Experimental and Computational Study of T- and L-Outlet Effects in a Dilute Circulating Fluidized Bed Pilot Riser

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Introduction

The performance of riser reactors may be strongly influenced by hydrodynamic inlet and outlet effects. Experimental and computational studies focusing on such effects are limited. De Wilde et al. (2005a) have studied inlet effects in dilute risers. The present work focuses on outlet effects in dilute risers. The effects induced by abrupt T- and L-outlet configurations are studied experimentally and computationally. The influence of the extension height of the T-outlet, the outlet surface area, and the gas flow rate are investigated.

Experimental set-up

Outlet configuration effects are quantitatively determined in a cold-flow circulating fluidized bed pilot unit by measuring the mean and fluctuating particle velocities using 3D LDA. The pilot riser has a diameter of 0.1 m and a height of 8.765 m. The cold flow pilot unit is operated in the dilute regime with a superficial gas velocity in the range of 2.65 to 7.43 m s^{-1} and a solids flux of 3.0 kg m^{-2} s^{-1}.

With an outlet surface area equaling the riser surface area, an L-outlet configuration and T-outlet configurations with an extension height of respectively 0.13 m and 0.34 m are investigated. Additionally, the effect of reducing the outlet surface area by a factor 2 and 4 is studied.

Computational approach

The 3D simulations make use of the Eulerian-Eulerian approach. The solid flow model used is based on the kinetic theory of granular flow (KTGF).

A line-implicit simultaneous solution algorithm based on dual-time-stepping is used for the numerical integration (De Wilde et al., 2005b). Preconditioning is applied. The discretization of the inviscid fluxes is based on a low-Mach reformulation of the multi-phase advection upstream splitting method (MP-AUSMP).

Results and discussion

Experimental observations

A T-outlet configuration (Figure 1 (b) and (c)) induces recirculation by vortex formation in the extension part of the riser above the outlet. The vortex is 3D in nature, but always recirculates the flow along the wall opposite the outlet, inducing downflow down to about 0.1 m upstream of the outlet. As a result of the vortex formation, an increased solid volume fraction is observed upstream of the outlet, both at the side of the outlet and, more pronounced, at the opposite side.

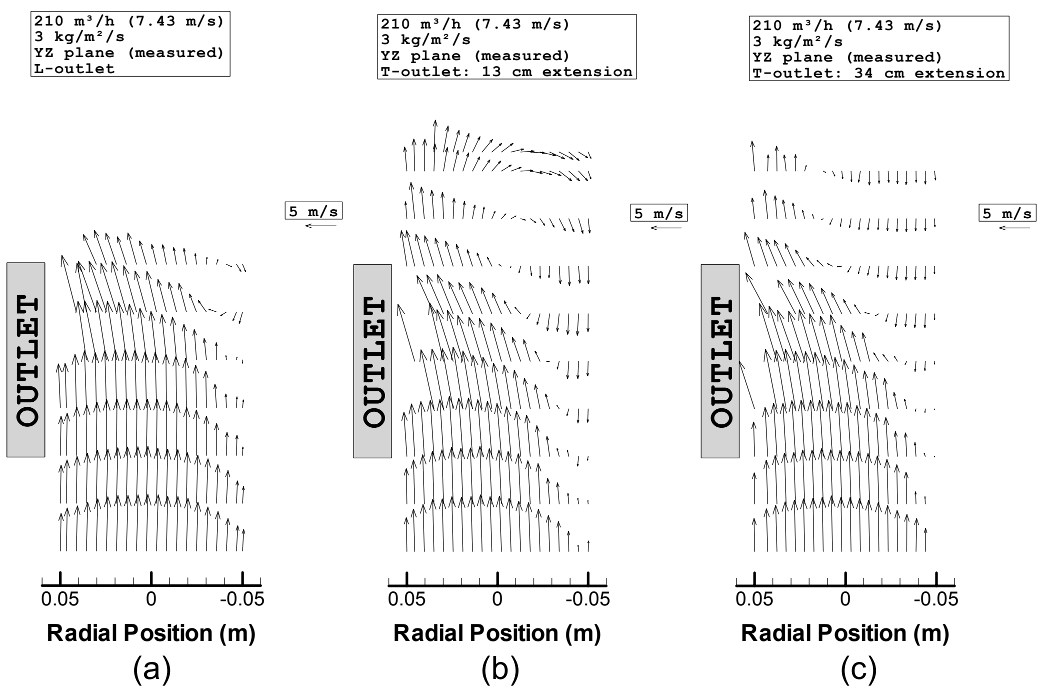

Figure 1: Time averaged particle velocities (m/s) in the YZ-plane, gas flow rate = 210 m³/h, solids flux = 3 kg/m²/s, 0.1m diameter outlet opening: (a) 0m extension (L-outlet), (b) 0.13m extension (T-outlet), (c) 0.34m extension (T-outlet).

In general, the axial and radial fluctuating particle velocities increase with increasing gradients in the mean axial and radial velocities, but the solid wall of the riser dampens the particle velocity fluctuations. Hence, a maximum in the axial particle velocity fluctuations is observed at height of the outlet, where upflow and downflow, the latter being induced by the vortex, encounter. In the extension part above the outlet, the fluctuating particle velocities are less pronounced as a result of the reduced gas flow rate downstream of the outlet, but still high compared with fluctuating velocities from the fully developed zone. A clear anisotropy between the axial and radial fluctuating particle velocities is observed, the axial fluctuations being the most pronounced.

With increasing gas flow rate, the vorticity of the vortex and the fluctuating velocities increase, but the axial and radial position of the vortex, the riser height down to which downflow is induced, and the anisotropy of the fluctuating particle velocities are hardly affected.

As the extension height increases, the length of the vortex increases and the rotation intensity in the vortex decreases (Figure 1 (b) and (c)). Moreover, with decreasing extension height, a shift of the position of the vortex towards the side opposite the outlet and more upstream in the reactor is observed. As a result, the width of the vortex reduces, the vortex being captured between the circular wall of the riser opposite the riser outlet.

With an L-outlet configuration (i.e. an extension height equal to zero), a small vortex is formed in the top corner of the riser at the side opposite the outlet (Figure 1 (a)). Again, with increasing gas flow rate, the vorticity increases.

A reduction of the outlet surface area of a T-outlet results in overall higher axial and radial particle velocities near the outlet opening and in an increased solids hold-up in the extension part of the riser. The position of the vortex, the length of the vortex and the height in the riser down to which downflow is induced are, however, hardly affected. Downflow at the side opposite the outlet increases only slightly when reducing the outlet surface area.
Reducing the outlet surface area, the axial fluctuating particle velocities are hardly affected. The radial fluctuating particle velocities are, on the other hand, observed to increase near the outlet of the riser. This increase is the more pronounced with increasing gas flow rate.

Simulation results

In general, the 3D simulation results are in good agreement with the experimental observations. The gas-solid flow model is capable of describing the experimentally observed vortex formation, both for the T- and the L-outlet configuration. The influence of the gas flow rate and the extension height of the T-outlet are correctly predicted.
Finally, flow patterns in developing zones (near in- and outlets) are found to bring in more valuable information than those in fully developed zones.

References

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