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HYDRODYNAMICS OF A SPOUT-FLUID BED WITH AN ENLARGED COLUMN FOR FINE PARTICLES

Jian Xu* Lei Gong†
Xiaojun Bao Dr.‡ Weisheng Wei**

*China University of Petroleum
†China University of Petroleum
‡China University of Petroleum, Beijing, baoxj@cup.edu.cn
**China University of Petroleum

HYDRODYNAMICS OF A SPOUT-FLUID BED WITH AN ENLARGED COLUMN FOR FINE PARTICLES

Jian Xu, Lei Gong, Xiaojun Bao*, Weisheng Wei
The Key Laboratory of Catalysis, China National Petroleum Co.,
China University of Petroleum, Beijing 102249, China

ABSTRACT

In order to improve the spoutability for fine particles, a new type of spout-fluid bed with an enlarged column section was proposed. Comparison of flow regime maps for the new design with a conventional spout-fluid bed showed that the range of stable spouting regime was extended when an enlarged column section was employed.

Key Words: Spout-fluid bed, Enlarged column, Flow regime map, Stable spouting

INTRODUCTION

Spouted beds possess certain structural and flow characteristics that are very desirable for fast, highly exothermic and endothermic catalytic reactions (1, 2, 3, 4). However, the use of spouted beds as chemical reactors may suffer from less catalyst interfacial area due to relatively larger particles, especially for fast catalytic reactions which are limited by mass transfer and only the external catalyst surface is effective. Therefore, it may be more favorable to operate spouted beds with relatively finer particles when applying as catalytic reactors (1).

For spouting of fine particles, stable spouting and regular circulation of solids are obtained only for a narrow gas velocity (5, 6, 7). Moreover, in order to fulfill the criteria for stable spouting, relatively smaller nozzle is required, which gives rise to the formation of dead zone in the bed bottom and serious particle attrition (5). By introducing auxiliary fluid through a porous or perforated distributor surrounding the central orifice, the spout-fluid bed technique increases the fluid-solid contact in the annulus and alleviates the likelihood of dead zones (8).

In the present paper, a novel design of spout-fluid beds, i.e. a conical-cylindrical structure with an enlarged column section was proposed in order to improve the spout stability for fine particles.

EXPERIMENTAL

Three spout-fluid beds were build, one is the conventional conical-cylindrical configuration (Configure A) with an inside diameter D_1 of 0.15 m and height of 2.0 m equipped with a 60° conical based perforated distributor (See Fig. 1(a)). There were 48 orifices, each 2 mm in diameter, evenly spaced over the conical surface. The other two spout-fluid beds have the same size and configuration of conical section

* Corresponding author. Email: baoxj@cup.edu.cn. Fax: (8610)89734979.

as Configure A, but with an enlarged column section, whose inside diameters D_2 are 0.17 m (Configure B) and 0.18 m (Configure C), respectively, as shown in Fig. 1(b). Spouting gas and fluidizing gas, both provided by an air compressor, were controlled and measured separately by pressure regulators and rotameters. Two narrow size-distributed alumina particles were used as bed materials. Their properties are listed in Table 1.

Differential pressures at 10 axial locations with a vertical interval of 30 mm were measured simultaneously using rapid-response pressure transducers (Omega, PX164-010D5V). Measurements were all taken from the wall. The bed voidage was measured by an optical fiber system, which deduced the solids volume information from the reflection of emitted light. Pre-tests were carried for each kind of particles to obtain a correlation between light attenuation and bed voidage by linear fitting. For each voidage measurement, the time interval and the number of data sampled were 0.005 s and 3000, respectively, and their averages were then adopted as experimental data.

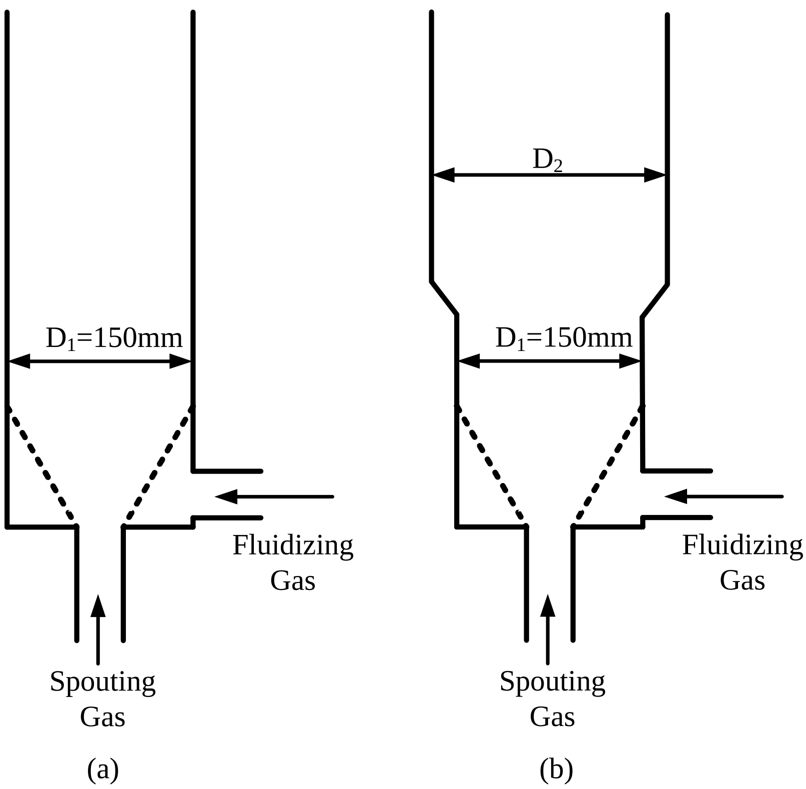

Fig. 1. Schematic of experimental setup

Table 1. Properties of bed materials

Material	d_p (mm)	ρ_b (kg/m^3)	ρ_p (kg/m^3)
Alumina #1	0.461	1076	1811
Alumina #2	0.253	1103	1206

RESULTS AND DISCUSSION

The flow regime maps for the three spout-fluid bed configurations were determined on the basis of visual observations, for a given bed height, by changing the spout gas velocity while keeping the fluidizing gas velocity constant or by adjusting the fluidizing gas velocity while maintaining the spouting gas velocity. For the combination of gas, solids, and vessel configuration employed in the present study, five flow regimes were visually observed:

- Fixed bed regime: The particles were loosely packed and immobile.
- Stable spouting regime: Stable fountain and regular particle circulation were formed.
- Unstable spouting regime: This regime was characterized by swirling and pulsation of the spout with time.
- Bubbling regime: In this regime, the momentum of the spout jet was not strong enough to penetrate through the bed. Bubbles formed instead in the central region when the fluidizing flow rate was low. When the fluidizing flow rate was high, bubbles also formed in the annular region.
- Slugging regimes. Bubbling was evolved to slugging when the fluidizing gas velocity or spouting gas velocity was further increased.

For the 0.461 mm diameter alumina particles with a bed height of 300 mm, the flow regime maps of the three spout-fluid beds are shown in Figs. 2-4, with the fluidizing gas velocity plotted on the ordinate axis and the spouting gas velocity plotted on the abscissa. Fig.5 compares the stable spouting regimes observed at the same bed height for the three spout-fluid bed configurations as shown in Figs 2-4. Clear expansion of the stable spouting region can be found for the spout-fluid beds with enlarged column, comparing with the conventional structure. It also can be seen from Fig. 5 that, as the diameter of the enlarged section increased from D_2=170 mm to 180 mm, the region of stable spouting regime expanded. Fig.6 compares the stable spouting regimes observed at bed height of 350 mm for the three configurations, similar results were obtained.

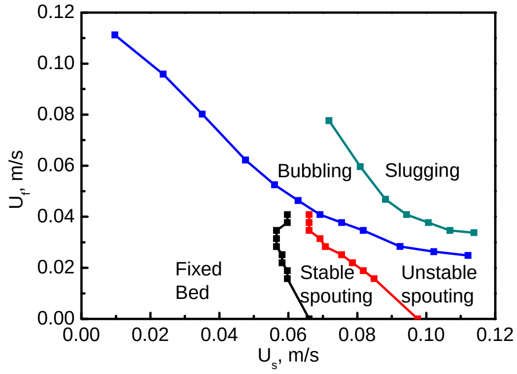

Fig. 2 Flow regime map for the conventional spout-fluid bed (Configure A) at H=300 mm, d_p=0.461 mm, D_1=150 mm

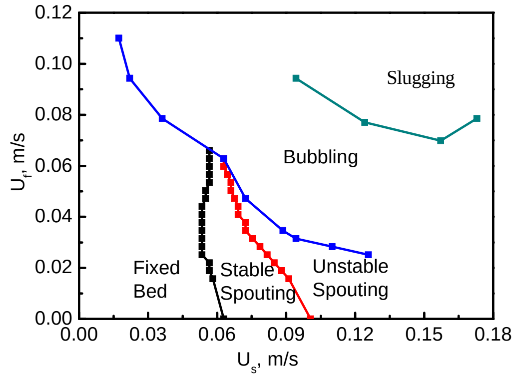

Fig. 3 Flow regime map for the spout-fluid bed with enlarged column (Configure B) at H=300 mm, d_p=0.461 mm, D_1=150 mm, D_2=170 mm

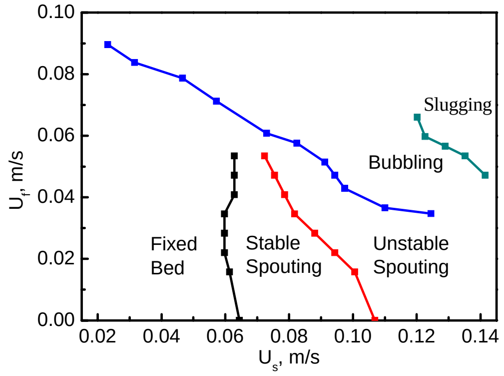

Fig. 4 Flow regime map for the spout-fluid bed with enlarged column (Configure C) at H=300 mm, d_p=0.461 mm, D_1=150 mm, D_2=180 mm

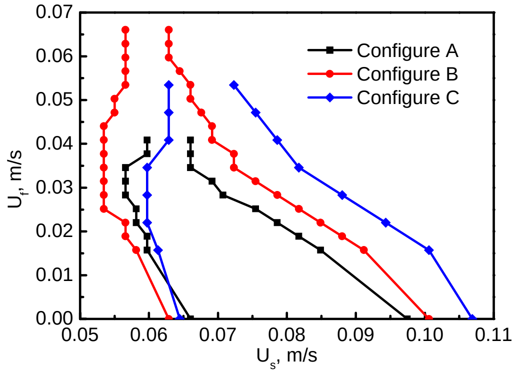

Fig. 5 Comparison of stable spouting regimes for the three spout-fluid bed configurations at H=300 mm, d_p=0.461 mm

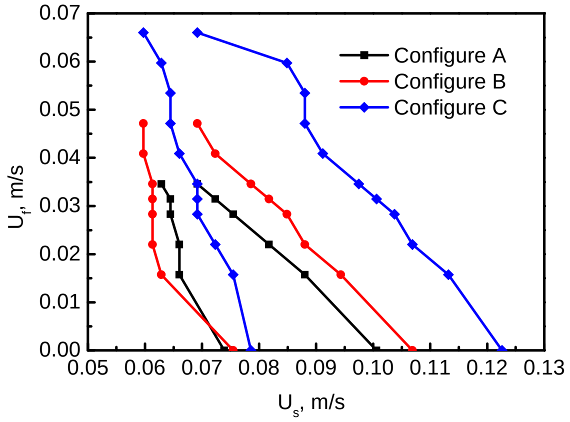

Fig. 6 Comparison of stable spouting regimes for the three spout-fluid bed configurations at H=350 mm, d_p=0.461 mm

The effect of the diameter expansion in the cylindrical section on the spout ability of the spout-fluid beds was investigated by a rough estimation of the axial distribution of gas flow rate in the annular region. For a short bed height L, the pressure drop ΔP was measured by pressure transducer as described in the experimental section. The gas velocity in the annular region U_a can be calculated according to Ergun equation (9):

$$\frac{\Delta P}{L}=\frac{150\mu}{\varphi_p^2 d_p^2}\frac{\left(1-\varepsilon^3\right)}{\varepsilon^3}U_a+\frac{1.75\rho_g}{\varphi_p d_p}\frac{1-\varepsilon^3}{\varepsilon^3}U_a{}^2 \tag{1}$$

Where ε is taken as average bed voidage of the annular region for the bed height of L, which was measured by the optical fiber system. The gas flow rate in the annular region Q_a can then be determined by:

$$Q_a=U_a\times\frac{\pi}{4}\left(D_c^2-D_s^2\right) \tag{2}$$

Where D_c is the bed diameter, D_s is the average spout diameter for bed height L which was determined by measuring the radial bed voidage profile.

The calculated axial distribution of the gas flow rate in the annular region for the three spout-fluid bed configurations were shown in Figs. 7-9, respectively. It can be seen that the expansion of the bed diameter results in a decrease in annular gas flow rate, which means that more gas was penetrated from the annular region into the spout region. The increase in spout gas flow rate increases the spout jet momentum flow rate, which leads to an increase of penetration ability of the spout jet (10, 11). This may explain why the range of stable spouting regime is extended for the new design with an enlarged column.

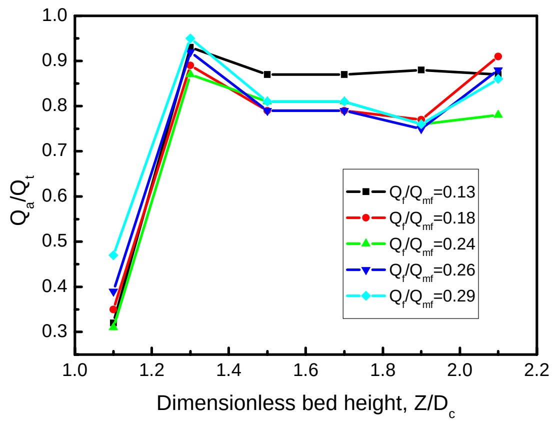

Fig. 7 Axial distribution of gas flow rate in the annular region in the conventional spout-fluid bed (Configure A) at H=350 mm, d_p=0.461 mm, Q_s=4.8 m^3/h

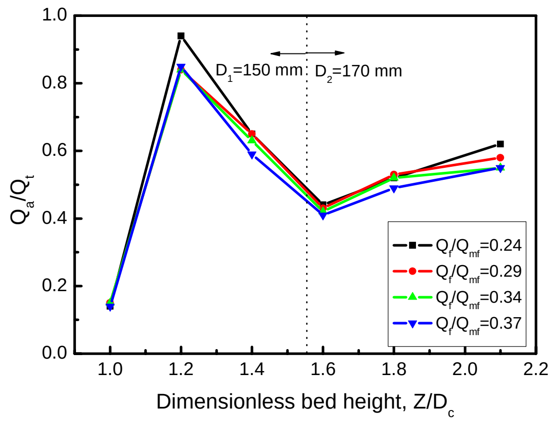

Fig. 8 Axial distribution of gas flow rate in the annular region in the spout-fluid bed with enlarged column (Configure B) at H=350 mm, d_p=0.461 mm, D_1=150 mm, D_2=170 mm, Q_s=4.6 m^3/h

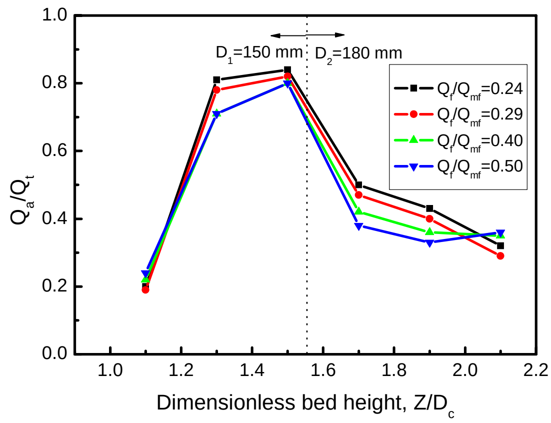

Fig. 9 Axial distribution of gas flow rate in the annular region in the spout-fluid bed with enlarged column (Configure C) at H=350 mm, d_p=0.461 mm, D_1=150 mm, D_2=180 mm, Q_s=5.0 m^3/h

CONCLUSION

In order to improve the spoutability for fine particles, a novel configuration of spout-fluid beds, i.e. a conical-cylindrical structure with an enlarged column section was proposed. Three spout-fluid beds were build, one is the traditional conical-cylindrical configuration (Configure A) with an inside diameter of 0.15 m. The other two spout-fluid beds have the same size and configuration of conical section with Configure A, but have an enlarged column section, whose inside diameters are 0.17 m and 0.18m, respectively. The flow regime maps of the three beds obtained by means of visual observation showed that the range of stable spouting regime of the new design was extended, indicating improved spoutability.

The axial distribution of the gas flow rate in the annular region for the three spout-fluid bed configurations was calculated. It can be seen that the expansion of the bed diameter results in an increases in the spout jet momentum flow rate, which leads to an increase of penetration ability of the spout jet. This may explain why the range of stable spouting regime is extended for the new design with an enlarged column.

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NOTATION

D_1	Normal bed diameter, mm
D_2	Enlarged bed diameter, mm
D_c	Bed diameter, mm
d_p	Particle diameter, mm
D_s	Spout diameter, mm
H	Bed height, m
U_f	Fluidizing gas velocity, m/s
U_s	Spouting gas velocity, m/s
Q_a	Gas flow rate in annular region, m^3/h
Q_f	Fluidizing gas flow rate, m^3/h
Q_{mf}	Minimum fluidizing gas flow rate, m^3/h
Q_t	Total gas flow rate, m^3/h
μ	Gas viscosity, Pa s
ρ_g	Gas density, kg/m^3
ρ_p	Particle density, kg/m^3
φ_p	Particle sphericity

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