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Mean Velocity, Reynolds Stress and Static Pressure Measurements in an Air Cyclone

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Abstract

The flow field in a gas cyclone with no particulate load was documented using a dynamic Cobra pressure probe. The six Reynolds stresses as well as the time-averaged velocity vectors were mapped for nine stations. A relatively low turbulence level vortical flow was found in the outer regions of the cyclone body but high turbulence levels were measured below the vortex finder, although here the mean tangential velocity distribution was well defined as solid body rotation. The time-averaged results were in fair agreement with a numerical study and further work is planned with a low particulate load in the flow.

Introduction

The extensive use of gas cyclones within industry as a means of removing particulate matter from two phase gas-solid flow, makes the characterisation of the flow field generated within this relatively simple geometry of considerable practical interest. However, measurement of the gas phase alone within a cyclone body presents a number of experimental difficulties, due in part to the rapid variation in the direction of the mean total velocity vector, the high turbulence levels associated with the vortex finder, and the problem of flow interference by introduced probes. These problems are compounded by the introduction of solid particles to the gas phase, which further eliminates most measurement techniques. As a means of characterising the gas phase alone, this paper presents the mean velocity, Reynolds stress and static pressure distributions within a 470 mm industrial pattern cyclone.

Experimental Apparatus

The gas cyclone had an internal diameter of 470mm, with the cylindrical inlet zone extending axially for 300 mm. The cone angle was 17.05 degrees, and tapered to a 100 mm diameter exit spigot. A cylindrical section, 100 mm diameter and extending 50 mm, was attached to the spigot (see Figure 1). The vortex finder, 170 mm diameter, was 230 mm long, with 50 mm extending above the inlet cylinder. Flow entered tangentially at the top of the cylinder through a 150 mm square section duct, which in turn tapered to a 100 mm diameter inlet pipe over a 160 mm transition section. Measurements were made at eight axial stations of the radial distribution of the mean velocity distribution (three components), turbulent or Reynolds stresses (six components), and mean static pressure distribution within and external to the body of the cyclone. The Cobra pressure probe (Hooper and Musgrove, [4]) used in the experimental study, was used at axial stations 30 mm above the vortex finder, 100 mm, 200 mm, 290 mm, 395 mm, 490 mm, 605 mm and 710 mm below the cylindrical top of the cyclone and inside the cyclone. A radial traverse was also made 30 mm below the open outlet of the spigot. The Cobra pressure probe, which has an acceptance half-cone angle of 45 degrees, was rotated 330 degrees in yaw at each radial position to search for the direction of the mean total velocity vector.

This probe, which uses high frequency differential pressure transducers located as closely as practical to the four hole faceted head, uses the calculated and experimentally verified pressure field transmission function to recover the undistorted time record of the four probe pressures at the head. The upper frequency resolved was 1.5 kHz.

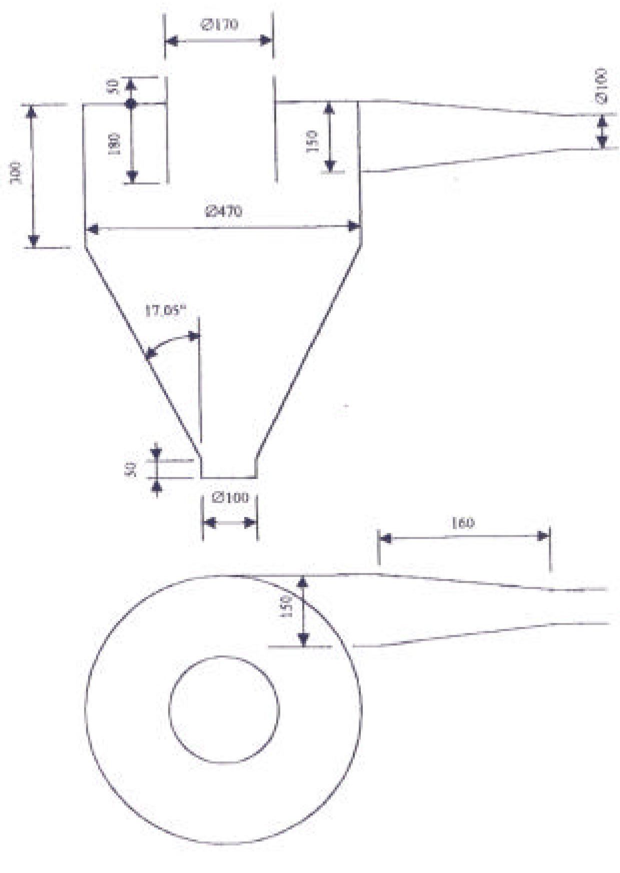

Figure 1: A Schematic of Experimental Apparatus

Experimental Results

The experimental results (at three representative levels) show a relatively low turbulence vortical flow to be quickly established in the outer regions of the cyclone body, for both the annular flow zone adjacent to the vortex finder and the conical lower section of the cyclone. Very high turbulence levels are shown to be present below the vortex finder, although the mean tangential velocity distribution is well defined here as solid body rotation.

Although the top of the vortex finder and the cone spigot were open in this experimental study, the results showed that the majority of the flow exiting the cyclone was still via the vortex finder. The flow field at the exit (or top) of the vortex finder was complex (Figure 2 (a)), with an axial flow out of the cyclone for the outer part of the vortex finder but with a flow reversal of this velocity component for the central core. This result shows the potential for the re-entrainment of the particulate load leaving a gas cyclone.

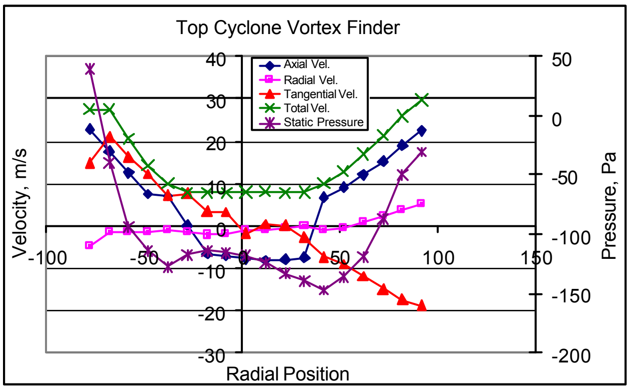

Figure 2 (a): Mean Flow and Static Pressure Distribution, Top of Cyclone Vortex Finder.

The corresponding Reynolds stress distributions, Figure 2 (b), show that the mixing zone at the outer edge of the cyclone has the highest normal stress values. Interestingly, the peak normal stress is shown by the axial component at one edge of this mixing zone, and by the tangential component at the other edge. The flow field here is not completely symmetrical about the centre-line axis of the cyclone.

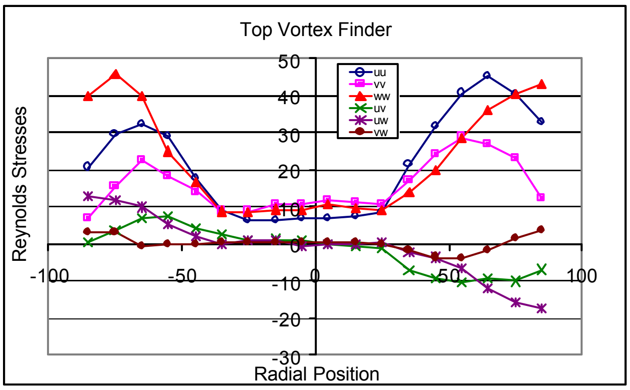

Figure 2 (b): Reynolds Stress Distribution, Top of Cyclone Vortex Finder.

The flow field 100 mm below the top of the cylindrical part of the cyclone body is show by Figure 3 (a). This radial traverse was made across the annular zone defined by the cyclone body and the outer surface of the vortex finder, at an azimuthal location 270 degrees from the tangential entry. The mean velocity distribution, disregarding edge effects for radial positions greater than 235 mm, show the flow field to be uniform, with a large tangential component. The tangential entry duct certainly has regions of flow separation, and extends 50 mm axially below this measurement station. However, the flow rapidly attains a vortical form.

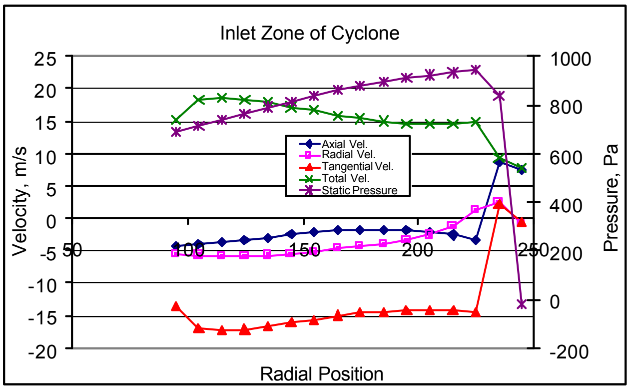

Figure 3 (a): Mean Velocity and Static Pressure Distribution, Inlet Zone of Cyclone.

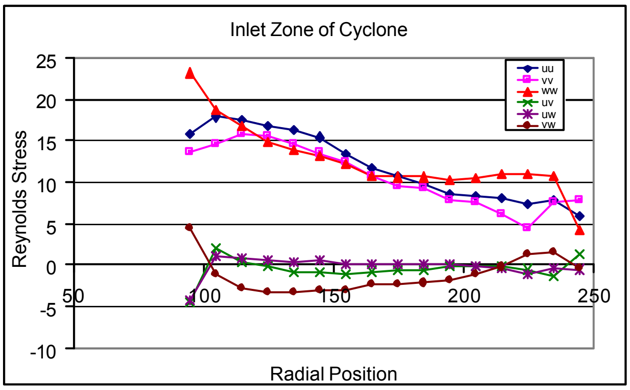

Figure 3 (b): Reynolds Stress Distribution, Inlet Zone of Cyclone.

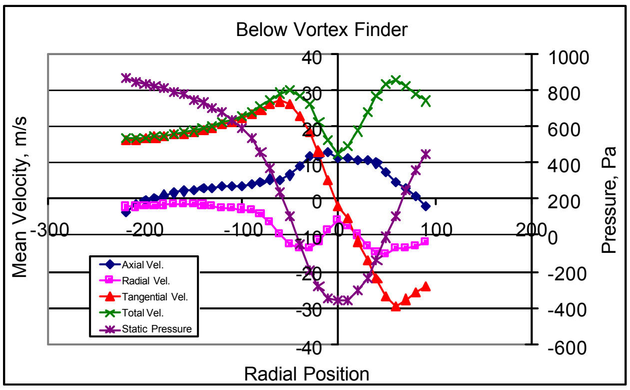

Figure 4 (a): Mean Velocity and Static Pressure Distribution, Below Vortex Finder.

The Reynolds stress distributions, Figure 3 (b), show lower values than for the mixing zone at the top of the cyclone, with the normal stresses having almost the same magnitude.

The mean flow and static pressure distribution is shown by Figure 4 (a) for the region immediately below the vortex finder, at an axial station of 200 mm. This zone of the cyclone is critical to the separation process, as it is at this location that the gas phase enters the vortex finder leaving the particulate load to largely travel down the cyclone walls to the spigot (Heumann, [3]).

The static pressure field falls from a pressure of 900 Pa above atmospheric to nearly 400 Pa below atmospheric at the centre of the cyclone, a distribution similar to the results of Bach and Gouldin [1] for a model of a cylindrical swirling combustor. The tangential mean velocity component is predominant in magnitude, with Rankine structure or a free vortex in the outer wall region and a forced vortex immediately below the vortex finder for the whole extent of the vortex finder (Syred and Beer [5]). The zero value of the tangential velocity coincides very closely to the axis of the cyclone, indicating that the flow is nearly symmetrical by this station. The Reynolds stress distribution, Figure 4 (b), show very large values inside the flow region below the vortex finder.

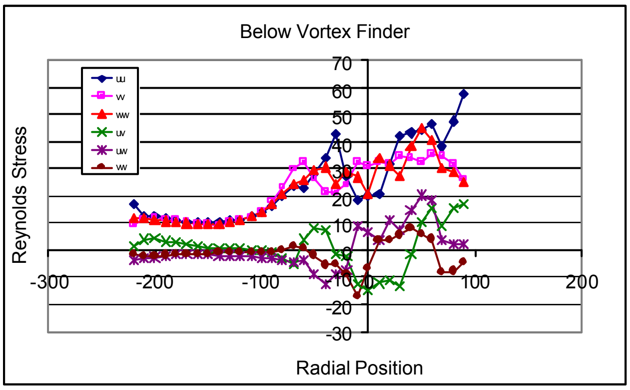

Figure 4 (b): Reynolds Stress Distribution, Below Vortex Finder.

Numerical studies of the same cyclone geometry (Baoyu et al, [2]) with the cone spigot closed, showed the presence of a precising vortex core within the vortex finder and below within the cyclone body. Although the predicted mean velocity profiles from this simulation are in fair agreement with the experimental data, the time averaging process inherent in calculating the Reynolds stresses destroys evidence of this structure. A more extensive time series analysis of the experimental data is currently being used to search for this structure, with the power spectra of the axial velocity component showing evidence of a peak at approximately 60 Hz, close to the predicted frequency.

Conclusion

The experimental results presented show that the characterisation of the flow field in the cyclone is within the capability of the high frequency Cobra pressure probe. The proposed extension of this work to lightly loaded particulate flows should form an interesting comparison with the single phase study.

References

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