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FLOW DEVELOPMENT IN THE INLET SECTION OF A RISER

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ABSTRACT
Coincident LDA three-component solids velocity measurements are conducted near the solids inlet section of a cylindrical pilot riser. A jet-like flow of solids and gas bypassing this solids jet are observed. Solids velocity fluctuations become more intense with increasing gas flow rates and diminish as the solids move away from the solids inlet section.

INTRODUCTION
The complexity of gas-solid riser flow remains a major difficulty in the design and optimization of Circulating Fluidized Beds (CFB), despite extensive experimental and computational research. In the inlet and outlet sections of the riser the gas-solid two-phase flow is disturbed, enhancing its complexity. In two recent studies (1, 2) the influence of the riser outlet section configuration has been examined and the flow was found to be significantly affected by the riser outlet configuration. Experimental and computational work (3, 4) near the solids entrance section of a pilot riser set-up has shown that a one-side particle inlet configuration, often used in industry, results in flow patterns where the gas bypasses the solid, thus hindering the gas-solids mixing. It is obvious that the configuration of the riser inlet section affects the gas-solid flow and in particular the gas-solid mixing in the riser entrance section. However, experimental work studying the solids velocity fields in the riser inlet section and their effect on the flow development are scarce (4). Experiments are mostly limited to measuring coincident two-component solids velocities (5). The latter is insufficient, especially for capturing the turbulent riser flow behavior. Furthermore, computational studies often provided contradictory results. For instance, Li et al. (6) concluded that the solids flow and distribution are significantly affected by the applied inlet configuration. On the contrary, You et al. (7), performing 2D simulations of the riser flow, reported that the flow development along the riser height is hardly influenced by the solids inlet configuration. It must be concluded that computational tools need to be optimized for use in riser applications. For the validation of existing and the development of new numerical research tools, accurate and complete experimental solids velocity fields are required. In the presented work, the gas-solid flow in the solids inlet section of a riser is studied experimentally. The solids enter the riser through a one-side solids inlet configuration, implying that a *three-dimensional* flow field is created. C*oincident* measurements of the *three* components of the solids velocity have been acquired using a two-probe Laser Doppler Anemometer (LDA) and preliminary results are presented.

EXPERIMENTAL SET-UP AND OPERATING CONDITIONS

The CFB pilot set-up mainly consists of an 8.7 m long and 0.1 m diameter Pyrex glass cylindrical riser, two glass cyclones, a fluidized bed storage tank for the solids, a 2 m long and 0.08 m diameter standpipe/solids inlet line and a mechanical iris valve to regulate the solids flow into the riser. A detailed description has been given in previous publications (2-4). The riser is operated in 'cold flow', that is only non-reactive solids flow patterns are studied. The solids used in the presented work are FCC-E catalyst particles with a density of 1550 kg/m^3 and a Sauter mean diameter of 77 μm, classified as Geldart Group A particles (8). The gas phase, air, enters the riser via the bottom through a 0.05 m diameter line. This inlet line expands to the riser diameter at 0.3 m above ground level (Figure 1). The origin (0,0,0) of the coordinate axes used, corresponds to the center point of this expansion ring. The riser operates under atmospheric conditions. Experimental volumetric flow rates of 100 and 150 Nm^3/h in the air inlet line are used, corresponding to 3.5 and 5.3 m/s of superficial air velocity in the riser, respectively. The solids flux rate in the riser is constant at 10 kg/m^{2}s, implying that the mean solids volume fraction, ε_s, is less than 0.2% while the mass loading, m, is less than 2.4. The air inlet tube lies at θ=90^o. The solids enter the riser through a single side inlet situated at the plane δ=0^o and inclined 35° clockwise as compared to the Z-axis (Figure 1). The intersection of the riser and the solids inlet tube is positioned at a height of 0.47 to 0.63 m above the axes origin. In the presented study, a blinded T-outlet (2-4) with a 0.1 m diameter and a 0.34 m extension height, positioned at θ=51^o, is used.

The system is equipped with a two-probe Laser Doppler Anemometer (LDA) setup, that allows to perform coincident three-component solids velocity measurements in the gas-solids flow. A water-cooled class IV Argon-Ion laser (Stabilite 2017, Spectra Physics®) is used as light source. Two FiberFlow backscatter probes (60 mm diameter, DANTEC) transmit a pair of 'green' and a pair of 'blue' laser beams (2D probe) and a pair of 'violet' laser beams (1D probe). The probes are positioned at a plane perpendicular to the z-axis with a 90^o angle in between

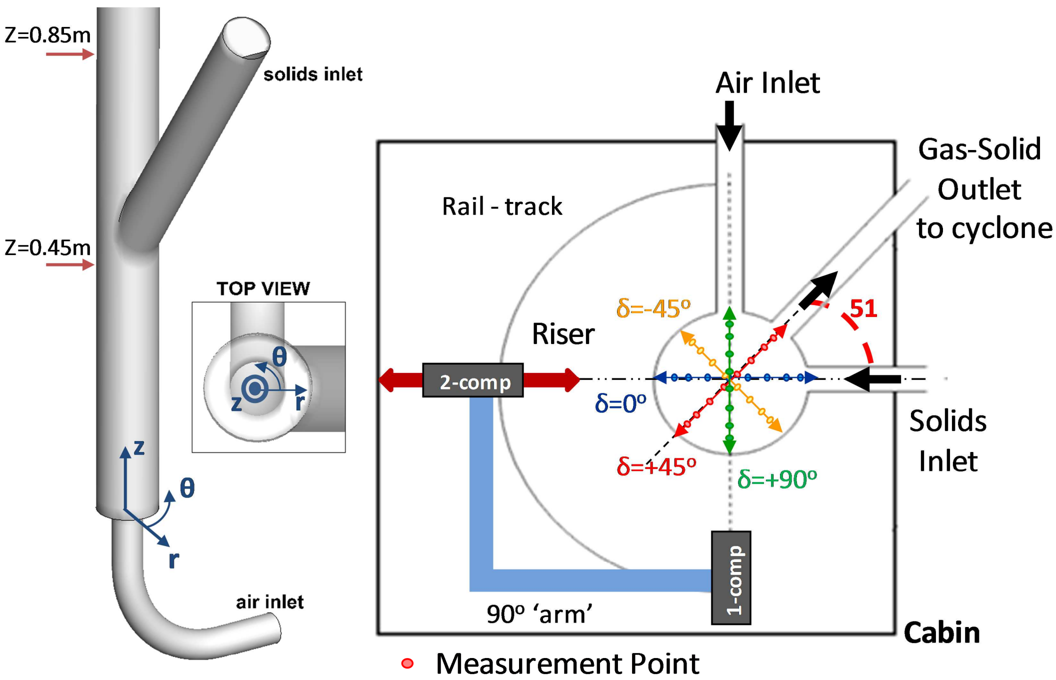


Figure 1: Riser inlet section and detail of the riser measurement section with a representation of the measuring planes.

them (Figure 1). The three velocity components of a single particle passing through the LDA measuring volume are simultaneously determined, referred to as performing coincident measurements. The latter requires the two probes to be aligned very accurately. The probes are fixed on a traverse manifold that enables the adjustment of the relative position of the two probes on one hand, and a stepwise and accurate repositioning of the whole measuring volume relative to the riser on the other hand. The LDA with the traverse manifold is placed inside the cabin of an elevator, which allows to position the LDA at any desired riser height. At each riser height, measurements are performed along four diameters on various riser cross-sections, marked with δ-angles (Figure 1). In the presented study experimental data are gathered close to the solids inlet section, at riser heights between 0.45 m and 0.85 m.

RESULTS AND DISCUSSION

It is visually observed that the solids enter the riser, creating a jet-like flow near the solids inlet tube. The latter is a consequence of the geometrical configuration of the solids inlet line. The results show that the axial solids velocity component has a negative, i.e. downwards, mean value close to the solids inlet (Figure 2), which is gradually reduced and finally becomes positive due to the upward flow of the gas. Missing vectors in the figures indicate that the position is either inacces-

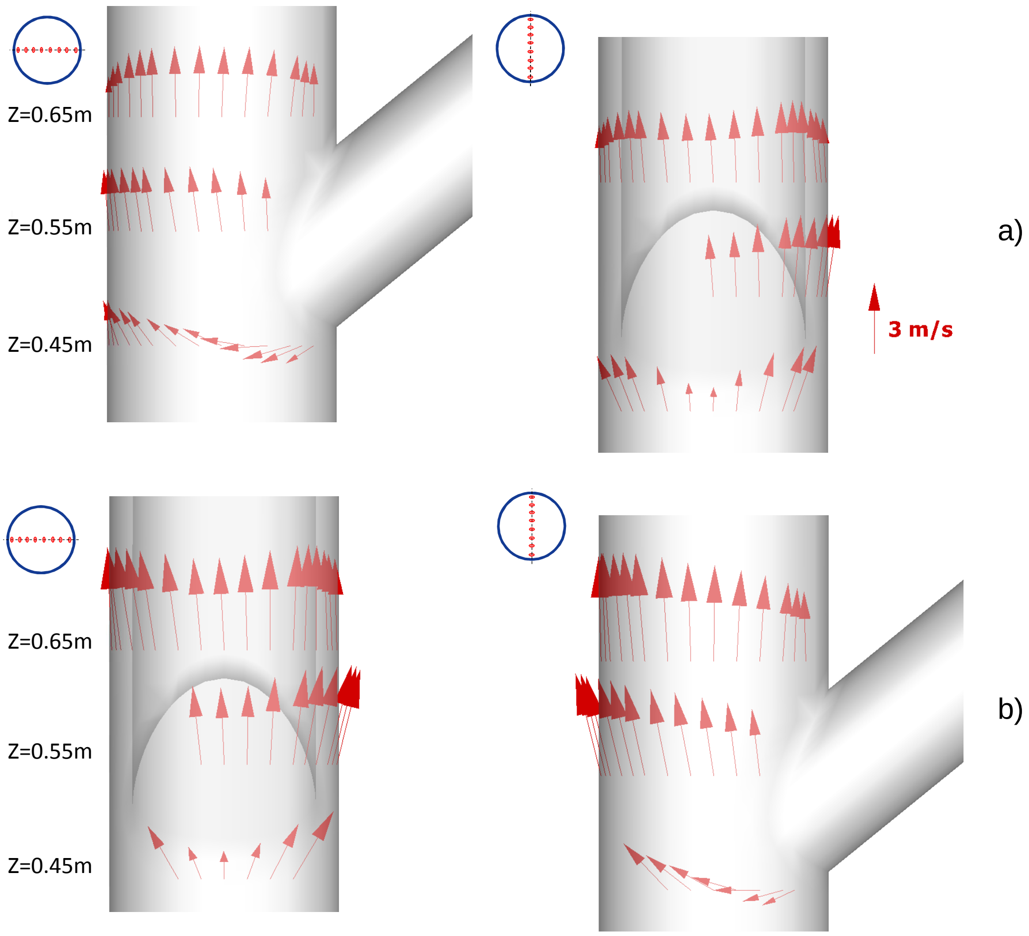


Figure 2: Side view of the riser flow for three riser heights, 0.45, 0.55 and 0.65 m and a) 100 m^3/h and b) 150 m^3/h gas flow.

sible by the LDA due to construction constraints of the set-up (as for Z=0.55 m and 90° in Figure 2b) or that no solids are detected at that position. Reference is made to the lowest measuring height, Z=0.45 m, for the 150 m^3/h gas flow rate (Figure 2b), where the solids jet is restricted close to the solids inlet due to the high gas flow. Hence, the solids do not reach the riser wall opposite the solids inlet. This indicates that the ascending gas bypasses the solids at that position, as previously reported based on two-component coincident measurements (3, 4). In the plane δ=90° at the center of the riser, where the bulk of the solids is found, the solids velocities are lower as compared to those near the riser walls. This is another indication of gas bypassing the solids jet from aside, that is, close to the riser walls. Experimental work has already shown (9) that this jet-like flow in the solids inlet section affects the solids velocity up to a significant riser height, resulting in non axi-symmetrical solids flow fields. A completely developed flow in the riser has not been yet obtained at a riser height of 0.65 m. The latter is also concluded when comparing with previous measured solids velocity results in the middle section of the riser (9). It is noted, however, that the solids axial velocity increases fast with increasing riser height, as solids are entrained by the gas phase.

A top view of the solids flow developed close to the solids inlet is given in Figure 3. These results show that the radial and azimuthal velocity components are much higher at the lower riser heights and for the higher gas flow rates. The

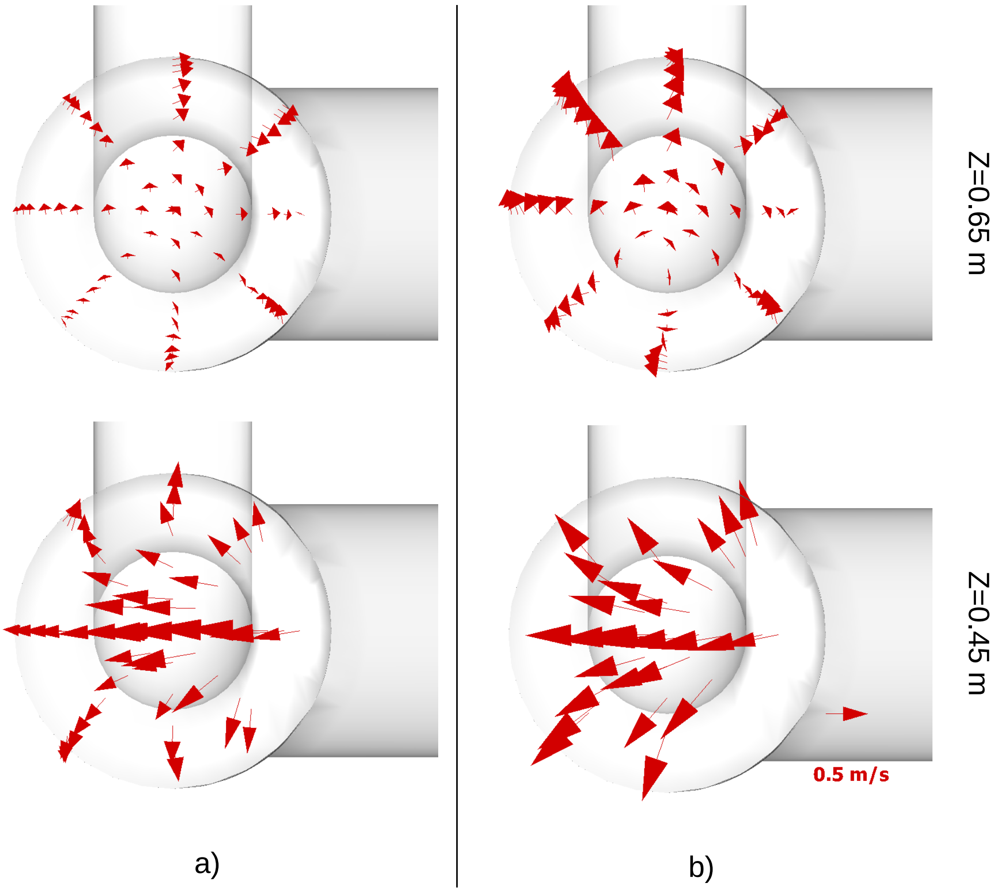
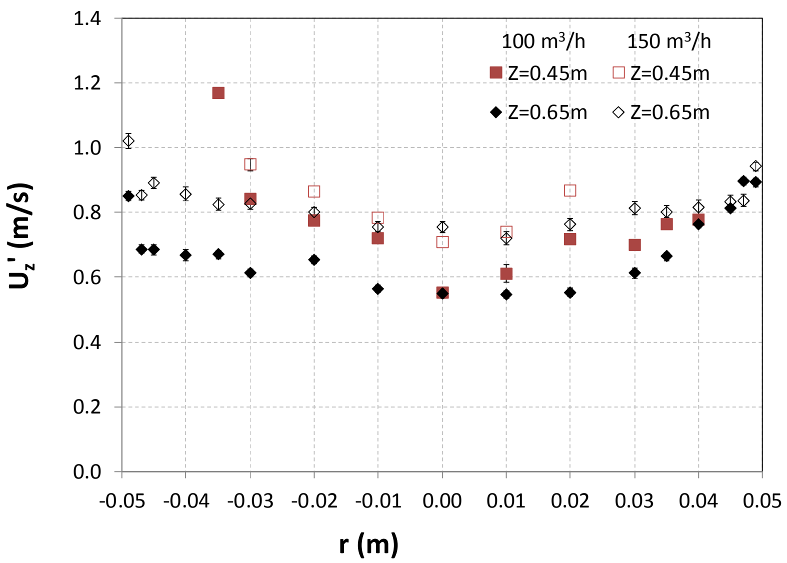


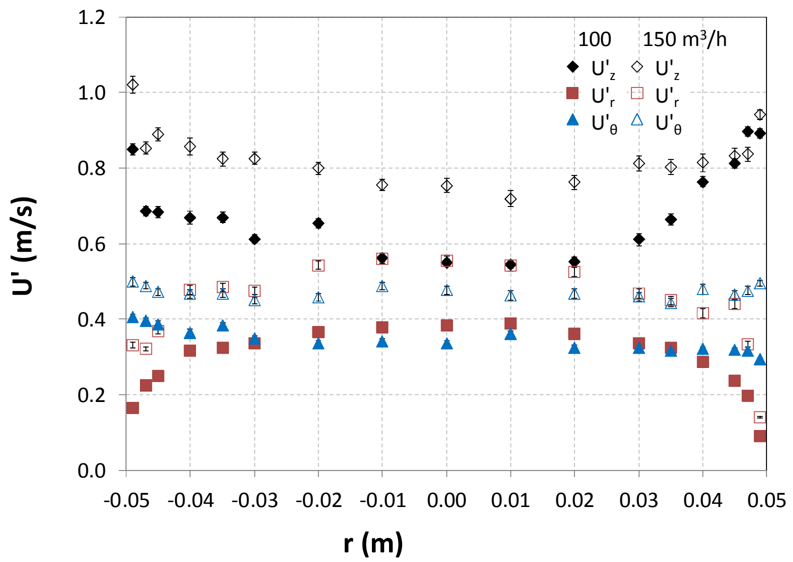
Figure 3: Top view of the riser flow for two riser heights, 0.45 and 0.65 m and a) 100 m^3/h and b) 150 m^3/h gas flow.

smaller cross-sectional area occupied by the solids jet is more clearly observed in Figure 3b for Z=0.45 m and 150 m^3/h. From both Figures 2 and 3, it is clear that the major disturbances of the solids flow due to the solids inlet geometry get quickly damped out. However, the solids flow becomes fully developed only at riser heights above 1.5 m, as found in previous experiments in the middle section of the riser (9).

In Figure 4a, the axial velocity fluctuations in the plane δ=90^o are presented. The general trend is that they are lower at the riser center and increase towards the wall, where the flow is more dilute and gas bypassing occurs. The fluctuations decrease as the particles move higher in the riser and the inlet disturbances start being damped out.



a)



b)

Figure 4: a) Axial solids velocity fluctuations and b) fluctuating solids velocity components at Z=0.65 m (δ=90^o, positive and negative r for θ=270^o and θ=90^o respectively, error bars for the 95% confidence intervals)

In Figure 4b all fluctuating solids velocity components are plotted at a height of 0.65m for the δ=90^o plane . It is observed that higher gas flow rates induce higher fluctuating velocities. In general, the instantaneous radial and azimuthal particle velocities exhibit a rather broad distribution of slightly positive and negative values. However, when averaged, the latter result in very low radial and azimuthal mean velocities, close to zero (Figure 3). On the other hand, the radial and azimuthal solids velocity *fluctuations* are significant, even comparable to the axial solids velocity fluctuations (Figure 4b). It is observed that the azimuthal fluctuations are almost constant along the riser radius, while the radial fluctuations are observed to be higher at the riser center and lower close to the riser walls.

CONCLUSIONS

Preliminary experimental data of three-component solids velocities have been gathered near the solids inlet section of a pilot cold-flow riser set-up using a two-probe LDA. A solids jet-like flow close to the solids inlet and bypassing of this solids jet by the gas phase are observed close to the solids inlet. Axial velocities increase very fast from negative values, measured at the lowest height close to the solids inlet, to positive (upwards) values. The radial and azimuthal velocity components are much higher in the lower riser heights and decrease as solids move away from the jet. The three fluctuating velocity components are of the same order of magnitude, the axial being always higher than the radial and the azimuthal ones.

ACKNOWLEDGMENT

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NOTATION

m	mass loading, -
r	radial coordinate, m
U	mean solids velocity component, m/s
U'	fluctuating solids velocity component, m/s
Z	axial coordinate, m
Greek letters	
δ	angle of the plane of measurements, ^{o}
ε_s	solids volume fraction, -
θ	azimuthal coordinate, ^{o}

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