

Numerical Simulations of Bubbling Fluidized Beds

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Aim of the present work is to evaluate the actual capability of commercial CFD software to accurately simulate the hydrodynamics of a purposely built lab-scale two-dimensional bubbling fluidized bed, operating under bubbling conditions.

Numerical simulations were performed using the CFX-10 code, adopting an Eulerian-Eulerian Multi-phase Flow Model (MFM) coupled with the Granular Kinetic Theory (GKT).

Simulations results were collected in the form of maps of particle-phase volume fraction distributions to be post-processed with an original image analysis technique purposely developed for the analysis of experimental results of the real system. A thorough validation of computational results has been performed using available experimental and literature data.

1. Introduction

Many of the important characteristics of gas fluidised beds depends upon the behaviour of gas bubbles, which are generated near the distributor and rise through the bed, growing in size and decreasing in number because of coalescence.

There have been numerous investigations on the bubble gas flow of bubbling fluidised beds; many researches have been focusing on linking the behaviour of bubbles to the performance of a bubbling fluidised bed (Rowe, 1971, Clift *et al.*, 1974, Atkinson and Clark, 1988). More recently works by Caicedo *et al.* (2003) and Shen *et al.* (2004) studied the dynamics of 2D bubbling fluidized beds, specifically developing digital image techniques.

Meanwhile computational fluid dynamics (CFD) models have been continuously developed to tackle the task of simulating complex multiphase systems, such as fluidised beds. Most of the current fluidization modelling is based on the well established Multi-phase Flow Model (MFM) coupled with the Granular Kinetic Theory (GKT) to describe the characteristics of the particle phase (Gidaspow, 1994).

2. Numerical simulations

In this study CFD simulations of bubbling fluidized beds were performed adopting an Eulerian-Eulerian Multi-phase Flow Model (MFM) coupled with the GKT, available as standard options of the CFX10 code used for this investigation. The aim is a quantitative and detailed validation of the simulations performed, in order to assess the actual capability to reliably reproduce bubbling fluidization dynamics.

The geometry and computational grid of the simulated fluid bed is depicted in Figure 1. Real dimensions are 1440mm (height), 180mm (width) and 18mm (thickness). Simulations were performed in a 2D fashion adopting in all cases a simple grid with 5mm square cells, resulting in a computational domain of 288 cells along the height and 36 cells along the width, resulting in a total of 10368 cells. The walls were modelled using the standard no-slip boundary condition. A simple pressure boundary condition was imposed at the top of freeboard, i.e. acting as outlet for the gas-phase only. Dirichlet boundary conditions were employed at the bottom of the bed to specify a uniform gas inlet velocity throughout the distributor. The initial conditions for the settled bed of solids were the following: the solid volume fraction was set equal to 0.65 and the filling height was set to 360mm. More details on numerical aspects may be found in Vella (2007).

The investigation was mainly focused on particles of two different typical industrial sizes, i.e. 500-600 μm and 212-250 μm , resulting in typical Geldart group B fluidization at inlet gas velocities of 1.7, 3.4, 5.0 and 7.0 u_{mf} for the latter and 1.2, 1.4 and 1.7 u_{mf} for the former.

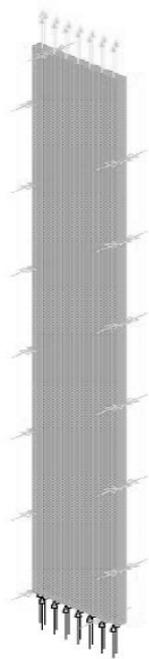


Figure 1. Computational grid.
36(x)*288(y)*1(z).

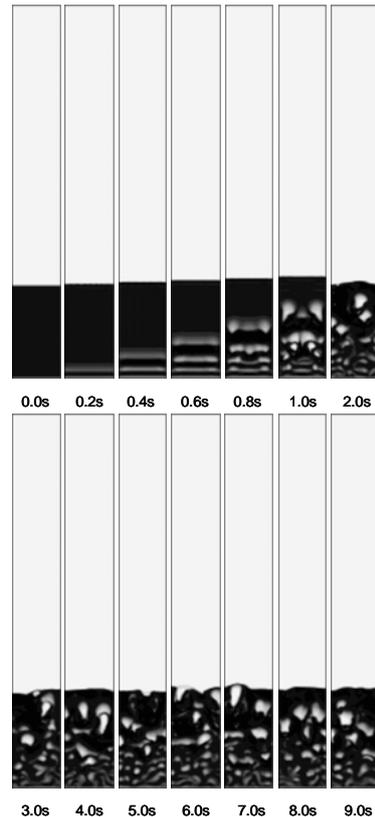


Figure 2. Simulated maps of volume fraction distributions. Glass ballottini:
($\rho=2500\text{kg/m}^3$, $d_p=212-250\mu\text{m}$), $u=1.7u_{mf}$.

3. Results and Discussion

Typical CFD results are shown in Figure 2 in the form of solid concentration maps. From a qualitative point of view one may well observe that the bed expansions as well as the formation and presence of bubbles are realistically reproduced throughout the 9 seconds of real time simulated.

Suitable image post-processing of the above maps was performed to get accurate measurements of bed height, bubbles average dimensions and average rising velocity.

The image post-processing procedure here adopted was originally developed for the analysis of experimental investigations; full details may be found in Vella (2007).

As far as bubble growth is concerned, two semi-empirical models proposed respectively by Darton et al. (1977) and by Shen et al. (2004) have been considered to validate present computational results. The proposed Darton's correlation, which gives the bubble diameter as a function of the bed height, is:

$$d_b = 0.54 (u - u_{mf})^{0.4} (h + 4\sqrt{A_0})^{0.8} / g^{0.2} \quad (1)$$

where d_b is the bubble diameter, u is the inlet gas velocity, u_{mf} is the minimum fluidization velocity, h is the height above distributor and A_0 is the area of distributor per orifice. The constant 0.54 has been obtained experimentally.

Parallel to the approach of Darton an equation for the bubble diameter of two-dimensional beds has been developed by Shen et al. (2004):

$$d_b = 0.89 \left[(u - u_{mf}) (h + 3.0 A_0 / t) \right]^{2/3} / g^{1/3} \quad (2)$$

where t is the thickness of the two-dimensional bed. In the absence of available data on the distributor characteristics, Darton et al. (1977), and Shen et al. (2004), suggested a value for A_0 equal to 0.

Figure 3 reports the dependence of bubble diameter on vertical distance from the distributor as it is obtained from CFX-10 simulations. The dependencies according to the models by Darton et al. (1977) and Shen et al., (2004) are also plotted in the form of curves. It can be seen that the agreement between the models and the CFD results is acceptable as the trends of bubble growth predicted by CFD remain well positioned within the trend of the Darton and Shen models.

Figure 4 reports the bubble rise velocities obtained by CFD, as function of bubble diameter. Moreover the correlation by Davidson (1963), ($u_b = 0.71(gd_b)^{0.5}$) and that by Shen et al., [2004], ($u_b = \Phi(gd_b)^{0.5}$, with $\Phi = 0.8-1.0$) are also reported.

CFD results appear to be in very reasonable agreement with Davidson's findings, though the two distributions do not fully overlap.

Consistently the CFD results reported in Figures 3(right) and 4(right) show larger values of bubble diameters with increasing particle diameter and larger values of bubbles velocities.

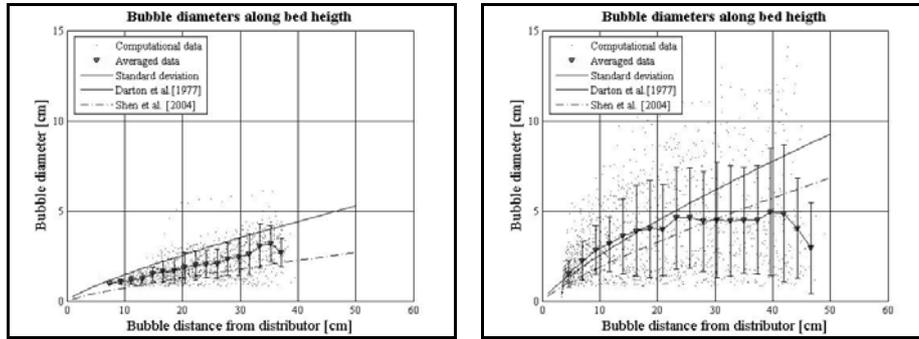


Figure 3. Bubble diameters along bed height. (left) $d_p=212-250\mu\text{m}$, $u=1.7u_{mf}$; (right) $d_p=500-600\mu\text{m}$, $u=1.7u_{mf}$.

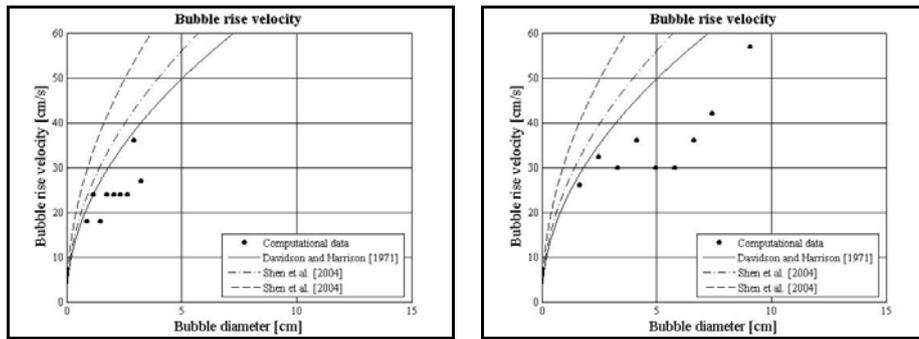


Figure 4. Bubble rise velocity versus bubble diameters. (left) $d_p=212-250\mu\text{m}$, $u=1.7u_{mf}$; (right) $d_p=500-600\mu\text{m}$, $u=1.7u_{mf}$.

Figure 5 reports the whole set of predicted bubble rise velocities (full circles) and experimental results (empty circles) for the two particle sizes at all inlet gas velocities presently investigated. One may observe the noticeable scatter of the experimental data, an occurrence which is due to the intrinsically chaotic complex phenomena of bubble coalescence and break-up along the bed height, and it shall not be therefore attributed to measurements errors. However, the scatter of CFD results is practically equivalent to that observed for experimental data, and the relevant comparison of the whole set of CFD results with the experiments shown in Figure 5 indicates a self-evident substantial agreement. Within the present work an effort was made to see whether a correlation could be proposed similarly to that proposed by Davidson. Figure 6 shows the results of two regressions carried out for this purpose, for the experimental and computational data respectively. Interestingly the two correlations in the simple form of power laws

are almost identical, showing an exponent for particle diameter practically equal to that proposed by Davidson.

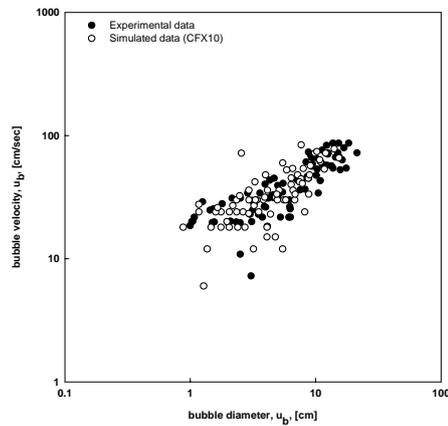


Figure 5. Bubble velocity vs bubble diameter. Comparison between experimental and CFD predictions for all cases investigated.

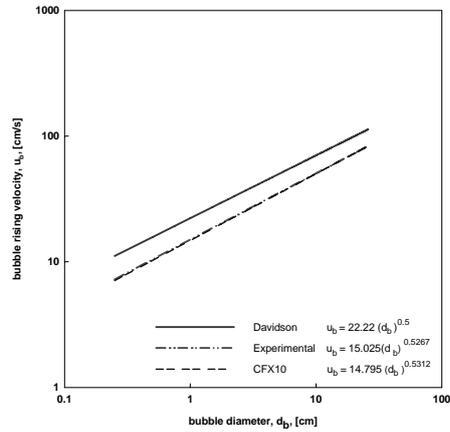


Figure 6 Bubble velocity vs bubble diameter. Comparison between experimental, CFD data and Davidson's predictions.

Finally in Figure 7 the predicted bed heights versus experimental ones are presented, for all cases simulated within the present work. It is worth noting that the agreement for this global indicator is fine in all cases.

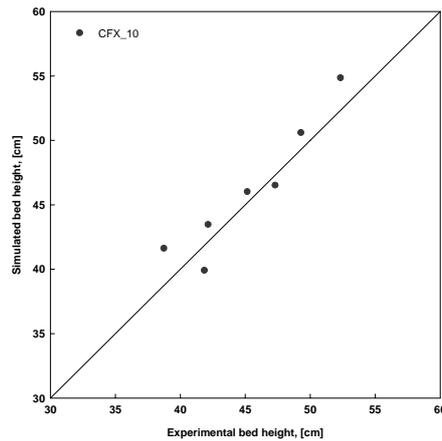


Figure 7 Comparison between experimental bed height with simulated bed height.

4. Conclusions

CFD Simulations were performed with the aim at investigating the reliability of current standard CFD models to reliably simulate the bubbling dynamics of fluidized beds. For this purpose an original post-processing technique based on image analysis has been used, thus allowing for a thorough validation of computational results with available experimental and literature data. Particular emphasis has been put on the characteristics of the bubble phase, with estimates of bubble size and bubble rise velocity distributions. An encouraging agreement has been found, showing that the CFD model here adopted are able to describe the hydrodynamic behaviour of the fluidized bed process for all the investigated flow conditions.

5. Acknowledgements

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6. References

- Atkinson, C.M. and Clark, N.N., 1988, Gas sampling from fluidized beds. A novel probe system, *Powder Technology*, 54, 59-70.
- Caicedo, G.R., Marques, J.J.P., Ruiz, M.G., Soler, J.G., 2003, A study on the behaviour of bubbles of a 2-D gas solid fluidized bed using digital image analysis, *Chemical Engineering and Processing*, 42(1), 9-14.
- Clift, R., Grace, J.R., Weber, M.E., 1974, Stability of bubbles in fluidised beds, *Ind. Eng. Chem. and Fundam.*, 13, 45-51.
- Darton, R.C., La Nauze, R.D., Davidson, J.F., Harrison, D., (1977), Bubble growth due to coalescence in fluidised beds, *Trans IChemE*, 55, 274.
- Davidson, J.F., Harrison, D., (1963), *Fluidised Particles*, Cambridge University Press.
- Gidaspow, D., (1994), *Multiphase flow and fluidization*, Academic Press, San Diego.
- Rowe, P.N., 1971, in: Davidson, J. F., Harrison (Eds.), *Fluidization* (Chapter 4, p.218). Academic Press, New York.
- Shen, L., Johnsson, F., Leckner, B., 2004, Digital image analysis of hydrodynamics two-dimensional bubbling fluidized beds, *Chemical Engineering Science*, 59, 2607-2617.
- Vella, G., *Analysis of bubbling fluidization dynamics*, PhD Thesis, Università degli Studi di Palermo, Dottorato di Ricerca in Tecnologie Chimiche e dei Nuovi Materiali, XVIII ciclo.