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Analysis and evaluation on pressure fluctuations in air dense medium fluidized bed

Sheng Cheng [a,b], Duan Chenlong [a,*], Zhao Yuemin [a], Dong Liang [a], Luo Zhenfu [a]

[a] Key Laboratory of Coal Processing and Efficient Utilization of Ministry of Education, School of Chemical Engineering & Technology, China University of Mining & Technology, Xuzhou 221116, China
[b] Forschungszentrum Jülich, Jülich 52428, Germany

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ABSTRACT

Pressure fluctuations contribute to the instability of separation process in air dense medium fluidized bed, which provides a high motivation for further study of underlying mechanisms. Reasons for generation and propagation of pressure fluctuations in the air dense medium fluidized bed have been discussed. Drift rate and collision rate of particles were employed to deduce the correlation between voidage and pressure fluctuations. Simultaneously, a dynamic pressure fluctuation measuring and analysis system was established. Based on frequency domain analysis and wavelet analysis, collected signals were disassembled and analyzed. Results show gradually intensive motion of particles increases magnitudes of signal components with lower frequencies. As a result of violent particle motion, the magnitude of real pressure signal's frequency experienced an increase as air velocity increased moderately. Wavelet analysis keeps edge features of the real signal and eliminates the noise efficaciously. The frequency of denoised signal is closed to that of pressure signal identified in frequency domain analysis.

1. Introduction

Fossil fuels, including coal, oil and renewables and unconventional fossil fuels, are projected to provide the majority of the world's energy needs, meeting two-thirds of the increase in energy demand out to 2035 [1]. By then, coal is estimated to account for approximate 30% share of primary energy consumption in the world. As an important primary energy resource with limited reserves, coal plays a significant role in electricity generation, iron making process and so forth [2]. It is estimated that the proportion of coal consumption of China has reached 70% in recent years [3]. China continues to lead the coal demand growth in coal consumption until the estimated peaks have been reached in recent years [1]. However, the rapid coal consumption has brought unprecedented environmental contamination, like water and solid waste pollution, emission of greenhouse gas (CO_2), dust emission, etc. [4]. Therefore, improving the coal quality, utilizing coal in environmentally-friendly ways, advanced coal beneficiation equipment are of great significance to energy conservation and environment protection [5].

Coal beneficiation before utilization is an effective and economical method for discarding hazardous components and gangue, thereby alleviating environmental pollution and improving coal utilization efficiency. Currently, water-based coal beneficiation technologies including dense medium shallow slot separation, hydraulic jigging and coal flotation, dominate in the coal separation industry. All around the world, droughts, heat waves and water shortages however have resulted in serious economic damages, which indicates that water shortage has become a global issue [6]. Due to large water consumption and difficulties of waste slime water disposal, wet separation technology is not suitable for water shortage areas [7]. In the field of coal preparation, dry coal separation technologies have become increasingly significant throughout the world, especially in arid area. Among these methods, air dense medium fluidized bed separation has numerous advantages of none water consumption, circulation usage of the dense medium, low operation cost, circulation usage of the dense medium, etc. Hence, it is a typical dry technology that has been studied intensively worldwide. China, the USA, South Africa and India endeavor to employ the technology in drought areas [8].

Air dense medium fluidized bed is an efficient method using magnetite powder as separation medium. When the threshold of fluidization where friction forces balance the weight of the bed is reached, the suspension of particles exhibits features analogous

* Corresponding author.
E-mail address: llaoduan@126.com (C. Duan).

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to liquids, e.g., viscosity, liquidity or expansion [9–11]. Therefore, coal particles can be segregated in the pseudo-fluid in terms of density difference. When a stable fluidization state is achieved, magnetite powder acts like pseudo fluid, which provides a favorable environment of density distribution for coal beneficiation [8]. However, unpredicted instability of the pseudo fluid, e.g., pressure fluctuations, bubble behavior, restricts further development of industrial scale-up for air dense medium fluidized bed [12–14]. Pressure fluctuations give rise of the instability, which seriously impacts the separation efficiency and yield. So as to gain better comprehension of underlying mechanism in air dense medium fluidized bed, pressure fluctuation is likely to be the preferential factor that needs to be considered [15,16].

In air dense medium fluidized bed, pressure fluctuation can reflect bubble behavior features, such as bubble size and bubbling frequency. A number of methods and models have been developed and employed to describe and investigate pressure fluctuations in fluidized beds [17–20]. Kage et al. investigated and measured pressure fluctuations in the plenum chamber of a fluidized bed using glass beads as the medium under spontaneous oscillation condition [19]. Wgner distribution analysis was implemented to analyze random pressure fluctuations in a gas-solid fluidized bed with results showing that nonstationary methods can be used for pressure fluctuations in fluidized beds [21]. Si et al. demonstrated pressure fluctuation signals measuring and analysis methods for bubbling fluidized bed [22]. However, analysis and study on pressure fluctuations in air dense medium fluidized bed have rarely reported.

Many approaches have been employed for the analysis of pressure fluctuations in fluidized beds, e.g., frequency domain analysis, wavelet analysis, statistical analysis, fractal and chaos method [21]. These methods have respective advantages and disadvantages. Frequency domain analysis makes it possible to decompose a signal into series of components with different frequencies and analyze the spectrum to determine which frequency is the target. However, it cannot obtain the actual signal from original pressure fluctuation signals and conduct the de-noising operation. Wavelet analysis, in this instance, has advantages of filtering noise signals from actual pressure fluctuation signals and providing different de-noising approaches that are useful in experiments.

In the proposed work, a dynamic pressure fluctuations measuring system for air dense medium fluidized bed has been demonstrated. Based on phase space concept, the origin of pressure fluctuation was investigated theoretically by importing drift rate and collision rate. The proposed research aims to present an effective method to characterize the dynamics pressure fluctuations in air dense medium fluidized bed based on combination of frequency domain analysis and wavelet analysis. Simultaneously, the scale structure of the fluidized bed is analyzed by decomposing the pressure fluctuations signals to obtain a better understanding of the hydrodynamics in air dense medium fluidized bed.

2. Experimental

The schematic experimental setup is shown in Fig. 1. It contains several subsections: air dense medium fluidized bed, piezometric tube, data acquisition unit, and data analysis unit. The main part of the flow chart is the air dense medium fluidized bed with four probes. The column made of perspex pipe has a height of 0.6 m and inner diameter of 0.4 m. The air distributor in the fluidized bed consists of 200 holes with 3 mm in diameter, which makes it possible for not only balancing the whole weight of magnetite powder, but also distributing the gas uniformly. Air was injected into the fluidized bed. Homogenous magnetic powder was implemented as the dense medium in the experiment.

Bed height was set as 20 cm. Four dynamic pressure sensors were used in this experiment to measure pressure fluctuations. Four axial positions of 1, 6, 11, and 16 cm above air distributor were chosen to install pressure probes.

Prior to injecting the air into fluidized bed, the static pressure was primarily measured as reference pressure fluctuations. Afterwards, when the fluidization was steady, measuring processes was carried on to obtain the real-time pressure fluctuations. Piezometric tube transits the real-time pressure signals to data acquisition unit, which transforms analogue signals into digital signals and then delivers signals to the terminal-data analysis computer, where data is investigated correspondingly.

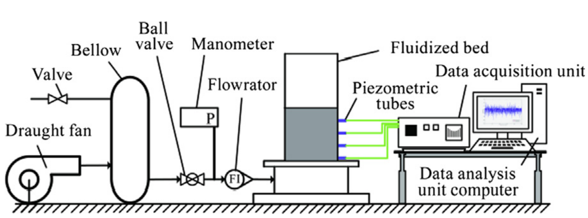

Fig. 1. Schematic diagram of pressure fluctuation measuring and analysis system.

3. Theoretical analyses

3.1. Basic assumptions

Air dense medium fluidization is one of the most extremely complex processes in the industry. In this work, we endeavor to explore the reason for generation and propagation of pressure fluctuations in this process. Prior to theoretical analysis, a number of assumptions need to be emphasized: magnetite powder is the homogeneous spherical particles with same size; magnetite powder appears to be the closest packing in static condition. Maximum occupancy of magnetite powder is a constant; and due to weak effect on the whole behavior of particles, the rotation of each particle is not taken into consideration in proposed work.

3.2. Correlation between voidage variation and pressure fluctuation

In the static bed (Fig. 2a), magnetite particles maintain static packing status in the fluidized bed. In the steady fluidization bed (Fig. 2b), magnetite powder behaviors like pseudo fluid. It is known that static bed has a relative bulk density. Similarly, in fluidization state, the bed has a characterized density- ρ_c. Thus ρ_c can be defined as follows:

$$\rho_c = \alpha \cdot \rho_M + \beta \cdot \rho_A \quad (1)$$

$$\alpha + \beta = 1 \quad (2)$$

where ρ_M is the density of magnetite powder; ρ_A the density of air; α the volume fraction of magnetite powder; and β the volume fraction of air.

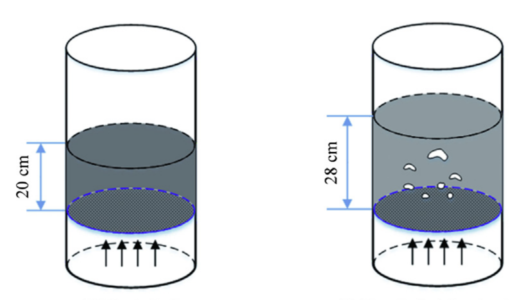

Fig. 2. Diagrammatic sketch of fluidized bed.

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