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Investigating effect of pulsed flow on hydrodynamics of gas-solid fluidized bed using two-fluid model simulation and experiment

Hamed Khosravi Bizhaem, Hassan Basirat Tabrizi *

Mechanical Engineering Department, Amirkabir University of Technology, Tehran, Iran

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ABSTRACT

Gas-solid flow behavior in a pulsed fluidized bed was studied experimentally and numerically. Eulerian-Eulerian two-fluid model approach in conjunction with the kinetic theory of granular flow was used for simulation of dense gas-solid flow. The effect of pulsating flow with frequency range of 1 to 10 Hz for particle sizes of Geldart B and A/B group with variation of particle density was investigated. Model simulation results were compared reasonably well with researcher's findings and the experimental data. Time-averaged local pressure drop and solid volume fraction were obtained and the effect of various pulsation frequencies on the bed expansion ratio, solid volume fraction, voidage and solid axial velocity was discussed. By increasing the pulsation frequency up to 10 Hz, results show reduction in the bubble size, bed expansion ratio and pressure fluctuation. Time-averaged axial velocity and voidage have a flatter profile with increasing pulsation frequency.

1. Introduction

Gas-solid fluidized beds are found in many plant operations in oil, chemical, biochemical, power, medical and pharmaceutical industries, which involve fluid, heat, and mass transfer such as drying, coating, combustion, gasification, catalytic cracking, separation etc. Despite their widespread applications, most of the design and development of fluidized beds has been empirical. The complex gas-solid flow behavior in these systems makes flow modeling a challenging task [1,2]. Various assisted fluidization techniques have been proposed and tested in order to overcome the limitations and to improve their intrinsic performance such as centrifugation, mechanical vibration, pre-mixing with coarse particles, gas injection, pulsating flow, magnetic field, electric field and acoustic excitation [3].

A pulsating fluidized bed is operated with two sequential durations designated as an on period with injection of fluidization gas and an off period without injection of fluidization gas. A common method to obtain a forced pulsation of gas flow is to use an on-off solenoid valve [4,5].

The flow pulsation has already been shown to be effective in overcoming defluidization, especially when applied to cohesive particles [5] and is an efficient tool to enhance the segregation process of dissimilar particles [6]. Pulsation flow is expected to reduce channeling and bypassing, therefore hard-to-fluidize materials can be readily fluidized when pulsation or vibration is introduced [7]. Due to these advantages, many research efforts have been devoted to various aspects associated to pulsating fluidization e.g. heat transfer [4], mass oscillation [8] and transfer [9], numerical simulation [10–12] and many other industrial applications such as drying [7,13]. Despite interest and a growing number of researches focused on the benefits of applying pulsed flow to fluidized and spouted beds, practical use of this method in industry has been limited. Effects of pulsed flow differ greatly and depend on pulsating frequency, amplitude, particle density, shape, moisture, and size [3]. Due to some complexity of the pulsed flow concept related to various types of pulsed flow generation and application to suitable particle sizes and materials [3], high-pressure fluctuations and movements in pulsating flow cause abrasion and break down some particles. Hence, more researches are needed for complete understanding and industrial usage of pulsating flow in fluidized beds.

Zhang and Koksal [4] studied hydrodynamics and surface-to-bed heat transfer in a pulsed bubbling fluidized bed. A solenoid valve was used to pulse the fluidization air to bed at 1 to 10 Hz. They found that the heat transfer coefficient increases about 17–33% for Group A particle compared with the steady flow at high pulsation frequency (7–10 Hz). Moreover, the enhancement of heat transfer depends on the particle size, superficial gas velocity and the frequency of pulsation. Saidi et al. [6] studied air pulsation effect on segregation of mixed particles in fluidized bed. Their experiments indicated significant increase in the segregation efficiency of mixed binary particles by changing continuous to pulsed airflow with the fixed flow rate. In addition to increase in the magnitude, the rate of segregation increased considerably by using

* Corresponding author at: P.O. Box: 15875-4413.
E-mail addresses: hkhosravi@aut.ac.ir (H. Khosravi Bizhaem), hbasirat@aut.ac.ir (H. Basirat Tabrizi).

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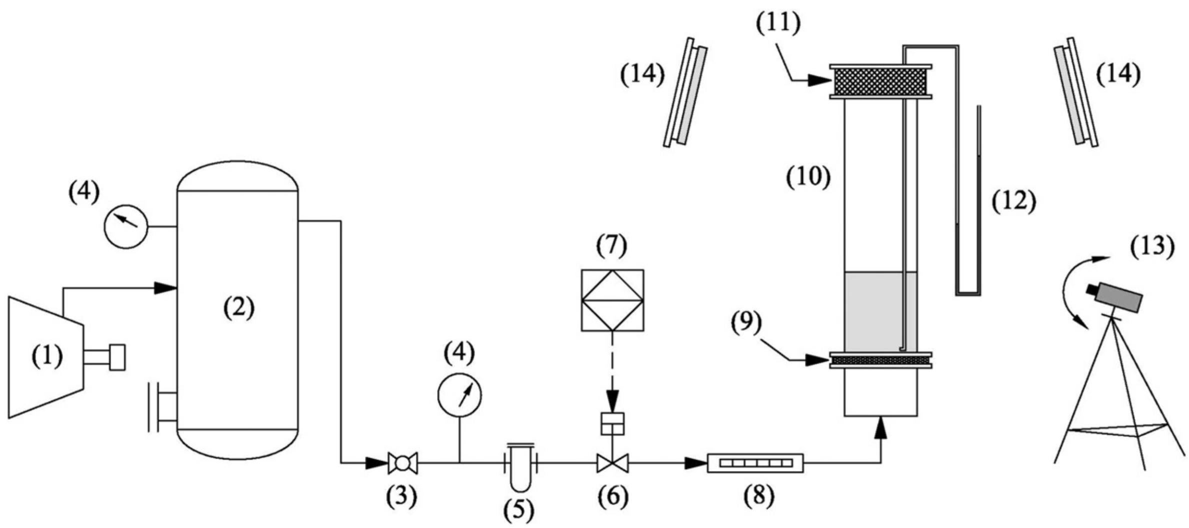

Fig. 1. Schematic of experimental setup. (1) Compressor, (2) air tank, (3) ball valve, (4) pressure gauge, (5) filter, (6) solenoid valve, (7) electronic circuit, (8) flow meter, (9) distributor, (10) Plexiglas cylinder, (11) filter, (12) manometer, (13) high speed camera, (14) LED [5].

Table 1
particle properties used in experiments [5].

Particle	d_p (μm)	ρ_p (kg/m^3)	Group
Silica	196	2550	B
Alumina	95	3860	A/B

airflow pulsation. Jia et al. [14] investigated the effect of pulsed flow on gas-solid mixing and mass transfer for wet biomass particles. They studied different pulsation frequencies from 0.25 Hz to 6.67 Hz and observed improvement in fluidization quality and mass transfer rate.

Besides many experimental studies, numerical simulation can be a useful technique for achieving detailed information about the hydrodynamics and heat transfer of the gas-solid flow in fluidized and spouted beds. Two different approaches were used for computational fluid dynamics (CFD) modeling of gas-solid fluidized beds. A discrete method

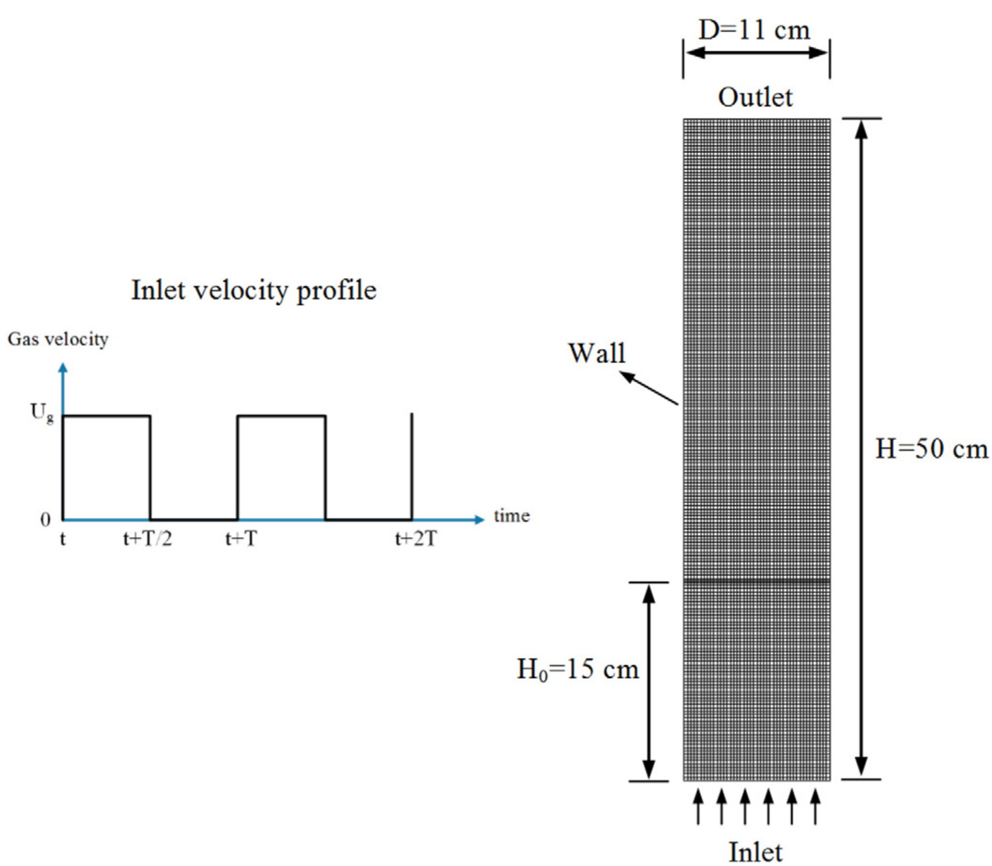

Fig. 2. Computational domain and meshing of fluidized bed.