Chemical Engineering and Processing 48 (2009) 178–186

Contents lists available at ScienceDirect

Chemical Engineering and Processing: Process Intensification

journal homepage: www.elsevier.com/locate/cep

Experimental analysis of bubble velocity in a rotating fluidized bed

Hideya Nakamura*, Tomohiro Iwasaki, Satoru Watano

Department of Chemical Engineering, Osaka Prefecture University, 1-1 Gakuen-cho, Naka-ku, Sakai, Osaka 599-8531, Japan

ARTICLE INFO

Article history:
Received 8 October 2007
Received in revised form 5 March 2008
Accepted 8 March 2008
Available online 16 March 2008

Keywords:
Fluidization
Rotating fluidized bed
Bubble velocity
Centrifugal force field

ABSTRACT

The bubble velocity in a two-dimensional rotating fluidized bed (RFB) was experimentally analyzed. The motion of bubbles was observed by means of a high-speed video camera, and the radial and angular components of bubble velocity were experimentally measured. The radial bubble velocity (U_{Br}) and angular bubble velocity (ω_B) were expressed as a function of actual centrifugal acceleration acting on the bubble (g'_B), bubble diameter (D_b), and angular velocity of the rotating vessel (ω_v): $U_{Br} = K_r(g'_B D_b)^{0.5}$ and $\omega_B = K_\theta \omega_v$, respectively. The effects of the operating parameters (gas velocity and centrifugal acceleration) on the bubble velocity coefficients (K_r and K_θ) were analyzed experimentally. The distribution of both bubble velocity coefficients could be well correlated by the log-normal distribution function. The distributions of K_r and K_θ showed almost unchanged with the gas velocity and centrifugal acceleration, because the buoyancy force acting on a bubble under high centrifugal force field is so high, and the interaction from other bubbles can be neglected. The bubble velocity coefficients in an RFB could be empirically obtained as $K_r = 0.52$ and $K_\theta = 0.96$. The experimental mean bubble velocities at the various operating conditions were compared with the predicted ones by using the obtained bubble velocity coefficients and our proposed model for the bubble diameter [H. Nakamura, T. Iwasaki, S. Watano, Modeling and measurement of bubble size in a rotating fluidized bed, AIChE J. 53 (2007) 2795–2803]. The radial and angular bubble velocities could be predicted only by the operating parameters.

1. Introduction

Fluidized beds have been widely used in many industries because of its desirable characteristics such as high heat and mass transfer rates between gas and particles, temperature homogeneity, easy handling and rapid mixing of particles. However, the conventional fluidized beds cannot still overcome some existing limitations: it is difficult to operate under high gas velocity since the gas–solid contact becomes poor due to the formation of large bubbles, slugs and particle entrainment; fine particles such as Geldart's group-C particle [1] fluidize poorly, exhibiting channeling, plugging, and forming large agglomerated.

Recently, a rotating fluidized bed (RFB) has gathered a special interest because it has high potential to overcome the conventional limitations. The RFBs have unique fluidization concept [2] as shown in Fig. 1. The system consists of a cylindrical gas distributor rotating around its axis of symmetry inside the stationary plenum chamber. Due to the rotational motion of the gas distributor, particles are forced to move toward the rotating vessel (gas distributor) by the centrifugal force, forming annular particle bed on the gas distributor. Fluidization gas flows inward through the distributor, and particles are balanced by the fluid drag force and centrifugal force, leading to fluidization of particles in a high centrifugal force field. The RFBs have such advantages as (1) the RFBs can prevent growth of large bubbles and entrainment of particles even at relatively high gas velocities by controlling the vessel rotational speed [3]; (2) the RFBs can smoothly fluidize fine cohesive particles [4] such as Geldart's group-C particles, because it imparts high centrifugal force and drag force to the particles; (3) its space requirement is very small. The RFBs have been expected to be used as some advanced industrial processes from the advantages, such as the reactor for rocket propulsion system in micro-gravity field [5], high efficient dust filter [6], simultaneous removal process of NOx and soot from diesel engine exhaust gas [7], incinerator of sludge waste [8], granulator and coater for fine particles [2,9] and processor for handling of nano-particles [10,11]. In spite of many published studies, the reliable RFB process has not been established yet, because design and operation of the RFB processes have been conducted depending on experiences and skills without scientific justification. Therefore, in order to establish the design methodology of RFB processes, elucidation of the fundamental fluidization mechanisms is strongly required.

It is well known that bubbling characteristics in gas–solid fluidized beds greatly affect the fundamental fluidization phenomenon, such as gas–solid contact, particle mixing, entrainment, and so on [12]. The bubbling characteristics thus become the critical

* Corresponding author. Tel.: +81 72 254 9305; fax: +81 72 254 9305.
E-mail address: nakamu@chemeng.osakafu-u.ac.jp (H. Nakamura).

0255-2701/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.cep.2008.03.003

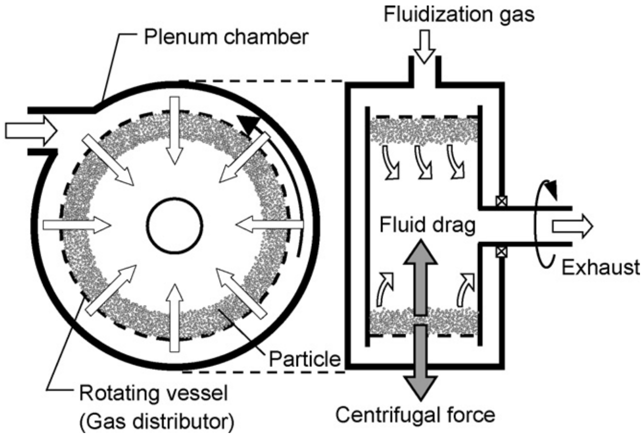

Fig. 1. Rotating fluidized bed (RFB) system.

parameters for design and operation of the fluidized bed processes. Therefore, in an RFB the bubbling characteristics should be elucidated. However, there has been no report anywhere with regard to the RFB. Only Chevray et al. [13] studied the bubbling characteristics and derived equations for bubble velocity and trajectory based on the Lagrangian approach. However, there was no experimental data for evaluating the validity of their model.

The overall objective of this study is to analyze the bubbling characteristics in an RFB. We here focused on the bubble velocity, which is one of the most important bubbling characteristics. The motion of bubbles in an RFB was observed by means of a high-speed video camera, and the radial and angular bubble velocities were experimentally measured. The effects of the operating parameters such as gas velocity and centrifugal acceleration on the bubble velocities were investigated. Furthermore, an empirical correlation to estimate the bubble velocity was proposed using the obtained experimental data.

2. Bubble velocity in gas–solid fluidized beds

So far, many researchers have studied the bubble rising velocity in conventional gas–solid fluidized beds. Davis and Taylor [14] theoretically derived the following equation expressing a single bubble rise velocity (U_B):

$$U_B = K\sqrt{gD_B} \quad (1)$$

where K, g, and D_B are the bubble velocity coefficient, gravitational acceleration, and bubble diameter, respectively. This has been recognized as the fundamental equation for giving the bubble rise velocity. The value of K depends on a depth of particle bed, and determined as 0.71 for a three-dimensional bubble [14] and 0.5 for a two-dimensional bubble [15]. The bubble rise velocity in a bubble swarm is generally higher than the rise velocity of a single bubble due to the acceleration effects caused by the bubble–bubble interaction and the overall circulation of particles [16]. Many researches have proposed several equations to estimate a bubble swarm rise velocity by modifying Eq. (1) [16–19], and empirically derived many types of additional or multiplication correction terms in order to take into account the wall effect and the acceleration effects.

In RFBs, the bubbles mainly move in the two directions, i.e., radial and angular directions. The radial bubble velocity (U_{Br}) and angular bubble velocity (ω_B) were thus analyzed in this study. It was assumed that the radial bubble velocity (U_{Br}) could be expressed as the following equation, which is similar to Eq. (1):

$$U_{Br} = K_r\sqrt{g'_B D_B} \quad (2)$$

where g'_B is the actual centrifugal acceleration acting on the bubble, and K_r is the radial bubble velocity coefficient. In RFBs, bubbles move along the rotating vessel without any significant random motions. The angular bubble velocity (ω_B) was thus assumed as the following correlation:

$$\omega_B = K_\theta \omega_v \quad (3)$$

where ω_v is the angular velocity of the rotating vessel (gas distributor), and K_θ is the angular bubble velocity coefficient. In this study, the effects of operating parameters (gas velocity and centrifugal acceleration) on the bubble velocity coefficients (K_r and K_θ) were experimentally analyzed.

3. Experimental

Fig. 2 shows the experimental set-up for visualization of bubbling behaviors in the RFB. A thin porous cylindrical plate (i.d. 250 mm × D. 5 mm), which was made of stainless sintered mesh

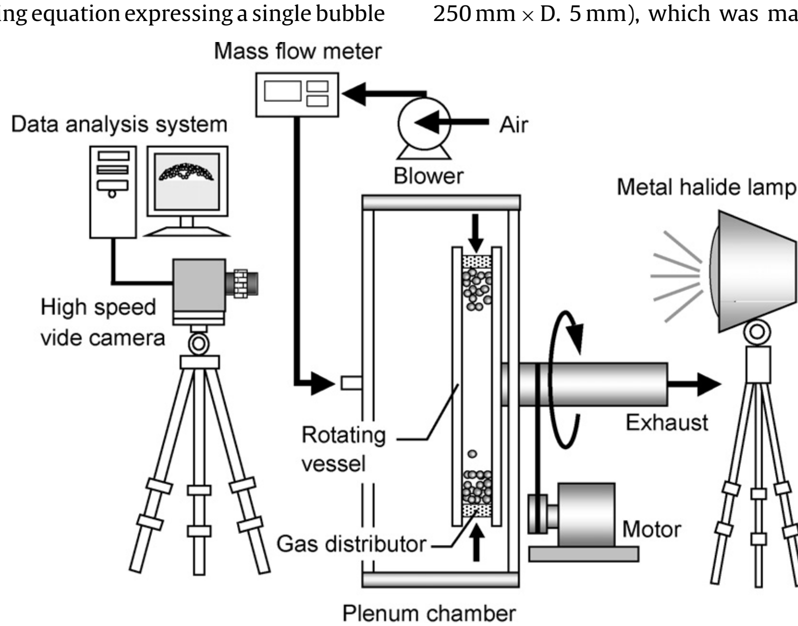

Fig. 2. Experimental set-up.