Hydrodynamic Modeling of Supercritical Fluidized Bed: Eulerian Approach

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ABSTRACT

Computational fluid dynamics (CFD) is becoming a very important tool in the research and design of new processes and even, to get a better understanding of the hydrodynamics of some widespread industrial applications, such as fluidized bed; mainly, dealing with supercritical fluids whose fluid dynamics behaves very differently.
CFD simulations are based on the multiphase Eulerian model. Particle-particle interactions and fluid-particle interaction are considered by the kinetic theory for solid particles and the Gidaspow drag function, respectively. The turbulence closures are calculated according to the *k–ε Realizable model*.
The aim of this work is to test the utility of the a methodology based on the solution of a transport equation to determine the local mean age of the fluid, in combination with the residence time distribution analysis of the system, to identify the presence and location of undesirable dead zones inside the bed.

KEYWORDS

CFD, Fluidized bed, Supercritical fluids, Residence time distribution, local mean age

INTRODUCTION

Fluidized bed technology is widely used in different industrial processes for reactions, drying, coating and combustion. Regarding coating, the combination of fluidized bed and supercritical fluids (SCFs), mainly supercritical carbon dioxide (SC-CO_2) is a promising technology for the processing of microparticles of high added value. On the one hand, fluidized bed provided good mixing conditions, homogeneity in temperature and concentration and low agglomeration tendency; on the other, SCFs make possible the solubility control of the coating agent by small changes in pressure and temperature, and reduce interfacial forces between fluids decreasing the agglomeration of particles. Besides, high pressure has been probed to improve fluidization [1] of microparticles through increasing fluid density, and fluid – particle interactions [2].

In a first work [3], CFD simulations were carried out to study a supercritical fluidized bed of glass beads (d_p = 176 μm). The CFD model is based on the multiphase Eulerian framework; the particle-particle interactions and fluid-particle interaction are considered by the kinetic theory for solid particles and the Gidaspow drag function, respectively.
Concerning the different approaches to predict turbulent flow based on the Reynolds-Averaged Navier-Stokes (RANS) models, the *k–ε Realizable model* has been proved to be able to reproduce the age of the supercritical fluid in jets and inside reactors with an absolute average deviation below 20 % by Sierra-Pallares and co-workers [4]. Numerical simulations were performed in supercritical carbon dioxide ambient in a range of pressure from 8 to 12 MPa and temperatures from 30 to 45ºC at a fluid velocity

of twice the minimum fluidization velocity. The macromixing characteristics were determined by means of the external residence time distribution (RTD) analysis, which were compared with experimental findings [5] with a good agreement between experimental and simulated data.

In this work, the macromixing characteristics of the fluidized bed are investigated by means of the local mean age of the fluid, as well. This method enables to locate those zones in the reactor where the fluid spends more time. Both methods are complementary: the calculation of local mean age can facilitate the understanding of the shape of the RTD distributions.

EXPERIMENTAL

The CFD simulations where carried out in a two-dimension axi-symmetric domain (Figure 1.a) reproducing the height and width of the three-dimension geometry of the experimental fluidized bed basket. This basket was provided with a porous plate at the bottom to provide uniform fluid inlet velocity across the inlet section. The experimental device is explained in detail elsewhere [5].

As mentioned in the previous section, the simulation of fluidized bed was performed by solving, firstly, the governing equations of mass, momentum and energy conservation using the Eulerian Multiphase model implemented in the Fluent 6.3.26 CFD software. Secondly, the turbulence closures according to the *k–ε Realizable model*.

Two cases a) and b) have been simulated in order to verify the importance of a good distribution of the fluid in the wind-box (Fig. 2 section before going into the fluidized bed: a) Uniform gas velocity across the whole inlet section. b) Uniform gas velocity across the half of the inlet section. The study was carried out by simulating the pulse injection of a tracer in the by a non – stationary fluid inlet velocity profile, implement in the model as boundary condition [3][4]. The results where analysed by the output Residence Time Distribution curve, E(t), and the local mean age of the fluid, τ_p.

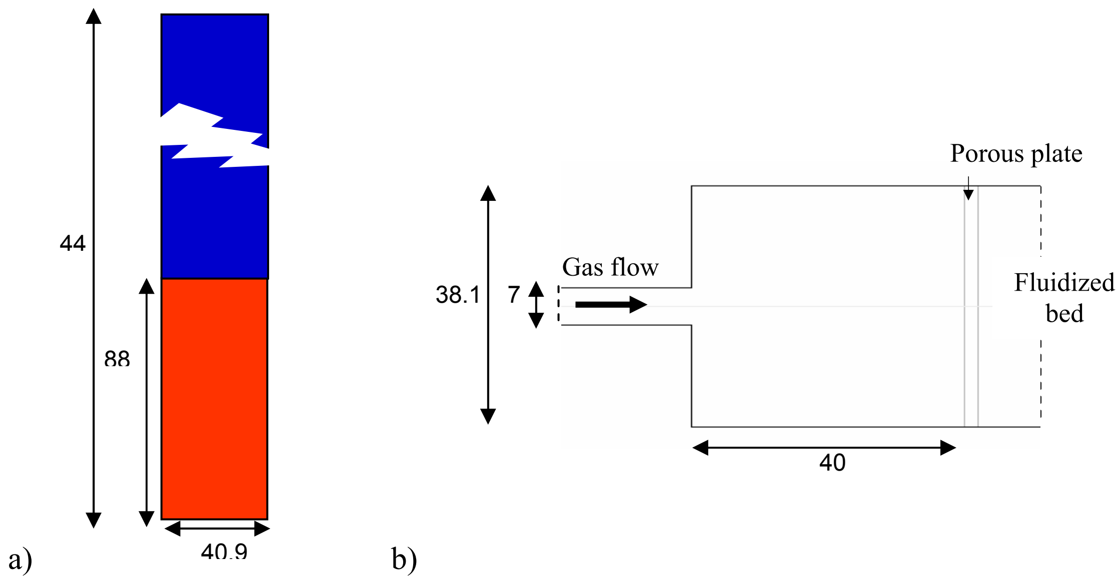


Figure 1. a) Contour plot of solids fraction at initial conditions. Schema of the simulated fluidized bed. Dimensions in mm. b) Schema of the wind-box in the experimental equipment. Dimensions in mm.

The External RTD curve is calculated from the outlet profile (C(t)) as follows:

$$E(t) = \frac{C(t)}{C^{o} \cdot t_{m}} = \frac{C(t)}{\int_0^{\infty} C(t)dt} \qquad (1)$$

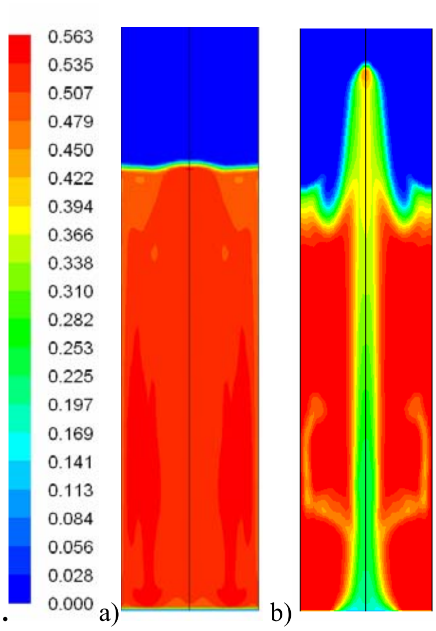
The local mean age of the fluid, τ_p, is calculated by solving a partial differential transport equation for compressible turbulent flow just as Ghirelli and Leckner [6] established:

$$\frac{\partial \bar{\rho}\tilde{\tau}_p}{\partial t} + \frac{\partial}{\partial x_j}\left(\bar{\rho}\tilde{u}_j\tilde{\tau}_p - \bar{\rho}D^T\frac{\partial \tilde{\tau}_p}{\partial x_j}\right) = \bar{\rho} \qquad (2)$$

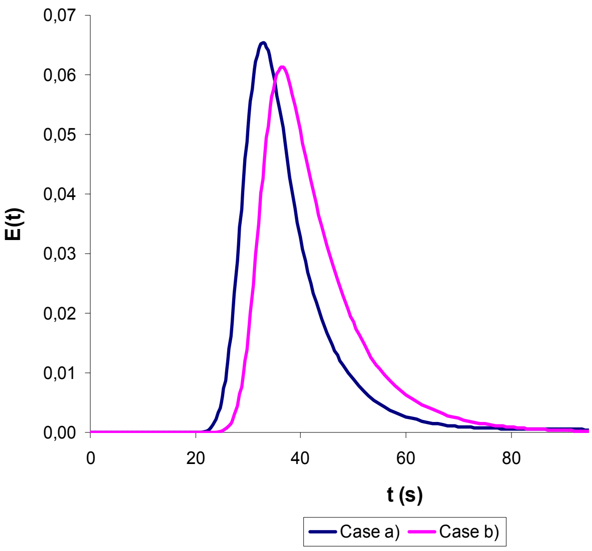
Where ρ is the mean density, u_j is the component in the j direction of the mean velocity and D^T is turbulent diffusivity.

RESULTS AND DISCUSSION

The effect of the gas distribution at the inlet in the fluidized bed is clearly shown in the contours of solid fraction (Figure 2.1); whereas the bed in case a) has achieved a flat and pseudo-stationary hold-up, the bed in case b) for the same time shows a clear jet of the inlet flow. In Figure 2.2, RTD curves are displayed showing small differences between both cases. However, the information provided by these contours and by the RTD curves themselves is not enough to investigate the causes of these differences.



1. a) b)



2.

Figure 2.1.-Contour plot of solid fraction of the beds fluidized by CO_2 at 10 MPa and 42.0ºC at a superficial fluid velocity of $2 \cdot u_{mf}$ for t = 22.5s. 2.2- RTD curves predicted at the same operating conditions. Case a) Uniform gas velocity across the whole inlet section. Case b) Uniform gas velocity across the half of the inlet section

As stated in the introduction, the calculation of local mean age can facilitate the understanding of the RTD curves. As shown in Figure 3, the span in fluid age in case b) is much broad and it is not uniformly distributed in the area of the bed, as in case a), meaning that there are dead-zones located at coins of the bottom (red areas).Besides the plug flow pattern in the empty area above the bed is clearly depicted in Figure 3.a

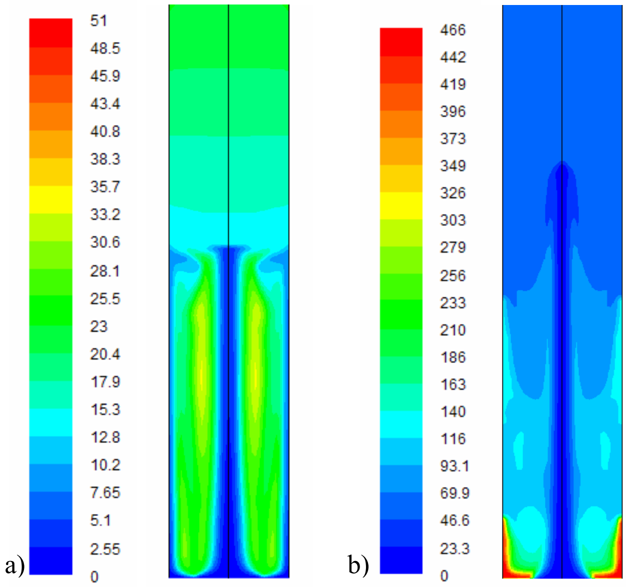


Figure 3. Contour plot of fluid mean age, τ_p, at 10 MPa and 42.0ºC at a superficial fluid velocity of $2 \cdot u_{mf}$ for t = 22.5s. a) Uniform gas velocity across the whole inlet section. b) Uniform gas velocity across the half of the inlet section

CONCLUSIONS

The CFD simulations results indicate the usefulness of calculating the local mean age of the fluid, in combination with the stimulus–response method to determine the residence time distribution curves, to better detect the presence and location of undesirable dead zones inside the bed. This methodology seems appropriate in order to design the wind-box of fluidized beds to get a uniform distribution of the fluid in the inlet of fluidized bed itself. Nevertheless, further simulations and improvements should be addressed to widen the range of operating conditions (pressure, temperature, fluid flow rate and particle size).

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