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ScienceDirect
Chemical Engineering and Processing 47 (2008) 237–244
Chemical Engineering and Processing
Process Intensification
www.elsevier.com/locate/cep

Influence of a gas maldistribution of distributor design on the hydrodynamics of a CFB riser

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Received 11 October 2006; accepted 7 February 2007
Available online 3 March 2007

Abstract

Solids volume concentration and solids velocity were determined in an 8.5 m high circulating fluidized bed (CFB) riser with two types of bubble-cap distributors by applying a capacitance probe. In the bottom region of CFB, the solids volume concentration in the centre region is low, while solids concentration increases significantly towards the wall with the highest solids concentration at wall approaching the value at the packed bed. Furthermore, solids volume concentration at high-pressure drop of a bubble cap is lower than that at low-pressure drop of a bubble cap at all lateral positions. The pressure drop of the distributor has little influence on the profiles of solids volume concentrations and on the profiles of solids velocities in CFB upper dilute region. It has been found that the pressure drop of the distributor has little influence on the axial apparent solids concentration in upper dilute region and on the external circulation rate.

Keywords: Circulating fluidized bed; Gas distributor; Solids volume concentration; Solids velocity; External solids circulation rate

1. Introduction

The hydrodynamics of circulating fluidized bed (CFB) risers are highly complex. A good understanding of CFB risers is of great importance on the design, scale-up, and the performance of the CFB. Up to know, a number of investigations have been conducted on axial structure and radial structure in risers. Generally, the axial solids distribution can be depicted by a dense region, transition region, dilute region, and exit region [1–3]. The radial flow structure in a riser is characterized by a core-annulus flow: a dilute core region, in the central portion of a riser surrounded by a dense annular layer of solids at the wall [2,4,5]. With respect to the flow structure in the bottom zone of a circulating fluidized bed, a few papers were published in the open literature. Bai et al. [6] employed a solids momentum probe to explore the flow structure in the bottom zone of a circulating fluidized bed, suggesting that the CFB bottom zone are in a violent turbulent. The study by Johnsson [7] indicated that the bottom zone in the Chalmers CFB boiler was described as an exploding bubble regime. However, Werther et al. [8] demonstrated that there exists a core-annulus-like structure in the bottom zone of the Chalmers CFB boiler by using capacitance probes. Rhodes et al. [9] used a momentum probe and capacitance tomography to find that the core-annulus structure of the upper dilute region is extended into the bottom region.

It is worth pointing out that all previous investigations on flow structure in circulating fluidized beds were performed in one distributor. There is still a lack of knowledge regarding effect of various distributors on CFB hydrodynamics. In this paper, the solids volume concentration and solids velocity were measured by a capacitance probe in a plant CFB with two types of bubble-cap distributors. Measurements were conducted in two typical heights, one located at the bottom dense region and the other at the upper dilute region.

2. Experimental

2.1. CFB system

Fig. 1a illustrates the cold circulating fluidized bed. The riser has a cross-section of 0.3 m × 1 m and a height of 8.5 m. Air from a 200 kW roots blower was fed to the windbox and distributed

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doi:10.1016/j.cep.2007.02.027

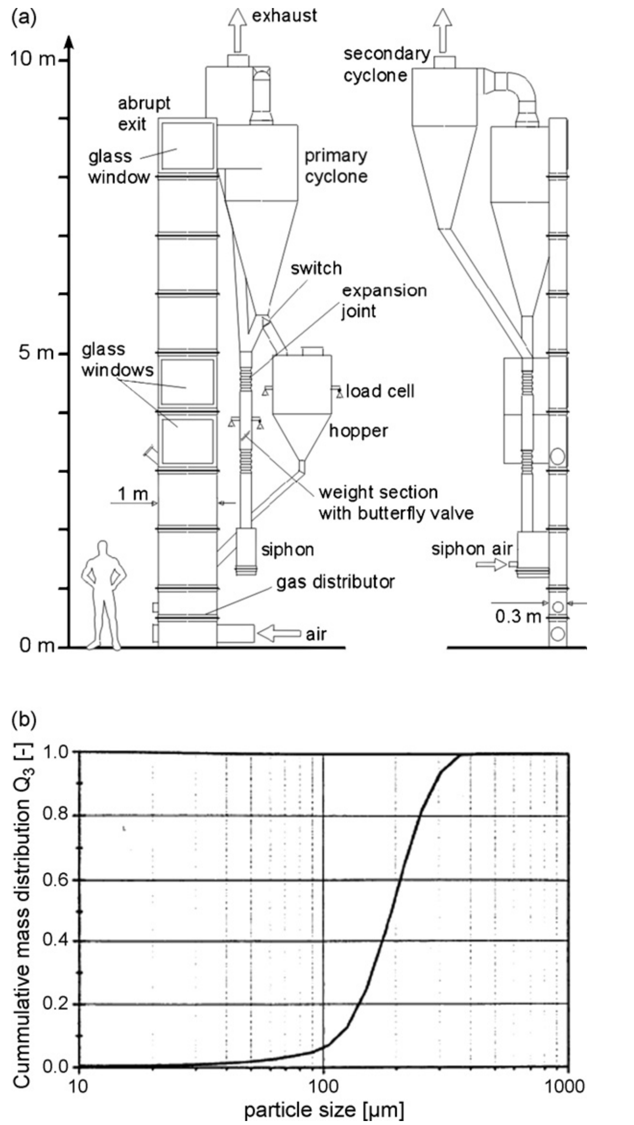

Fig. 1. (a) Schematic diagram of plant CFB system. (b) Cumulative mass distribution of particle sizes for quartz sand.

by bubble caps. The off-gas was cleaned by a two-stage cyclone and a filter, and the separated solids were returned to the riser at a height of 1 m above the distributor with an angle of 45°. The externally solid circulating rate was measured by a weighting section in the downcomer pipe.

The riser of CFB is equipped with 16 pressure sensors to measure the pressure drop profiles along the riser. The downcomer has five pressure sensors. A data acquisition system was used for sampling of all data, including pressure, superficial gas velocity, sand weight in the hopper, external circulation rate, etc.

Quartz sand is used as bed material and its physical properties are listed in Table 1. Fig. 1b illustrates the particle size distribution of quartz sand.

2.2. Gas-distributor

The design characteristics of the distributors are presented in Table 2. Two types of distributor served to this investigation, one has 14 bubble caps and the other has 33 bubble caps. For convenience, the 14 bubble-cap distributor is named as Distributor A and the 33 bubble-cap distributor named as Distributor B. The 82.5 mm i.d. bubble caps were used in Distributor A and 54.5 mm i.d. bubble caps used in Distributor B. For Distributor A, two decreased caps with 58 mm i.d. and 35 mm i.d. were used to screw into the bubble cap for changing its flow resistance. Distributor B employs 23 and 38.5 mm i.d. decreased caps to vary its flow resistance. Fig. 2 exhibits the cross-section of distributors.

Six bubble caps were utilized to detect the pressure drops across different bubble caps under various experimental conditions. More details of measurement configuration of the bubble cap are illustrated in Fig. 3. For Distributor A, bubble cap 1, 2, 4, 8, 10, and 14 were utilized for measurement of the pressure drops across bubble caps. Bubble cap 1, 2, 4, 10, and 14 have two pressure probes. Note that bubble cap eight has five pressure probe tips with four low pressure measuring pipe welded along the annulus wall and the high pressure measuring pipe fixed in the low pressure measuring pipes, as shown in Fig. 2. The pressure drop of bubble cap 8 is the average of the four individual pressure drops. For Distributor B, bubble cap 12, 13, 15, 17, 20, and 22 located in the middle row were used to determine the pressure drop across the bubble cap. There were five measurement pipes for bubble cap 17. To investigate the effects of the measurement bubble caps positions on the flow rate distribution, six bubble caps in Distributor B were moved from middle row to border row, in which their new positions were 1, 2, 4, 6, 9, and 11. For CFB distributor pressure drop measurement, the high-pressure port is connected with the windbox, while the low pressure port is at 0.18 m above the distributor (Fig. 3).

Table 1
Physical properties of quartz sand

Particle density (kg/m^3)	2600
Volume concentration of fixed bed	0.55
Surface mean diameter (µm)	140
Minimum fluidization velocity[a] (m/s)	0.03
Terminal settling velocity[a] (m/s)	0.93

[a] At ambient experimental conditions.

Table 2
Parameters of bubble caps A and B

Parameter	Unit	Distributor A	Distributor B
Total volume	m^3/s	1.2	1.2
Number of bubble cap		14.0	33.0
Number of orifice		4.0	4.0
Outlet inside diameter, D_1	mm	126.0	84.0
Orifice diameter, D_2	mm	42.0	28.0
Inlet inside diameter, D_3	mm	82.5	54.5
Decreased diameter, D_4	mm	58, 35	38.5, 23
Inlet area	m^2	0.00535	0.00233
Orifice area	m^2	0.00554	0.00246
Annulus area	m^2	0.00626	0.00269