Density calculation of a compound medium solids fluidized bed for coal separation

by Z. Luo*, Y. Zhao*, M. Fan†, X. Tao*, and Q. Chen*

Synopsis

The structure of a gas-solid fluidized bed is introduced in brief. The forming process and density distribution characteristics of a dense phase fluidized bed are analysed and discussed. Based on coal process characteristics, a density calculation method for a fluidized bed for coal separation, and a regression model for bed density forecast are proposed. The results show that the proposed density model of a fluidized bed is of high precision with a maximal relative error of 2.27% between the measured values and calculated values. The compound medium solids fluidized bed has good separation performance with an *Ep* value of 0.068.

Keywords: compound medium solids, fluidized bed, density, coal separation

Introduction

The Wet process of coal separation is almost the only method universally used in the field of coal preparation. However, water resources are not equally distributed throughout the globe and, as such, more than two- thirds of the coal resources are distributed throughout arid areas. Therefore, it is very important to develop high efficiency dry coal cleaning technology. The dry coal cleaning method with air dense medium fluidized beds, introduces fluidization technology to coal processing, has the advantage of not requiring water, and has a high separation efficiency[1–2].

The dry coal cleaning method using air dense medium fluidized beds, taking gas-solid two phase suspension as the separation medium, is a gravity separation method[3–5]. The separation efficiency, such as the probable error *Ep* value, is as effective and good as that using the wet heavy medium process, which has the best separation efficiency of all wet processes. It is necessary to determine and form a fluidized bed with a specific density. During separation, the original and second fine coal will be produced continuously. Therefore, there are at least two types of solid particles in the separation medium, such as magnetite powder and fine coal[1,6]. Hence, it is important to study the characteristics and calculate the density of a compound medium solids fluidized bed.

Experimental apparatus and material

The schematic diagram of the experimental system is shown in Figure 1. It consists of a fluidized bed of 350 x 500 mm cross-section, an air supply, measurement of parameters. The fluidized bed is the main part, which is made up of a gas distributor and bed wall. The bed density can be measured by a pressure detector or fibre densimeter. The air pressure can be controlled in 0–0.025 MPa, and the air velocity adjusted by flowmeters. Magnetite powder and fine coal are chosen as the medium solids.

A uniform and stable fluidized bed with a certain density is formed under optimal technical and operating conditions, including air pressure, gas velocity, etc.

Mathematic model of density of a compound medium solids fluidized bed

A gas-solid fluidized bed belongs to the agglomerative fluidized bed (bubbling fluidized bed), which is a non-homogenous suspension[7]. For a compound medium solids fluidized bed, its density is determined by many parameters, including material composition, size distribution, shape, etc.

Theoretical model

It is first necessary, to analyse the single medium solid fluidized bed system. The porosity and volume of the bed will increase while the bed changes from a fixed bed to a fluidized bed (shown in Figure 2).

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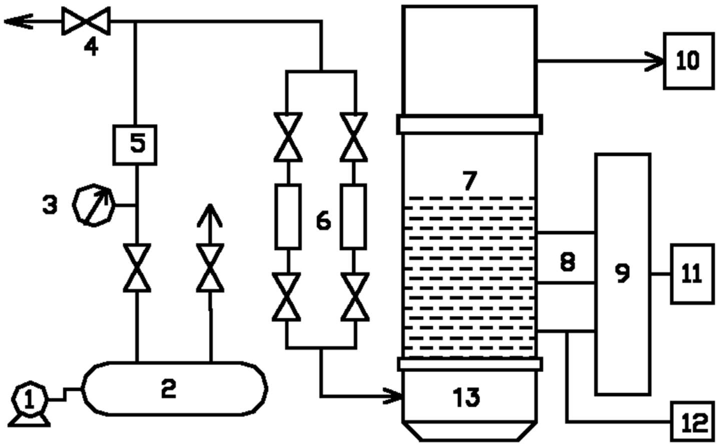

Figure 1—Schematic diagram of a fluidized bed system for coal process; 1. air blower, 2. air buffer, 3. pressure meter, 4. valve, 5. filter, 6. flowmeter, 7. a fluidized bed, 8. pressure detector, 9. pressure transmitter, 10. dust catcher, 11. recorder, 12. fibre densimeter and 13. gas distributor

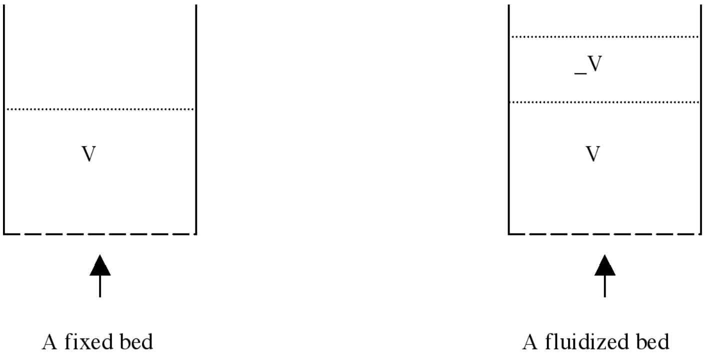

Figure 2—Comparison between a fixed bed and a fluidized bed

According to the equilibrium principle of mass, the equations below apply.

$$\rho_f V_f = \rho_b V \qquad [1]$$

$$V_f = V + \Delta V \qquad [2]$$

Let $m = \frac{\Delta V}{V}$, m is the expansion ratio of a fluidized bed. From Equation [1] and Equation [2], the ρ_f can be expressed as

$$\rho_f = \frac{\rho_b}{1+m} \qquad [3]$$

For a single medium solids fluidized bed, ρ_b and m may be obtained by experiments and therefore ρ_f can be calculated from Equation [3]. However, ρ_b is uncertain for compound medium solids.

Similarly, according to the equilibrium principle of mass, the Equations below apply.

$$V_1\rho_1 + V_2\rho_2 = \rho_b' V' \qquad [4]$$

For a compound medium solids fluidized bed, the ρ_f can be expressed as

$$\rho_f = \frac{\rho_b'}{1+m} \qquad [5]$$

Let

$$V_1 + V_2 = V_0 \qquad [6]$$

When two types of particle material are mixed and deposited, the smaller particles will fill the spaces among bigger particles, resulting in $V' \neq V_0$ and $V' \leq V_0$, that is the bulk volume of compound medium solids (fine coal and magnetite powder) less than the sum of bulk volumes of two types of single medium solid. In the case of two types of particles having the same size, size distribution and sphericity, $V' = V_0$.

Let $V' = aV_0$, $0 < a \leq 1$, where a is a coefficient related to size distribution, material composition and shape coefficient of fine coal and magnetite powder. When the fine coal and magnetite powder have the same size and sphericity, a=1.

Therefore

$$\gamma = \frac{V_1\rho_1}{V'\rho_b'} = \frac{V_1\rho_1}{aV_0\rho_b'} \qquad [7]$$

We can obtain Equation [8] from Equations [4], [5], [6] and [7]

$$\rho_f = \frac{\rho_1\rho_2}{a(1+m)\left[\rho_1 + (\rho_2 \pm \rho_1)\gamma\right]}, 0 < a \leq 1 \qquad [8]$$

In the density calculation model of the compound medium solids fluidized bed above, ρ_1 and ρ_2 can be determined by experimentally measuring; *m* and *y* can be also obtained by measuring and calculation; but *a* is a variational parameter which is difficult to determine.

According to iterative experimental mensurations, the homologous values of γ, *m* and *a* were determined (shown in Table I). As shown in Table I, the rows 4 and 5 were the calculated values ρ_f and measured values ρ_f' of bed density, respectively for $\rho_1 = 0.8$ g/cm3 and ρ_2=2.15 g/cm3. The results show that Equation [8] is more precise with the maximum of relative errors of 2.27 % between calculated and measured values of bed density.

Regression model

The density of a compound medium solids fluidized bed can also be calculated by a regression model. As shown in Equation [8], ρ_1 and ρ_2 can be determined, and γ, *m*, *a* are the relating parameters. First, it is necassary to measure the density of a fluidized bed for different content of fine coal in compound medium solids, then to analyse and determine the corresponding relation between them. Finally, a regression model Equation [9] was determined by regression analyses and calculation.

$$\rho_f = \frac{1}{0.08 + 1.16e^{\pm(1\pm\gamma)}}, 0 \le \gamma \le 1 \qquad [9]$$

The comparison of the calculated and measured values of bed densities are given in Table II. The results show that the regress model is more precise with a maximum of 2.11% of relative errors between the calculated and measured values of bed density.

Separation performance of a compound medium solids fluidized bed

Taking a mixture of fine coal and magnetite powder as medium solids (note: the fine coal can be prepared in advance according to the requirement of separation density), a compound medium solids fluidized bed was formed immediately with a uniform and stable density of 1.65 g/cm3 under specific operating conditions (air pressure of 0.02 MPa and air velocity of 10.20 cm/s). The feed was fed into the fluidized bed vessel from the top, and then stratified and separated according to the bed density. Twenty seconds later the system was shut down and the separated materials were sampled. The clean coal (floats) and tailings (sinks) were obtained. For the 50 x 6 mm feedstock of 21.48% ash content, the partition curve of the product was completed according to the data of float-sink analysis of clean coal and tailings (shown in Figure 3). In Figure 3, the partition coefficients are the percentages of the feed of a particular density that report to the sink product. The partition curve between 25% and 75% gives a reasonable straight-line relationship, which shows the efficiency of the separation process. The density at which 50% of feed reports to sinks is known as the effective density of separation (ρ_{50}). The results show that the compound medium solids fluidized bed has good separation performance, with a clean coal yield of 86.20%, a clean coal ash content of 12.70% and an *Ep* value of 0.068, at a separation density of 1.67 g/cm3. The separation efficiency (*Ep* value) is as effective and as good as that using the wet heavy medium process.

Dry beneficiation of coal with an air dense medium fluidized bed was initiated in 1984 by China University of Mining and Technology. The first industrial plant using an air dense medium fluidized bed has been established in the north of China. The results show that this technology has the following advantages: water free, high separation efficiency, construction investment (about 50 Yuan RMB/MT of feed) and operating cost (about 5 Yuan RMB/MT of feed) are about half those of wet processes of the same scale, and no environment pollution by coal slime.

Conclusions

➤ For a compound medium solids fluidized bed, a calculation formula and regression model of bed density was proposed as following, respectively

$$\rho_f = \frac{\rho_1\rho_2}{a(1+m)\left[\rho_1 + (\rho_2 \pm \rho_1)\gamma\right]}, 0 < a \le 1;$$

$$\rho_f = \frac{1}{0.08 + 1.16e^{\pm(1\pm\gamma)}}, 0 \le \gamma \le 1.$$

Table I

The determined values of main parameters for densities calculation of a fluidized bed

γ (%)	1	10	20	30	40	50	60	70	80	90
m (%)	2	10	9.5	9.3	9.0	8.7	8.5	8.4	8.2	8.1
a	3	0.92	0.88	0.86	0.84	0.83	0.84	0.86	0.88	0.9
ρ_f (g/cm3)	4	1.82	1.67	1.52	1.40	1.29	1.17	1.06	0.96	0.88
ρ_f' (g/cm3)	5	1.84	1.66	1.51	1.40	1.29	1.15	1.03	0.95	0.90
Relative error (%)	6	1.10	0.60	0.66	0	0	1.71	1.89	1.04	2.27

Table II

The comparison of calculated and measured values of bed densities

γ (%)	1	10	20	30	40	50	60	70	80	90
ρ_f (g/cm3)	2	1.82	1.66	1.52	1.40	1.28	1.17	1.06	0.97	0.89
ρ_f' (g/cm3)	3	1.84	1.66	1.51	1.40	1.29	1.15	1.08	0.95	0.90
Relative error (%)	4	1.09	0	0.66	0	0.78	1.74	1.85	2.11	1.11

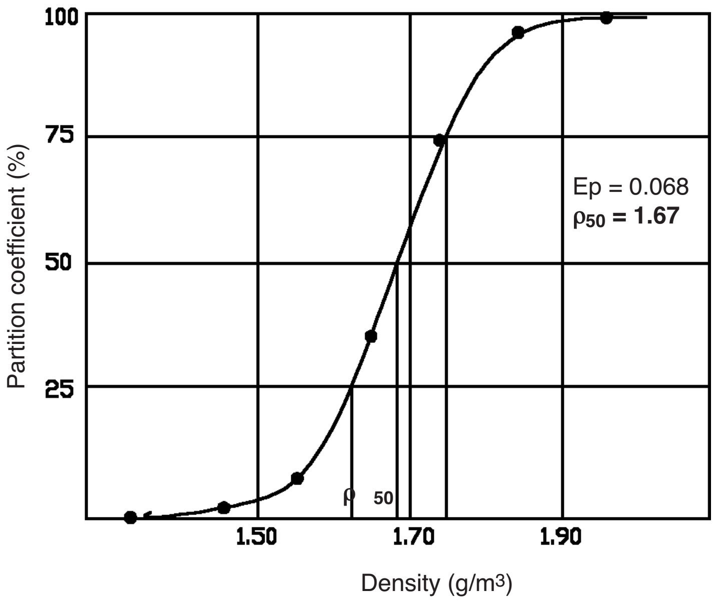

Figure 3—The partition curve of product

- The compound medium solids fluidized bed has good separation performance: when feedstock of 21.48% ash content was beneficiated at a separation density of 1.67 g/cm^3, a good separation efficiency was achieved with a clean coal yield of 86.20%, a clean coal ash content of 12.70% and an *Ep* value of 0.068.

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Nomenclature

ρ_f density of a fluidized bed, g/cm^3

ρ_b bulk density of medium solids (the density of a fixed bed), g/cm^3

V volume of a fixed bed, cm^3

V_f volume of a fluidized bed, cm^3

ΔV difference between the volume of a fixed bed and that of a fluidized bed, cm^3

m expansion ratio of a fluidized bed

V_1 bulk volume of fine coal, cm^3

V_2 bulk volume of magnetite powder, cm^3

ρ_1 bulk density of fine coal, g/cm^3

ρ_2 bulk density of magnetite powder, g/cm^3

ρ_b' bulk density of compound medium solids, g/cm^3

V' bulk volume of compound medium solids, cm^3

a coefficient

γ content of fine coal in compound medium solids

Ep index of judging separation efficiency in coal preparation, which is defined as half of the difference between the densities at which 75% reports to sinks and 25% reports to sinks

ρ_{50} effective density of separation, that is the density at which 50% of the materials reports to sinks.

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