



Original Research Paper

Investigations on the spouting stability in a prismatic spouted bed and apparatus optimization

Vitalij Salikov^a, Stefan Heinrich^{a,*}, Sergiy Antonyuk^b, Vinayak S. Sutkar^c, Niels G. Deen^c, J.A.M. Kuipers^c^a Institute of Solids Process Engineering and Particle Technology, Hamburg University of Technology, 21073 Hamburg, Germany^b Chair of Particle Process Engineering, Department of Mechanical and Process Engineering, University of Kaiserslautern, Gottlieb-Daimler-Strasse, 67663 Kaiserslautern, Germany^c Multiphase Reactors Group, Department of Chemical Engineering and Chemistry, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands

ARTICLE INFO

Article history:

Received 27 September 2014

Received in revised form 14 February 2015

Accepted 19 February 2015

Available online 4 March 2015

Keywords:

Prismatic spouted bed

Spouting stability

Draft plates

Pressure drop fluctuations

ABSTRACT

This paper deals especially with spouting stability in a slot-rectangular (prismatic) spouted bed. The flow stability was characterized by the pressure drop evaluation (the uniformity and amplitude of the fluctuations) and visual observations (the flow symmetry). The effect of several geometrical conditions, such as the inlet design, prismatic angle and draft plates on the bed behaviour was investigated for different particles and bed inventories exposed to different air flow rates. The prismatic angle was found to have a strong impact on the spouting characteristics. A method to improve significantly the spouting quality and to make the spouting stability independent on the gas inflow velocity is presented. Compared to the reference geometry the prismatic angle was changed to a higher value and the apparatus was equipped with draft plates. Whereas, to achieve a stable spouting in a wide range of the air flow rates the design of draft plates should be customized to the bed inventory. Dependent on the static bed height full or open-sided draft plates should be used. In the proposed apparatus implementation, the maximum spouting velocity was almost eliminated for large particles (Geldart D), i.e. a highly coherent dense spouting can pass continuously into the dilute-like stable regime, without stability loss at intermediate gas velocities. The spouting of Geldart B particles is also improved.

© 2015 The Society of Powder Technology Japan. Published by Elsevier B.V. and The Society of Powder Technology Japan. All rights reserved.

1. Introduction

Gas-spouted beds have a broad application spectrum in traditional industries, as well as a potential for innovative applications concerning solids' processing (e.g. [1,2]). The reported applications of spouted beds are (amongst others) the mixing, heating/cooling, drying, coating, granulation and chemical reactions, and the related industries are the chemical and electrochemical, metallurgy, food and agricultural, pharmaceutical, as well as energy and nuclear industries [3]. Spouted beds are also well capable for the treatment of irregularly shaped solids [4]. In dependence on the apparatus geometry (circular or rectangular), spouted beds can be sub-divided into conventional conical-cylindrical and entirely conical beds, as well as slot-rectangular and two-dimensional ones. The spouted bed investigated in this work has a rectangular cross-section and substantial apparatus depth (or thickness) and can be affiliated with the family of slot-rectangular

beds. An axisymmetric apparatus operated with static bed heights within the cone region is usually referred as a conical spouted bed. Similarly, we term this slot-rectangular geometry prismatic, since the used static bed does not usually exceed the prismatic apparatus region. The specific feature of the investigated apparatus is the gas supply through two thin horizontal slits, whereas the gas is introduced tangentially and deflected in the vertical direction by a central profile [5]. The spouting is in general sensitive to the inlet size (inlet to particle size ratio and inlet to bed size ratio) [4]. In the apparatus dealt with in this work the height of the slits is adjustable in the range of 0–3.5 mm by rotation of partially flattened cylinders; this is virtually a variation from thin to very thin slits. This adjustability of the inlets' size has some advantages in the application, e.g. flexibility in finding a suitable inlet size for spouting of solids, which are difficult to handle, or for different bed inventories. The apparatus can be comfortably filled with particles by keeping the gas inlets closed. Moreover, the clogging of the apparatus bottom area by cohesive particles can often be eliminated by temporary changing the inlets' size without a process interruption or increasing the gas flow rate. The bed is operated by underpressure, i.e. the gas is sucked through the apparatus.

* Corresponding author. Tel.: +49 040 42 878 3750; fax: +49 040 42 878 2678.

E-mail address: stefan.heinrich@tuhh.de (S. Heinrich).

Nomenclature

d_p	particle diameter (mm)	Re_{p_in}	particle Reynolds number in the area of gas inlet (–)
h	inlet height (mm)	v_{g_in}	gas velocity at gas inlets (m/s)
H	inlet-to-bed size ratio (–)	$\dot{V}$	air flow rate (m ³ /s)
H_{fr}	height of apparatus freeboard (mm)	W_{pl_bottom}	inner distance between bottom draft plates (mm)
H_{pl_bottom}	positioning height of the bottom pair of draft plates (mm)	W_{pl_top}	inner distance between top draft plates (mm)
h_{pl_bottom}	length of the bottom pair of draft plates (mm)	Greek letters	
H_{pl_top}	positioning height of the top pair of draft plates (mm)	α	apparatus width (m)
h_{pl_top}	length of the top pair of draft plates (mm)	β	apparatus depth (m)
H_{st}	height of the particle bed under static conditions (mm)	γ	inclination angle of bottom draft plate (°)
m	mass (kg)	μ_g	dynamic gas viscosity (kg/(m s))
max STD	maximum value of standard deviation of operating pressure drop signal (Pa)	ρ_g	gas density (kg/m ³)
		θ	included angle of prismatic region (°).

This spouted beds design was adopted by industry and applied for lab, pilot and industrial scale plants for batch and continuous agglomeration, film and powder coating, spray granulation, and encapsulation (ProCell spouted bed technology in [6]). This meanwhile established apparatus design which is reasonably appropriate for many applications was used in this work as a reference (starting) geometry. Due to the diversity of applications and different types of solids, the optimal implementation of a process demands appropriately designed “tailored” beds. For instance a further development of this apparatus concept was a purpose-designed spouted bed for treatment of fine and light solids, such as aerogel particles for pharmacy [7] and μ m-sized ceramic and sub-structured composite particles for a material science application [1,2]. This spouted bed has a small prismatic process chamber with adjustable gas inlets and a large and steep freeboard and is usually operated in dilute spouting regime.

The main aim of this work was a further development and improvement of this spouted bed concept with regard to improve the spouting stability in the dense spouting range. This apparatus has a stable operation range limited by applicable gas flow rate and the particle inventory. The main aim of the work presented here was to find a possibility to enlarge this range towards increased gas velocities and static bed heights, i.e. to achieve a simultaneously intense and uniform particle circulation within a wide range of gas velocity by optimizing of the apparatus geometry. For this purpose the influence of the shape of the central profile, prismatic angle and draft plates on spouting stability was investigated and the obtained results were condensed in a geometry “tailored” on increased flow stability.

2. Background

2.1. Spouting stability

There exist two stable flow regimes in spouted beds (Fig. 1): one in the dense and the second in the dilute range of the granular flow correspondingly termed the (dense) spouting and dilute or jet spouting [8]. Under stable operating conditions the granular flow in a spouted bed appears as characteristic uniform circulating patterns. A particle bed in the state of the dense spouting shows several distinct regions of different particle dynamics: (i) an upwards directed rather dilute spout formed by fast ascending particles, (ii) the dense annulus region, where the solids slowly flow downwards, and (iii) the fountain region, where the particles change the movement direction under the influence of the gravity. For the dilute spouting high gas velocity and high bed voidage are characteristic. The characteristic cyclic particle movement is also

maintained in this regime. Spouted beds provide an effective solid–fluid contact and a good heat and mass transfer, whereas the uniform circulation enables the product homogeneity [9]. Mathur and Epstein pointed out, that the flow stability in spouted beds depends on: (i) the static particle bed height, (ii) the solids properties, such as the interparticle friction, particle size and size distribution, (iii) the ratio of the inlet to bed diameter, (iv) the cone angle, as well as (v) the gas velocity [4]. For instance, for a given apparatus geometry and particle properties the stable spouting region (if one exists) is limited by the particle amount (this should be in the range between the minimum and maximum spoutable bed heights). Furthermore, the stable spouting appears only in a limited interval of gas velocities (the range between the minimum and maximum spouting velocities). Mathur and Epstein specified in [4] three mechanisms of the spout termination, responsible for the existence of the upper limit of the particle inventory, which can be spouted in conventional conical-cylindrical apparatuses, as: (i) fluidization of annular solids, (ii) choking of the spout, and (iii) growth of instabilities at the spout-annulus interface. The dilute spouting range is located between the minimum dilute spouting velocity and particle elutriation from the apparatus.

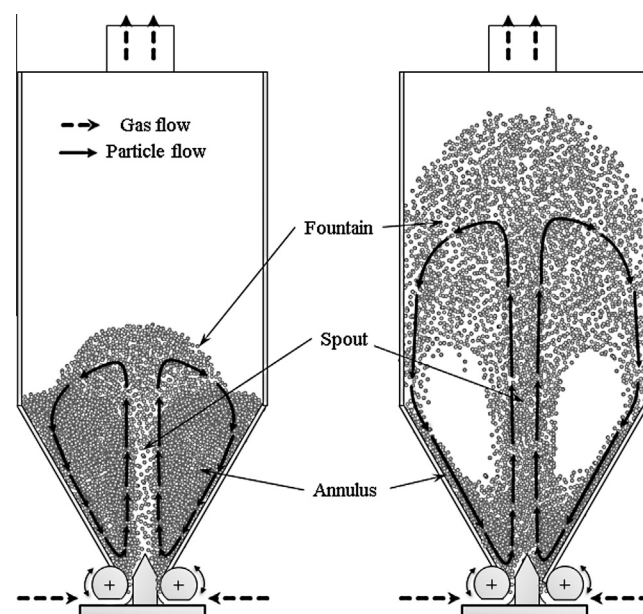


Fig. 1. A schematic representation of stable spouting regimes: left (dense) spouting; right dilute spouting.

Download English Version:

<https://daneshyari.com/en/article/10260383>

Download Persian Version:

<https://daneshyari.com/article/10260383>

[Daneshyari.com](https://daneshyari.com)