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Dynamic granular bed and its gas–solid separation process

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ABSTRACT

In this work, a new concept of dynamic granular bed was proposed based on the inertial number theory of powder mechanics. Compared with conventional moving granular bed, a fast-moving granular layer was formed on dynamic granular bed, which can capture the dust particulates and transport them away rapidly. The dust cake can be kept at a certain amount of thickness even after long-term operation. Hence the blowback process is not required in dynamic granular bed. Periodic working moving granular bed is then changed to continuous and steady working dynamic granular bed. Two kinds of dynamic granular beds were numerically and experimentally investigated in this work, i.e., vertical and inclined dynamic granular bed. It is found that inclined dynamic granular bed is superior to vertical dynamic granular bed. The experimental results show that there exist optimal parameters of both filtration superficial velocity and mass flow rate of filter granules for dynamic granular bed. Specifically the best collection efficiency occurred at a filtration superficial velocity of 0.3 m/s and a mass flow rate of 300 g/min for both vertical and inclined dynamic granular bed in the experiments.

1. Introduction

Granular bed filter for gas–solid separation can be usually divided into two categories, i.e., fixed bed and moving granular bed. Due to their inherent limitations, fixed beds have not been widely utilized. Compared with fixed bed, much intensive research has been conducted on moving granular bed [1–6]. Various flow patterns and louver–sublouver designs for moving granular bed have been developed for dust particulates filtration, for instance, moving granular bed with sublouvers and obstacles, declined sublouvers, circle louvers, and etc. [7–10]. Although moving granular bed has been reported as a superior dust removal technology, electrostatic precipitators and bag filters are still the widespread applied gas–solid separation processes [11–15]. So far the reason for moving granular bed not being industrialized has not been reported. Previous research regarding moving granular bed may have a few limitations. Firstly, the research was performed at a specified designed bed. Dust removal performance was examined by changing operating parameters. Secondly, most of them were carried out using a specific granule. The characteristics and performance of granules were not investigated. Last but not the least, previous research mainly applied conventional theory and accepted the reality of dust cake continuous growing.

Much research has shown that there exist static granules in moving granule bed, i.e., stagnant zone, which could cause an increase in operation resistance in the gas–solid separation process. To date great efforts have been made on moving granular bed regarding stagnant zones [7,9, 16–18]. However, the physical mechanism behind this phenomenon, i.e., the reason of self-locking of these particles in the force chains under gravity, was usually overlooked. Therefore, how to change the self-locking particles to dynamic particles is the key of the problem of stagnant zones. In this work, we investigated the self-locking mechanism of granules and designed a new type of dynamic granule bed based on inertial number theory. In order to evaluate the performances of the proposed filter system, several parameters including filtration superficial velocity, mass flow rate of the filter granules and pressure drop were examined.

The rest of this paper is organized as follows: Section 2 introduces the concept and theory of dynamic granular bed. Experimental results and discussions for vertical dynamic granular bed are given in Section 3. Section 4 presents comparisons of the performances between vertical and improved inclined dynamic granular bed. The conclusions are drawn in Section 5.

2. Concept of dynamic granular bed

2.1. Why called dynamic granular bed

In essence, dynamic granular bed belongs to moving granular bed category. There is not much difference on the appearance between them. However, stagnant zones almost vanish in dynamic granular bed. Some of the granules change to fast-moving granules. These fast-moving granules are located against the coming air flow, which can keep the dust cake within a certain amount of thickness. Thus, the

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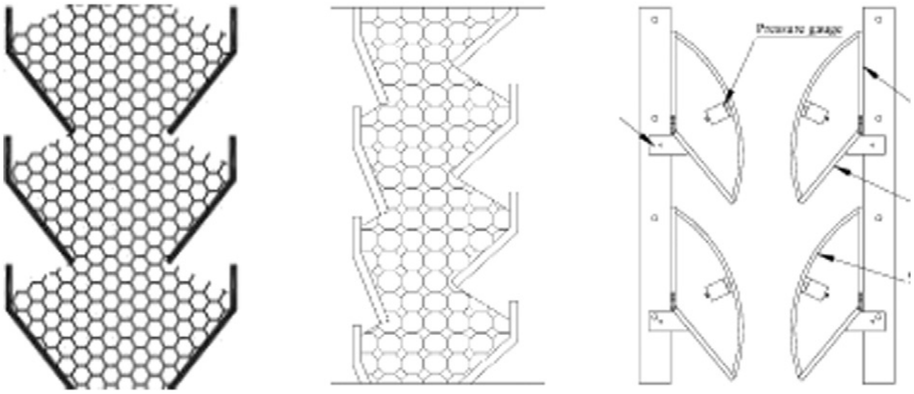

Fig. 1. Different deigns of louvers in moving granular bed. (a) Symmetric louvers. (b) Asymmetric louvers [17]. (c) Curved louvers [16].

operating resistance decreases and the collection efficiency can be guaranteed.

The explanation of 'dynamic' is 'of physical power and forces producing motion', which consist with the flow patterns of the granules in dynamic granular bed. This fast moving granular layer can transport the captured dust particulates away and keep granular bed capable of dust collection throughout the gas–solid separation process.

2.2. How dynamic granular bed proposed

From the framework view, previous research mainly focused on the arrangement of louvers, the appearances and locations of sublouvers. For instance, symmetric, asymmetric and curved louver-walled granular moving beds have been proposed to improve the movement of granules, as seen in Fig. 1. In addition some researchers introduced sublouvers to further improve the movement of granules, thus to enhance the dust separation efficiency. Fig. 2 demonstrates different sublouvers employed in moving granular bed.

However, all these adjustments are on the premise that the continuous increasing of dust cake is acceptable. A fatal shortcoming of this operation manner is that the resistance of gas–solid separation increases with time going on. Therefore, a blowback process is usually required in this situation to reduce the resistance after long-term operation. So far many efforts have been made to reduce stagnant zones in moving granular bed [21–23]. From the theory of powder mechanics, the physical essence behind this is the self-locking of granules, which is caused by the force chains of these granules. Stagnant zones could diminish as long as the force chains are controlled. This theory will be proved by the experiments in the next section.

Chevoir et al. [24] introduced a dimensionless parameter inertial number I to determine the states of granules, i.e., $I \le 10^{-3}$ denote that the materials tend to the quasi-static regime, where they are described as elasto-plastic solid, also known as critical state of soil mechanics. For $I \ge 10^{-1}$, they tend to the collisional regime, in which they are described through extension of the kinetic theory of dense gases to dissipative particles. The intermediate regime ($10^{-3} \le I \le 10^{-1}$) corresponds to dense flows. For moving granular bed, the granules are in active state as long as the inertial number $10^{-3} \le I \le 10^{-1}$ is kept. The stagnant zones could diminish significantly. The dimensionless parameter inertial number I is defined as

$$I = \frac{\tau_i}{\tau_c} \tag{1}$$

where $\tau_i = d\sqrt{\frac{\rho_g}{P}}$ is the inertial characteristic time, $\tau_c = 1/\dot{\gamma}$ is the shear characteristic time. The pressure P and shear force τ determine the effective friction coefficient $\mu^* = \tau/P$. For homogeneous shear flow

$$\dot{\gamma}(y) \approx \frac{\sqrt{\nu g}(\theta - \varphi)}{bd}\sqrt{H - y} \tag{2}$$

From Eq. (1), it can be seen that inertial number I is a function of shear rate $\dot{\gamma}$, physical properties ρ_g and d, and the operation pressure P. Eq. (2) indicates that the shear rate $\dot{\gamma}$ relates to the physical properties of the granules and container, as well as the operation parameters. Eqs.

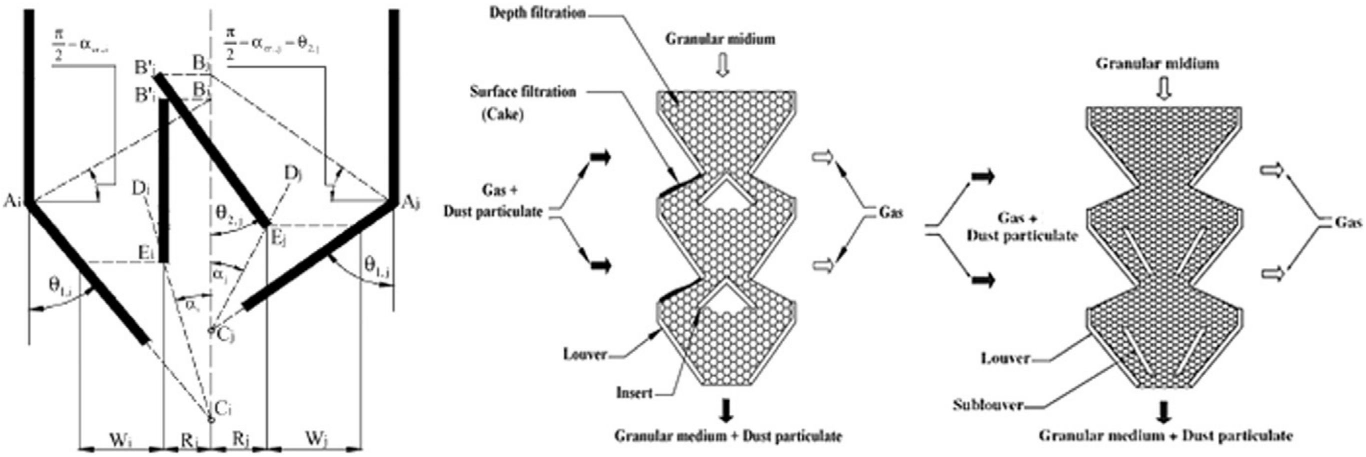

Fig. 2. Various inserts/obstacles/sublouvers employed in moving granular bed. (a) A wedge-shaped obstacle [19]. (b) Inserts in moving bed [20]. (c) Sublouvers in moving bed [21].