

The air-particle jet was injected via a 5 mm bore tube, into the centre of the duct; coaxial with the streamwise component of the background airflow. The injection of the air particle mixture was studied under conditions with a background having a minimal turbulence and where the background airflow contained grid-generated turbulence. In the experiments, background air velocity was set at 6 ms-1 and 10 ms-1. Several particle injection velocities were used (3.5 to 12.5 ms-1). The turbulence levels were varied from 1% level (no grid-generated turbulence) and 6% for grid-generated turbulence (Masanja (1993).

The background air velocity (in the absence of the particle jet) measurements, were made by Laser Doppler Anemometry, LDA, using 1m corn-oil droplets. This enabled the mean flow and turbulence characteristics to be determined.

The Particle Image Velocimetry, PIV was used to record the velocity profile of the whole flow volume. PIV and LDA measurement methods are explained elsewhere (Lourenco (1986), Greated (1980), Gary (1988), Gary (1992)). The scanning beam method was utilised to illuminate the particle air flow field for recording the PIV negatives. 15W Argon-Iron laser beam, collimated to 1 mm diameter using a system of lenses was used.

RESULTS

The mean flow characteristics in the test section, measured by LDA method is shown in Fig. 2. This shows the airflow on the downstream of the grid when the mean background velocity was 10 m/s. In the absence of grids, the background airflow had a turbulence level of less than 1%.

PIV method was used to record flow data of the whole flow volume. A photographic print of a PIV negative of a 10 ms-1 air-particle jet with particle loading of 4 kgm-3 in a background air flow which had a uniform velocity of 6 ms-1 and no grid generated turbulence is shown in Fig.3.

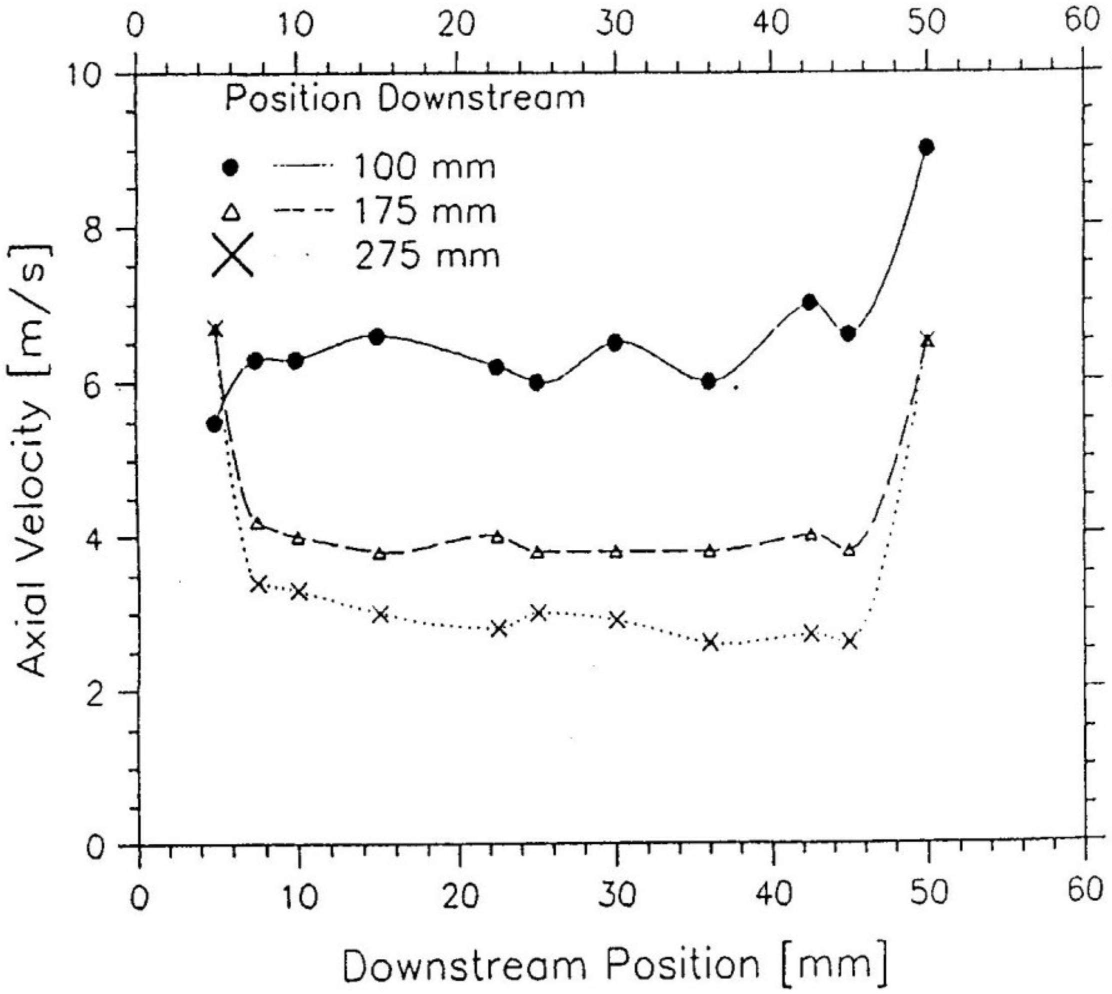

Fig. 2:Mean Velocity and Turbulence Characteristics of Air Flow (Background Air Velocity 10 m/s)

This negative was analyzed to produce the displayed velocity vectors in Fig. 4. The variation of the axial velocity component and that of the jet half width obtained from this analysis of the flow map are shown in Figs. 5 and 6 respectively.

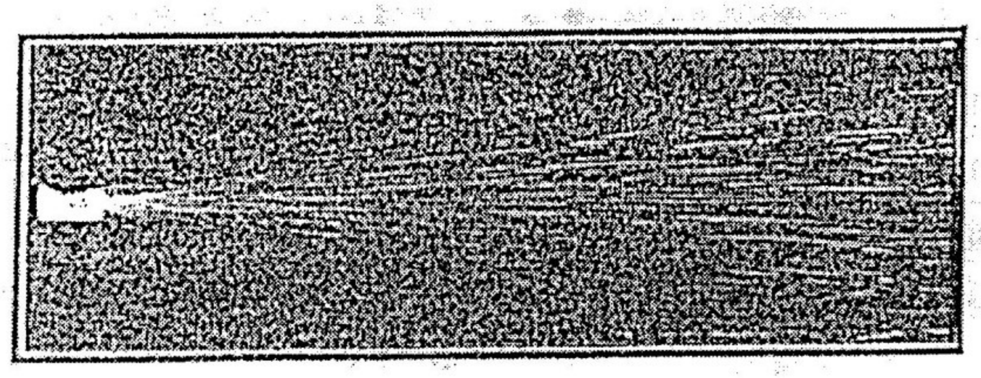

Fig.3: A Photograph of the PIV Negative

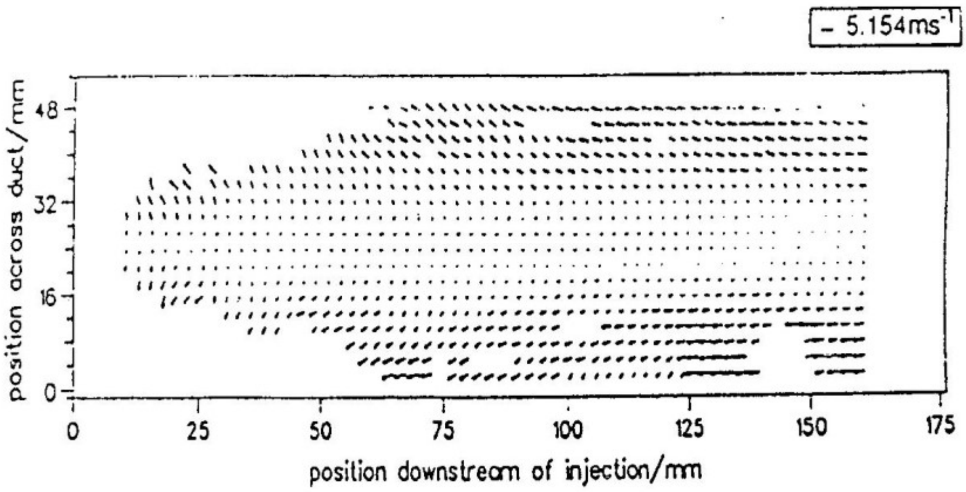

Fig. 4: Velocity Vectors of the PIV Negative Shown in Figure 3

DISCUSSIONS

In air-particle mixture, of a given velocity and particle loading, where issued into a background air flow of the same mean velocity, the subsequent behaviour of the air-particle mixture was unaffected by whether the background airflow contained grid generated coherent structures or not.

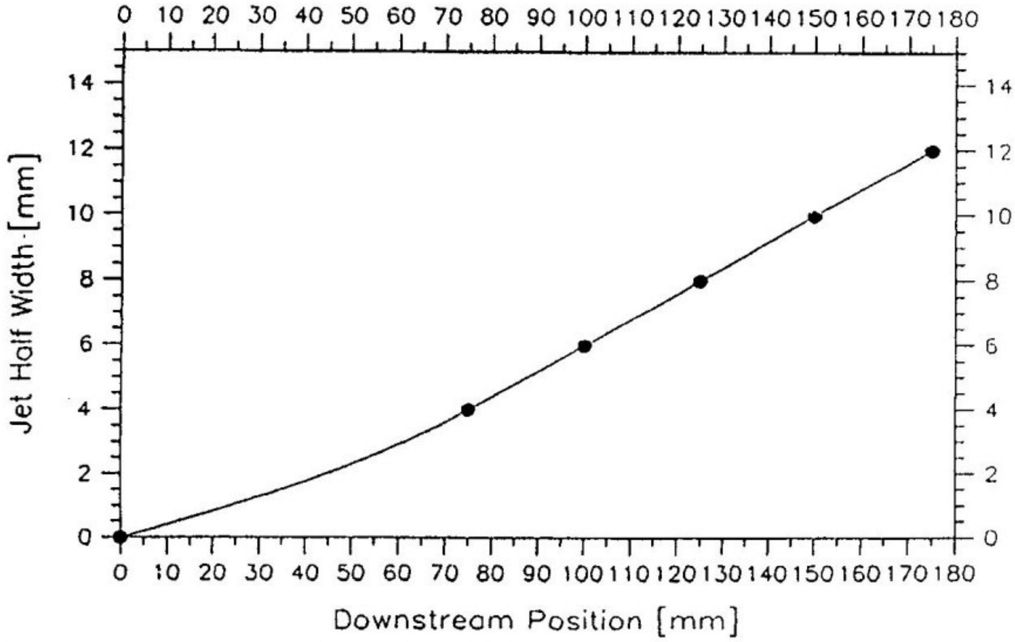

Fig. 5: Variation of Jet Half Width

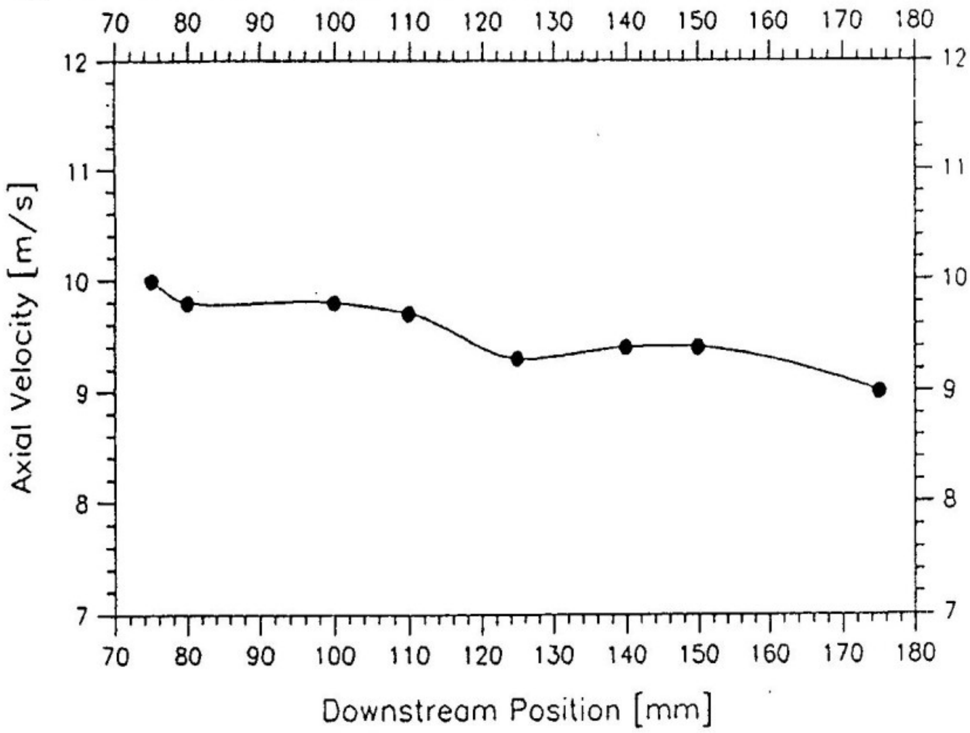

Fig. 6: Variation of Axial Velocity

This fact can be used to conclude that the air-particle mixture behaved like an equivalent jet of a single phase. If the air-particle mixture did not behave as an equivalent single phase jet, then the particles would be influenced by the grid generated coherent structures and so the behaviour of the air-particle mixture issued into a background flow with grid generated turbulence would be different to that of the behaviour of the air-particle mixture issued into a background flow which contained no grid generated turbulence.

It can be seen in figure 3 of the photo print that the jet disperses as it moves downstream. The velocity vectors in figure 4 shows that the particles in the jet decelerate as they move downstream from the injection position.

Particles at the outer edges of the jet decelerate more than those nearer the centre line of the jet. It was also found that as the air-to-particle ratio increases, that is particle loading decreases, then the particle deposits moves downstream, this is in agreement with Bagnold (1941) observations that the position of the sand dunes like deposit was similarly affected by the loading of sand particles in the air flow.

CONCLUSIONS

Several factors affect the particle deposits and their equilibria position. The study shows that the behaviour of air-particle jet issued into a background air flow are dependent upon, issuing velocity of jet, particle loading of the jet, velocity of the background air flow, and is independent of the presence of grid-generated turbulent coherent structures in the background air flow.

On the influence of the velocity of the background air flow, the higher the background air flow velocity, the greater the dispersal of the jet, and , the more uniform the velocity distribution across the jet and, the greater the rate of acceleration of the jets' centre line axial velocity component.

The particle loading effect on the behaviour of air-particle jets showed that, the higher the particle loading of the jet, the less the jet disperses, the narrower the velocity self-similar profiles i.e., the greater the velocity variation across the width of the jet, and, the lower the rate of acceleration of the jets' centre-line velocity as it travels downstream.

NOMENCLATURE

d = the particle diameter, m

t^* = the particle relaxation time, s

ρ = the particle density, kgm^{-3}

μ = the fluid viscosity.$kg.s.m^{-2}$

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