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# Modeling and optimization of the moving granular bed for combined hot gas desulfurization and dust removal

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**Abstract**

The development of the moving granular bed process for combined removal of particulates and gaseous pollutants is an attractive engineering solution for hot gas cleanup due to its advantages of process compactness and lower cost in comparison to separated process steps. The key to achieve the best performance of the combined process is to match the different unit operations. This work aims to simulate the cross-flow moving granular bed for combined hot gas desulfurization with dust removal and to realize the process optimization. Based on the hydrodynamics equations, particulate collecting equations and desulfurization equations, a mathematical model was established to simulate the performance of the combined process. The simulating results show that the combined process has advantages to improve the desulfurization efficiency and the sorbent conversion in comparison with the single desulfurization process because deposited dust may influence the gas flow pattern in the bed. The method based on the analyzing operating curves was proposed for the reactor design and the optimization of operating variables. The appropriate parameters can be determined according to an operating characteristic diagram given by the model.


*Keywords:* Hot gas cleanup; Desulfurization; Dust removal; Cross-flow moving granular bed; Combined process

## 1. Introduction

The emerging advanced coal-based energy production systems require fuel gas cleanup at high temperature to improve the process thermal efficiency and environmental performance. Fuel gas generated from the gasifier contains many types of contaminants, such as sulfur gases ($H_2S$, COS), HCl, $NH_3$, alkali metal gases and particulates. The combined concept for removal of multi-pollutant offers an attractive engineering solution for hot gas cleanup because it has the potential to simplify the complex sequence of selective process steps and lower the gas cleaning cost. The moving granular bed for simultaneous removal of particulates and hydrogen sulfide, the primary contaminants in the coal-derived fuel gas, has been developed and considered as a promising combined process [1], in which granular sorbents cannot only remove sulfur gases by chemical reactions but also act as the filtering media to remove particulates from fuel gas. It is obvious that the match of the two different unit operations is the key to improve the combined process efficiency and cost effective. Studies on the moving granular bed used for hot fuel gas desulfurization and dust removal have been conducted respectively in the previous works [2–4]. The present work aims to analyze the operation characteristics theoretically and to realize the process optimization by means of the simulation of the cross-flow moving granular bed for combined hot gas desulfurization and dust removal.

## 2. Model formulation

The rectangular cross-flow moving granular bed is studied in this work. Solid grain moves downward by the gravity and fuel gas flows through the granular bed in the horizontal direction. In order to simulate the combined process for simultaneous removal of sulfur gases and particulates, the following approximations are considered:

(1) Only steady-state operation conditions are considered.
(2) Isothermal condition prevails due to the small quantity of sulfidation heat.

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(3) Fuel gas composition remains unchanged after desulfurization except hydrogen sulfide.
(4) The fluid is continuity, Newtonian, and incompressible.
(5) Plug flow is assumed for solid phase and the granular bed voidage is uniform.
(6) The influence of deposited dust on the sorbent sulfidation reaction can be neglected [5,6].
(7) The horizontal and vertical dust distributions in the bed are considered.

According to the assumptions, the two-dimension model can be established based on a few fundamental equations including hydrodynamic equations, particulate collecting equations and desulfurization equations. The element balance and the coordinate system of the cross-flow moving bed are shown in Fig. 1.

### 2.1. Hydrodynamic model

The general method to characterize gas flow through the porous media is based on Darcy's law and Ergun's equation. In the combined process, the dust deposition in the granular bed and sulfidation reaction heat would cause gas flow deviation from plug flow. Because of little reacting heat due to the low $H_2S$ concentration in fuel gas, the isothermal condition assumption is used here. Dust deposit in the granular bed void would increase the resistance of gas flow through the bed. Furthermore, dust load is not uniform in the bed along the gas flow and the solid moving directions, which could lead the gas flow pattern with the 2-D distribution. Thus, the hydrodynamic equations are as follows:

Continuity equation:

$$\frac{\partial u_x}{\partial_x}+\frac{\partial u_y}{\partial_y}=0 \quad (1)$$

The presence of deposited dust can affect the pressure drop. Tien [7,8] has studied the effect in the fixed-bed filter. According to previous works [2], the empirical equation is as follows:

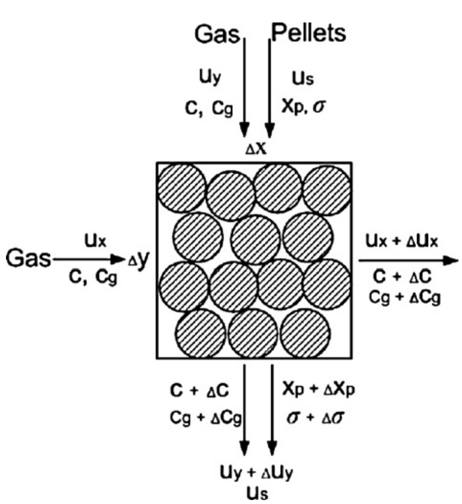


Fig. 1. Schematic diagram of the moving granular bed element.

$$\Delta P_i=[1+\beta_1\cdot(\sigma/\varepsilon)^{\beta_2}]\cdot\Delta P_0 \quad (2)$$

Here $\sigma$ is the specific deposit, the amount of deposited dust per unit volume of filter bed, used before by Tien et al [7–10]. $\beta_1$ and $\beta_2$ are two constants describing the influence of deposited dust on the pressure drop. $\Delta P_0$ is the initial pressure drop of the granular bed without dust deposit, which can be described by Ergun's equation.

To take into account the effect of deposited dust, the momentum equations are written as:

$$-\frac{\partial P}{\partial x}=(K_1+K_2)\cdot u_x\cdot(1+\beta_1\sigma_p^{\beta_2}) \quad (3.1)$$

$$-\frac{\partial P}{\partial y}=(K_1+K_2)\cdot u_y\cdot(1+\beta_1\sigma_p^{\beta_2}) \quad (3.2)$$

where $\sigma_p$ denotes $\sigma/\varepsilon$ to describe the dust deposit in the void of the granular bed. $K_1$, $K_2$ according to Ergun's equation are given as:

$$K_1=150\frac{(1-\varepsilon)^2}{\varepsilon^3}\cdot\frac{\mu}{(\phi_s d_s)^2},\quad K_2=1.75\frac{(1-\varepsilon)}{\varepsilon^3}\cdot\frac{\rho_g}{\phi_s d_s}|u| \quad (3.3)$$

where $u$ is the superficial gas velocity, $|u|$ can approximately be the average superficial gas velocity flowing through the whole granular bed. Eliminating the pressure item from Eq. (3.1) by the derivative of Eq. (3.1) with respect to y and Eq. (3.2) with respect to x, and then introducing the stream function $\Psi$, produce:

$$u_x=\frac{\partial\psi}{\partial y};u_y=-\frac{\partial\psi}{\partial x} \quad (4)$$

$$\frac{\partial}{\partial y}\left[(K_1+K_2)\cdot\frac{\partial\psi}{\partial y}\cdot(1+\beta_1\sigma_p^{\beta_2})\right]+\frac{\partial}{\partial x}\left[(K_1+K_2)\cdot\frac{\partial\psi}{\partial x}\cdot(1+\beta_1\sigma_p^{\beta_2})\right]=0 \quad (5)$$

### 2.2. The model of the cross-flow moving granular bed for dust removal

In a deep-bed filter, dust is collected inside the granular bed. According to the element mass balance of dust inside the granular bed filter, the following equation can be obtained to describe the dust load distribution and dust concentration distribution inside the granular bed.

$$u_x\cdot\frac{\partial c}{\partial x}+c\cdot\frac{\partial u_x}{\partial x}+u_y\frac{\partial c}{\partial y}+c\cdot\frac{\partial u_y}{\partial y}=-u_s\rho_p\frac{d\sigma}{dy} \quad (6)$$