ARTICLE IN PRESS

Advanced Powder Technology xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Advanced Powder Technology

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

Original Research Paper

Fabrication and characterization of low-cost silica spargers: Toward smaller bubbles

Behnam Mostajeran Goortani [a],*, Roghayeh Izadi [b], Mohammad Keramat [b]

[a] Department of Nano Sciences and Technologies Engineering and Department of Renewable Energy Engineering, Faculty of Advanced Sciences and Technologies, University of Isfahan, Iran
[b] Department of Nano Sciences and Technologies Engineering, Faculty of Advanced Sciences and Technologies, University of Isfahan, Iran

ARTICLE INFO

Article history:
Received 25 September 2016
Received in revised form 29 November 2016
Accepted 19 December 2016
Available online xxxx

Keywords:
Sintering
Sparger
CFD
Bubble size distribution
Glass bead

ABSTRACT

In this study, nano- and microstructured glass bead spargers were fabricated by an innovative pressureless sintering method in a temperature-controlled convection furnace. In comparison to existing commercial spargers, the spargers fabricated in the present study produce bubbles smaller than 100 μm in size. The novelty of the research is in the fabrication step of the spargers and in the study of bubble columns with bubbles in the range of 0.1 mm up to 1 mm. Scanning electron microscopy, X-ray diffraction, and porosimetry were used to further characterize the fabricated spargers. The bubble sizes and distributions were determined in an experimental setup comprising a bubble column equipped with a semi-professional camera to record the sizes and movements of the bubbles in the column. Computational fluid dynamics modeling performed using Fluent was further used as a diagnosis tool to improve our understanding of the velocity profiles and x–y coordinates of the bubbles and gas holdup in the column.

1. Introduction

Spargers are devices used for the continuous injection of gas bubbles into liquids. These porous materials have applicability in many areas, such as in bioreactors, fermentation (for aeration and gas injection), wastewater treatment, and flotation. The performance of spargers and the sizes of bubbles depend on the fabrication process and solid–liquid interface interactions. Therefore, three important tasks need to be considered in this regard. The first is a systematic study of the sintering conditions during fabrication. The second is the study of bubble formation and characterization in a bubble column. The third is an investigation of the bubble–liquid interactions in the column by means of modeling software such as Fluent. The third task provides a clear view of the velocity and location of the bubbles in the column, and this may consequently improve our understanding of the performance of spargers.

The most important commercial method of sparger fabrication is sintering of microsized particles in a furnace under pressure and under controlled atmosphere [Mott Corporation, Farmington, USA]. During sintering, at temperatures lower than the melting temperature of particles, they form necks at their contact points [1,3,2]. By controlling sintering conditions, spargers with macroporous structure [5] may be fabricated. Therefore, sintering time and temperature are two important factors in sparger fabrication for controlling the final porous structure. Zarifah et al. [6] showed that when glass particles are used and no sintering agent is employed, the pore size of the sintered surface reduces when the sintering temperature is increased from 800 °C to 1000 °C. Rahaman [4] showed that at a sintering temperature of 700 °C the neck growth increases with an increase in sintering time from 2 min to 30 min.

The size and distribution of bubbles are important factors for determining the performance of spargers. In a bubble column, these factors are determined by the gas flow rate, pore size of the sparger surface, and gas–liquid interactions. For example, Kazakis et al. [7] showed that in the case of metal spargers, the bubble size increased from 2.5 mm to 5 mm when the pore size was increased from 40 μm to 100 μm or when the gas flow rate was increased from 39.2 LPH (liters per hour) to 66.7 LPH. On the other hand, Thorat et al. [8] showed that the gas flow through a sparger is proportional to 0.73 times the power of the bubbles diameter and to 0.75 times the power of porosity. Chen et al. [9] used glass frit to produce bubble clusters 0.5–3 mm in size in a flotation experiment. The size distribution of bubbles depends on the pore size and uniformity of the sparger surface and on the liquid–bubble interactions.

---

* Corresponding author.
E-mail address: b.mostajeran@ast.ui.ac.ir (B.M. Goortani).

http://dx.doi.org/10.1016/j.apt.2016.12.017

Please cite this article in press as: B.M. Goortani et al., Fabrication and characterization of low-cost silica spargers: Toward smaller bubbles, Advanced Powder Technology (2017), http://dx.doi.org/10.1016/j.apt.2016.12.017

Computational fluid dynamics (CFD) modeling software such as Fluent can be used as a diagnostic tool to improve understanding of the fluid dynamics of bubble columns. At bubble velocities lower than 4 cm/s, the bubble column appears more homogeneous and the fluid regime is termed homogeneous, in contrast to the heterogeneous and turbulent regimes observed with large bubbles and at high velocities [10].

The performance of spargers can be improved significantly by achieving a tenfold reduction in the bubble size from the millimeter range and higher to a sub-millimeter range and lower, and such improvements are expected to open up new horizons and avenues for the application of spargers. Thus far, spargers have been fabricated by pressure sintering or other methods [11]. However, these methods have drawbacks such as being expensive or experiencing large pressure drops and producing large bubbles.

The present study explores an innovative pressureless sintering method for the fabrication of spargers and systematically characterizes the fabricated spargers. In comparison to existing commercial spargers, the spargers fabricated in the present study produce bubbles smaller than 100 μm in size. To the best of the authors' knowledge, this size range is one order of magnitude smaller than the size of spargers fabricated by sintering methods reported in the literature thus far. Results of CFD simulations of columns are in complete agreement with the experimental observations and measurements. The simulations are further used as a diagnosis tool to improve our understanding of the velocity profiles and *x*–*y* coordinates of the bubbles and gas holdup in the column.

2. Materials and methods

2.1. Sparger fabrication

The fabrication process comprises sintering of glass bead particles in an atmospheric convection furnace. Glass beads with sizes in the ranges of 425–600 μm and 0–63 μm (purchased from PANA Inc., Tehran, Iran) were used as the raw material. The chemical composition of the raw powder is listed in Table 1. The powder was first ball-milled and then placed in an oven at 80 °C for 2 h for being dried completely. The ratio of balls to powder in the ball mill was 5:1 and the ball milling speed was 500 rpm After ball milling, the powder was added in a heat-resistant stainless steel (A310) mold with a 40 mm diameter, 4 mm depth, 45 mm external diameter, and 20 mm thickness, and it was then heated for 2 h in an atmospheric furnace at a rate of 4 °C/min. Finally, it was slowly cooled down to form a sintered porous structure, which was used in the current study as the sparger.

Table 1
Chemical composition of raw powder.

Chemical composition	Weight fraction (%)
SiO_2	72.5
Na_2O	13.7
CaO	9.8
MgO	3.3
Al_2O_3	0.4
FeO/Fe_2O_3	0.2
K_2O	0.1

The porosity of the sparger, *P*, was measured by submerging it in water and measuring the weights of dry sparger (w_0) and wet sparger (w_1), sparger volume (v_0), and density of water (ρ) as given in Eq. (1):

$$P = \frac{w_1 - w_0}{\rho v_0} \tag{1}$$

Scanning electron microscopy (SEM) was further utilized to examine the morphology of the sparger surface.

2.2. Experimental characterization setup

A rectangular glass column with a height of 50 cm and cross section of 14 cm × 14 cm was used in this study. At the lower end of the column was a hole through which the gas tube feeding the sparger was passed, as shown in Fig. 1. Compressed air or N_2 was used as the gas for sparging into water, and a flow meter (model ACA 04, Taiwan) with a range of 0–5 LPH and precision of 0.2 LPH was utilized. The gas flows into the flow meter, pressure gauge, and finally into the sparger, and then, it leaves the sparger in the form of small bubbles.

To capture images of the bubbles and to record their movement in the column, a semi-professional camera (Exilim ex-z3000, Casio) was utilized. The images were then analyzed using ImageJ software to obtain the bubble size distribution (BSD). The recordings were used to obtain the velocity and location of the bubbles in the column and for comparison with the simulation results, presented in the next section.

2.3. CFD modeling of bubble column

Our experimental measurements of the bubble column were limited to the camera recordings of the column. From the recordings, it may be possible to determine the velocity profile of the bubbles and the liquid phases. However, this would be a very time consuming task or would require a professional camera with suitable analysis software. For this reason, CFD simulations of the column were used not only as general guidelines but also as a diagnosis tool in the analysis of the bubble column (see Fig. 2).

Three types of flow patterns are found in bubble columns: homogeneous or bubble, turbulent (churn-turbulent), and annular

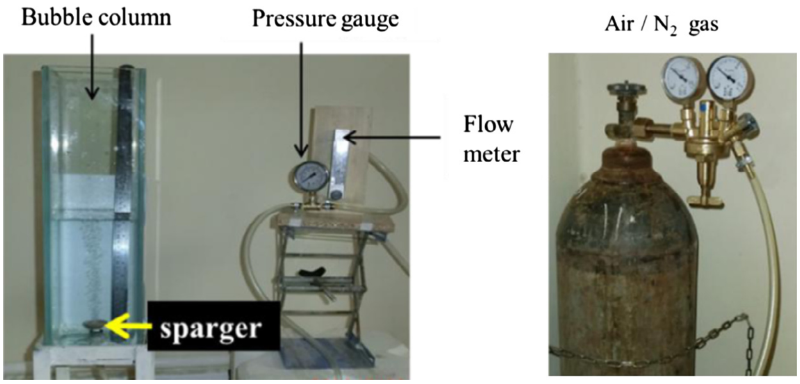

Fig. 1. Setup of bubble column for characterization of fabricated spargers.

Please cite this article in press as: B.M. Goortani et al., Fabrication and characterization of low-cost silica spargers: Toward smaller bubbles, Advanced Powder Technology (2017), http://dx.doi.org/10.1016/j.apt.2016.12.017