

Gas Flow Distribution Modelling in Conical Spouted Beds

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Abstract

The aim of this paper is to develop a simple and reliable model, based on widely accepted hydrodynamic equations and on the theory of streamtubes, which will allow for a rigorous determination of the gas flow pattern in the spout and in the annulus. In fact, the model will provide results for gas velocity at any point in the reactor, the distribution of residence times and the mean residence time. The model has been solved by means of a program in MATLAB and a statistical analysis has subsequently been carried out in order to ascertain the operating parameters that have influenced the distribution of the gas. In fact, particle properties have a greater influence than the geometry of the reactor in the distribution of the gas in the annular zone.

Keywords: Spouted bed, flow distribution, residence time

1. Introduction

The spouted bed is a fluid-solid contact regime that is different to the more conventional regimes of fixed or fluidized bed. It was discovered by chance in Canada by Mathur and Gishler (1955a,b), who showed that, when drying wheat, it allowed operation at higher temperatures without damaging the product. The absence of thermal shock is due to the countercurrent contact of the gas in the spout and the solid in the annular zone. Moreover, particles larger than in fluidized beds may be treated. Later units were used in different fields, among which their use in fertilizer granulation is worthy of mention. In this case, the success of the technique must be attributed to the characteristic solid recirculation in the bed.

The following are certain advantages of the spouted over the fluidized bed: a) easy construction and the non-requirement of distributor plate or any other gas distributor device; b) lower pressure drop than in a fluidized bed; c) higher turbulence, especially the conical spouted bed; d) materials can be processed that are difficult to handle (sticky, with particle size distribution, thermally sensitive).

Figure 1 shows the characteristic movement of the gas and the solid in a cylindrical spouted bed. The gas is fed into the bed through a hole that is smaller than the bottom diameter and creates a central spout. Furthermore, part of the gas crosses the bed through the annular zone. The solids rise along the spout, arrive at the fountain and fall down onto the annular zone, where they descend until they again enter the spout zone. Solid cross-flow from the annulus into the spout takes place all along the interface between the annulus and the spout and the particles are collected by the rising gas.

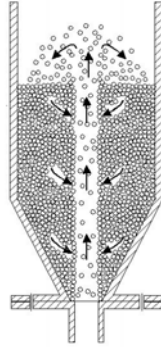


Figure 1. Scheme of the spouted bed regime.

- Amongst the applications of the spouted beds in physical operations, drying and granulation are the more typical ones, but they have also been used as an efficient heat exchanger or for solid blending or coal comminution. An innovative use of the spouted bed was developed for particle separation by shape at the Delft University of Technology in The Netherlands.
- Spouted beds have also been used in numerous chemical processes. Most of these are also carried out in fluidized beds but whenever coating or granulation are involved, spouted beds perform much better than fluidized beds. Moreover, the counter-current movement of the solid, upwards in the spout and downwards in the annulus, acts as a heat exchanger, which allows for burning solids of low heating value and lowering the flammability limit.

2. Model Proposed

Most of the models in the literature for gas flow distribution (Mamuro & Hattori (1968), Lefroy & Davidson (1969), Lim & Mathur (1976), Grbavcic et al. (1976), Littman et al. (1977), Rovero et al. (1983), Hadzismajlovic et al. (1986)) are empirical or semi-empirical. Consequently, they have considerable limitations, especially concerning the application range. The model proposed in this paper is based on a geometrical definition of the streamtubes and the pressure drop along each of these tubes is assumed to follow the Ergun equation written in scalar form:

$$\frac{\Delta p}{L} = \frac{150u_o\mu}{(\phi d_p)^2} \frac{(1-\epsilon)^2}{\epsilon^3} + \frac{1.75\rho u_o^2}{\phi d_p} \frac{1-\epsilon}{\epsilon^3} \quad (1)$$

This widely accepted equation allows for developing a model that is valid for a wide range of operating conditions in spouted beds. Thus, the pressure drop and the gas flowrate along each streamtube may be calculated. This allows for the calculation of the residence time of the gas that follows each streamtube and, consequently, the residence time distribution of the gas, for the different operating conditions and geometric factors of the contactor.

The model is especially useful for the calculation of the combination of operating parameters and geometric factors that lead to a given residence time of the gas.

The first step for developing the model is the definition of the volume elements in the bed. In this definition, the two typical zones of the bed (spout and annulus) must be taken into account.

Although it is well documented that the spout diameter is not constant along the bed (Mathur & Epstein (1974), San José et al (1996, 2001)), we will take it as constant and equal to the inlet diameter, D_o , which is a usual assumption in the literature. In order to avoid this simplification, the evolution of spout diameter with bed level must be established but this is very difficult to predict, given the major dependence of spout shape on operating conditions and geometric factors. A more realistic assumption is the consideration of an average spout diameter (usually greater than the inlet diameter), which is easy to introduce in our model. The spout is divided into s volume elements of cylindrical shape whose volume is greater as bed level is higher (Figure 2). The height of these volume elements defines the beginning of the streamtubes in the annulus.

The annulus is divided into streamtubes whose geometry is related to the geometry of the contactor and to its inlet diameter. As a consequence of this definition, there is dead zone, which was also experimentally observed, Figure 2.

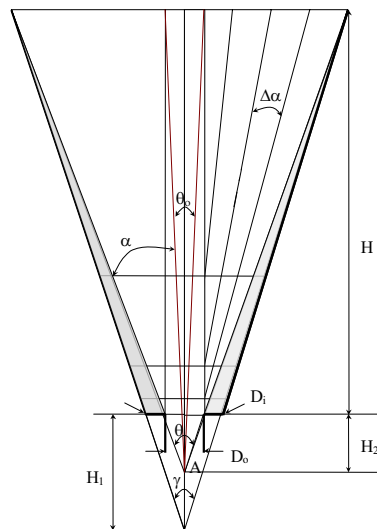


Figure 2. Volume elements and streamtubes in a conical spouted bed.

The origin for tracing the streamtubes, and for the delimitation of the dead zone, is obtained by joining the points that define the inlet diameter and those corresponding to the wall on the upper surface of the bed.

3. Computer Aided Solution

The great advantage of this model lies in the fact that it is very simple (streamtube definition based on contactor geometry and bed height and flowrate calculation by means of Ergun equation) and at the same time it provides reliable results.

In order to solve the model, a program has been written in MATLAB, which allows for introducing the operating conditions and geometric factors and for calculating bed voidage as a function of gas velocity and the flowrate that circulates along each streamtube, Figure 3. For that purpose, the function *fminsearch* finds the value of gas velocity for which pressure drop along a given streamtube is equal to the pressure drop along the spout from the beginning of this streamtube to the surface of the bed.

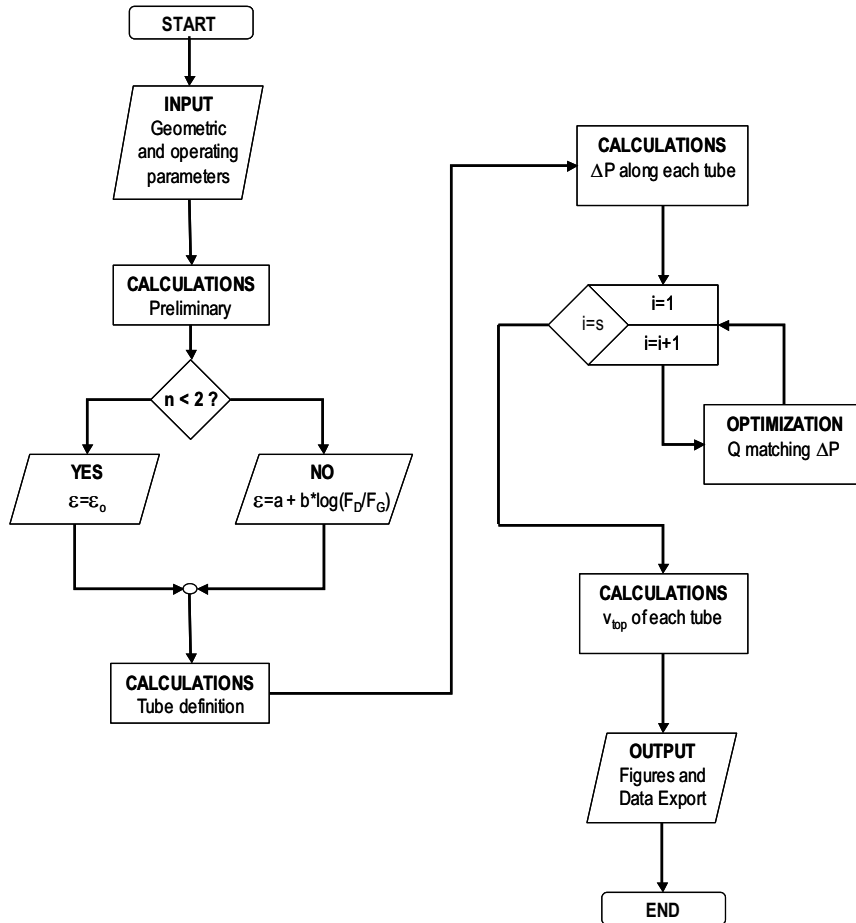


Figure 3. Flowchart of the program for solving the model.

Once these results have been obtained for each streamtube, the percentage of the gas flowrate that circulates along the different streamtubes, the residence time distribution of the gas and the gas velocity on the surface of the bed (v_{top}) are calculated. Finally, the program exports all the results obtained to an EXCEL file.

4. Results

Following the procedure described, the residence time distribution of the gas has been calculated for given conditions (particle characteristics, contactor geometry and operating conditions), Table 1. These data allow for calculating the radial and horizontal

components of gas velocity, Figure 4, and the percentages of gas flowrate that cross the spout and annulus, Figure 5.

Table 1. Cases studied using the model.

CASE No	H_o (m)	d_p (m)	D_o (m)	γ (°)	ρ_s (kg/m ³)
1	0.0335	0.0003	0.0310	28	1500
2	0.3434	0.0020	0.0310	28	1500
3	0.5921	0.0003	0.0310	28	500
4	0.0705	0.0020	0.0520	45	500

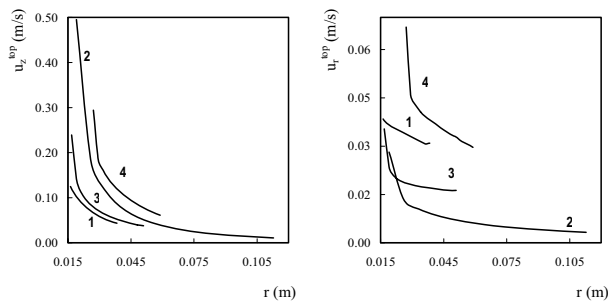


Figure 4. Radial profiles of vertical and horizontal components of gas velocity.

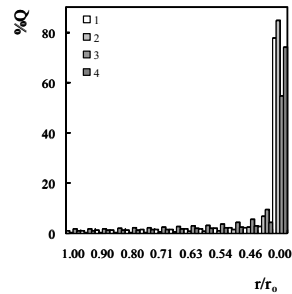


Figure 5. Gas flowrate distribution.

Figures 4 and 5 show that gas velocity distribution has a major dependence on the particle characteristics or contactor geometry. A statistical analysis has been carried out in order to ascertain the variables of greater influence and their significance. This will provide the parameters of greater influence on gas residence time distribution, which is valuable information for the design of these contactors.

5. Experimental Design and Statistical Analysis

A factorial design has been planned and carried out. The factors studied are: m_s (or stagnant bed height, H_o), d_p , D_o , γ , ρ_s and ϕ . The levels chosen for these factors are set out in Table 2.

We have decided to carry out a fractional factorial design consisting of 32 cases. Several responses have been studied but one that is worth mentioning is the distribution of gas flowrate between the annulus and the spout. The results obtained for the 32 cases range from 46% to 90.8% along the spout. These results clearly show that gas flowrate is a controllable parameter.

Table 2. Factors and levels used in the runs.

Factor	m_s (kg)	d_p (m)	D_o (m)	γ (°)	ρ_s (kg/m ³)	ϕ
Level 1 (-)	0.1	0.0003	0.031	28	1500	0.8
Level 2 (+)	5	0.002	0.052	45	500	0.6

The main conclusions drawn from the statistical analysis are that contactor geometry is of minor influence and that particle characteristics, such as diameter and sphericity, are the parameters of greater influence on gas flowrate distribution in a conical spouted bed.

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