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Gas residence time distribution in a conical spouted bed

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ABSTRACT

Conical spouted beds (CSB) are considered as promising contacting devices for several applications such as drying. One of the most critical parameters influencing the performance of a CSB is the gas partitioning between the spout and annulus regions. This study presents results from gas residence time distribution (RTD) experiments carried out using a radioactive tracer measurement in a fully instrumented laboratory CSB. RTD measurements were done in the conical empty vessel and in the CSB operating with and without a draft tube. Comparisons between the RTD curves obtained clearly show the influence of the operating parameters on the gas partitioning between the spout and annulus regions. It is highlighted that the fraction of total gas injected in the CSB that passes through the annulus reaches values up to 90% for large bed height. The fraction of total flow that passes through the spout and the annulus regions appears to be independent of the operating value of U/U_{ms}. The gas penetration in the annulus occurs along the entire interface between these two regions.

A predictive model for the partitioning of gas between the annulus and the spout is also developed based on the expression of mass and momentum balances for the gas in the different regions of the conical spouted bed. Experimental results are compared to the model's predictions in term of gas residence time distribution in the annulus and spout regions. The model is also successfully used to highlight gas-partitioning parameters.

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1. Introduction

Spouted beds are gas–solid contactors in which a cyclic solid flow occurs, defining three regions: the spout, the fountain, and the annulus (see Fig. 1). They are particularly interesting gas–solid contactors for many applications. For instance, regarding the drying of solid particles, they offer an intrinsic intermittent regime, since the solid particles successively and continuously pass from one region to the other [1].

In a spouted bed, the solid particles travel rapidly up the spout until they reach a position above the bed surface, and then they move downwards in the annulus. A fraction of the ascending gas passes in the annulus where it percolates through the downwards moving particles. In order to initiate this cycling movement of the particles, the injection gas velocity must be equal or superior to the minimum spouting velocity (U_{ms}). Above this specific velocity, the pressure drop through the bed remains constant for increasing gas inlet velocity [2].

The conical spouted bed, compared to the more common cylinder–conical spouted bed, has been reported to allow better operating stability over a wider range of gas flow [3]. Some characteristic parameters of a conical spouted bed are presented in Fig. 1.

The research group at the Universidad del Pais Vasco (Bilbao, Spain) is very active in the field of spouted bed research, with a particular interest in conical spouted bed applications and particularly the conical configuration [4]. This group makes mostly use of fiber optic probes for measurements of spouted bed hydrodynamics parameters. They determined operating and geometric conditions in order to obtain stable flow regimes in conical spouted beds. They have shown that correlations developed for cylinder–conical spouted beds are not valid for conical spouted beds [2]. They published numerous results about the solid particles flow characteristics in a conical spouted bed [5].

This group also studied the gas flow in a conical spouted bed under different conditions using static pressure probes and injecting a gaseous tracer (H_2 recorded by thermal conductivity detectors). They showed that the gas flow through the spout and the annulus may be represented by dispersive plug flow models. The group also reported that the gas velocity profile in the bed flattened as it moves toward the bed upper surface, observing that the gas velocity in the spout becomes of the same order of magnitude as in the annulus. A model was then proposed for the gas flow in the annular region based on stream tubes in which a dispersive plug flow is assumed [6]. A one-dimension model was also proposed for the entire conical spouted bed [7].

The solid particles flow in a conical spouted bed, and more specifically, the residence time distributions of the solid particles in the different regions of the conical spouted bed, has recently been characterized by radioactive particle tracking, which is a non-invasive technique [8].

In several applications, the gas residence time distribution (RTD) within the different regions of a conical spouted bed may be important information in order to model the operation of the bed. For instance,

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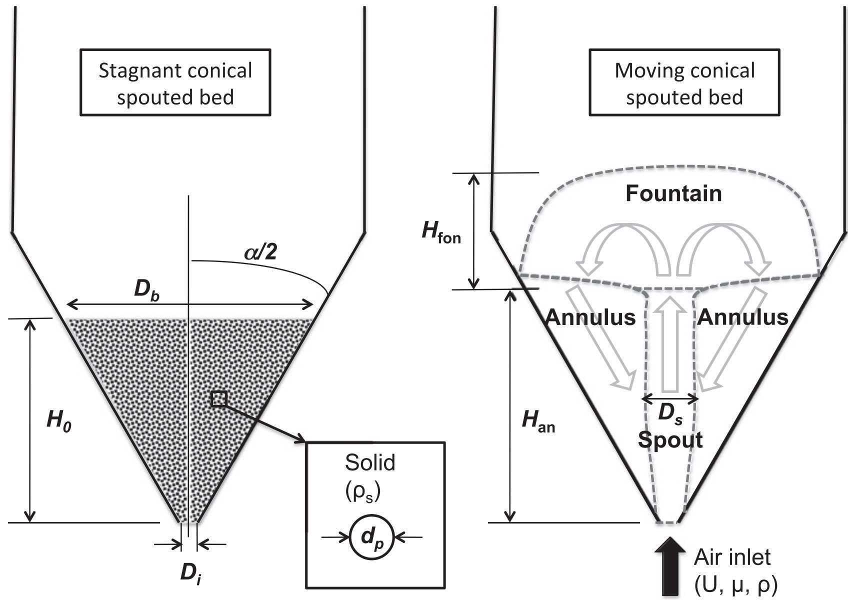

Fig. 1. Specific parameters for the static conical bed and the operating conical spouted bed.

regarding drying in a conical spouted bed, it is often assumed that drying only occurs in the spout. Therefore, the time spent by the gas in the spout region and the division of the gas between the spout and annulus regions are key parameters for modeling conical spouted bed dryers. Nevertheless, to our knowledge, there is no study reporting on gas residence time spent in the different regions of a conical spouted bed, or on the influence of the operating conditions on the partitioning of the gas between the spout and annulus regions in a conical spouted bed, while using non-intrusive measuring techniques. Indeed, reported experimental results are mostly obtained by using optical fiber probes or static pressure probes, which techniques present several limitations such as local perturbation of the gas–solid flow [9]. A welcome improvement of the models and correlations developed for the conical spouted beds would arise from using non-intrusive techniques such as tracking radioactive gas injections through the bed [10,11].

The overall objective of this work is to contribute to a better understanding of gas flow distribution in conical spouted beds. For this purpose, an instrumented laboratory conical spouted bed of glass beads, using air as the inlet gas, is used. The gas flow distribution in this spouted bed is characterized by tracking gaseous radioactive tracer injections. An innovative method is developed in order to derive mean values for key gas flow parameters from the RTDs of the gaseous tracer in the bed. The results are analyzed to highlight and to determine the key phenomena governing gas flow distribution in a conical spouted bed. A predictive model for the partitioning of gas between the annulus and the spout is developed based on the expression of mass and momentum balances for the gas in the different regions of the conical spouted bed. Experimental results are compared to the model's predictions in term of gas residence time distribution in the annulus and spout regions. The model is also used to highlight gas-partitioning parameters.

2. Materials and methods

2.1. Experimental setup: Conical spouted bed

The experimental setup is presented schematically in Fig. 2. It consists in a conical spouted bed wherein dry air is injected. The vessel is composed of a lower stainless steel conical base (inlet diameter D_i of 2.8 cm, cone angle α of 60°, cone height H_b of 51 cm, maximum diameter D_{max} of 62 cm) and an upper stainless steel cylindrical part (cylinder diameter D_c of 62 cm, cylinder height of H_c of 72 cm). The airflow is manually regulated using a pressure gage (0–100 psig) and two valves (V1 and V2 in Fig. 2) and by reading the pressure drop through an orifice plate (orifice of 0.02 m, pipes with a diameter of 0.024 m, FLC8667) on a water U-manometer. A second water U-manometer measures the pressure drop through the bed. A bypass in the air inlet pipe permits injecting the gaseous tracer instantly by using two valves (V3 and V4 in Fig. 2). Indeed, the gaseous tracer is first injected with a syringe and through a septum in the chamber closed by the two valves. When the syringe is removed, the tracer remains between the valves until their simultaneous opening, which provokes the injection of the tracer in the bed as a pulse. Two scintillation detectors (NaI crystal) are installed before and after the bed in order to detect the tracer signal before and after its passage in the bed of particles. In order to reduce the measuring window of the detectors, they are shielded with lead blocks that constrict the gamma rays arriving to the detector as being only those coming through the measuring window. The detectors are connected with coaxial cables to an acquisition system composed of an amplifier and a high-speed counter for each detector and a computer recording the number of counts measured by each detector during each sampling time.

For some experiments, a draft tube is placed in the center of the bed of solid particles in order to restrict the gas flow to the spout only. The draft tube is a non-porous copper tube with a diameter of 4 cm and a length of 15 cm; the draft tube is placed at a height of 9.4 cm above the injection level of the conical vessel and it is centered to the symmetrical axis of the cone.

2.2. Solid material

The particles chosen for this study are 3 mm glass beads with a density of 2500 kg/m^3. They are the same particles that were used for the study of solid particles flow in a conical spouted bed [8]. Hence, this allows the results obtained for both solid particles and gas flows in a conical spouted bed to be combined.

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