WALL EFFECT OF A PACKED BED WITH PELLET PARTICLES

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ABSTRACT

Fluid flow profile is a dominate role in the performance of packed bed reactor. In small ratio of column-to-particle diameter, velocity pattern is strongly affected by voidage distribution, which depends on radial coordinate, flow rate and bed height. In this study, effects of voidage distribution to gas velocity profile in a packed bed with pellet particles was empirically investigated. Uniformity of local velocity at the top of the bed was clearly observed with decreasing of bed height and flow rate. For 400 mm of bed height, the measured velocities are a well fitting to Fahien and Stankovich model for any expected flow rate.

Keywords: chlorination, titanium tetrachloride, wall effect, flow distribution, packed bed.

1. INTRODUCTION

In titanium metallurgical process, titania ores are firstly chlorinated to produce titania tetrachloride [1]. In presence of carbon as reducing agents, titania reacted with chlorine gas at high temperature and this reaction can be performed in a fixed bed reactor. In order to improve contact of titania and carbon powder, these materials must be well mixed with a binder; and then pressed to form pellets [2]. The chlorination occurs in pellets surface. Therefore, flow distribution of chlorine gas in bed is one of important properties that affect to efficiency of titania chlorination.

Fixed beds have been applied in various processes such as distillation, gas-liquid absorption, fluid-solid chemical reaction, etc. Voidage is a significant parameter to describe the fluid flow and heat transfer in a bed [3-4]. However, the radial distribution of bed porosity varies from center to wall of container. The voidage at the wall is remarkably the largest, this is so-called “wall effect” or “chanelling”, caused a non-uniform flow pattern in the cross section. There are several of correlations for modelling of the voidage variations in a bed [5].

The fluid velocity tends to be larger at the wall due to the wall effect. Experimental results demonstrated that wall effect is ignored with ratio of column-to-particle diameter $D_c / d_p$ larger than 50:1 [3, 4, 6]. However, mathematical models for wall effect were established for packed beds with uniform spheres. Recently, Karthik G. M and Vivek V. Buwa [4] simulated fluid flow and heat transfer of methane stream in beds with various particle shapes using CFD.
The vortex flow around the cylindrical particles was more than the cone and truncated cone particles and were caused by increasing the pressure drop of fluid in the bed [4, 7]. Observation of wall effect for packed bed with non-uniform particles size is not available in the literature.

2. EXPERIMENTS

Titania slag and coke powder were mixed with starch as binder. Next, this mixture pressed through a hole in 18 mm of diameter to form cylindrical pellets with random length. These pellets were dried at 120 °C for 4 hours and stored then.

The bed (100 mm in diameter) was obtained by packing the pellets in a cylindrical container (Figure 1). High of the bed (H) can controlled by changing of air distributor position (up or down). Air flow was charged from bottom of the container using an air blower with an expected flow rate. Float flow meter (F) was used to measure total air flow and all experiments were performed in 25 °C.

Air velocity at the top of the bed was measured by located thermal flow meter (L) in various sites (1, 2, 3, 4 and 5). Particularly, distances from sites to center (r) are 0, \( R/2 \), \( R/\sqrt{2} \), \( R\sqrt{3}/2 \) and 0.95R. Size of 150 pellet was determined by Vernier Calliper for characterization of size distribution. The void fraction was measured using the imbibition method [8]. OriginPro 2017 software was used for curve fitting of experimental database.

3. RESULTS AND DISCUSSION

3.1. Characterization of pellet bed

Length of pellets is one of factor that affects on voidage of the bed. It assumed that all of pellets are uniform in outside diameter. Length of the prepared pellets is in wide arrange from 10 to 55 mm. The volume distribution shows the particles in a given size range by percentage of the total volume and presents in Figure 2. It can be clearly seen that the pellets in 15–40 mm of length, its proportion is above 85 % of total volume, are more dominant than the others. The
average particle size $d_{p, mm}$ was defined by equation: 

$$d_p = \frac{1}{150} \sum_{i=1}^{150} d_{ep_i}$$

(where, $n = 150$ pellets and $d_{ep}$ is volume-equivalent sphere diameter). The calculated particle size is 23.2 mm.

Various particle size cause a difficulty for models application to determine voidage of a bed. Mean voidage of a pellet bed can established by following equation [9] and the obtained result is 0.443.

$$\varepsilon_b = \frac{1.703 \left( \frac{D_i}{d_p} + 0.611 \right)^2 + 0.373}{D_i / d_p}$$

In the order hand, voidage of pellet bed was experimentally found to be 0.437. The empirical and predicted voidage are similar in comparison.

Local flow velocity of gas through a bed varies in the radial distribution in the packed bed and this velocity depents upon the local voidage [7]. Therefore, quanlitative nessecery of local voidage need to be clear in knowledge.

Using the proposed relation by Arno de Klerk [10], radial voidage variation was predicted and expressed in Figure 3. Both the oscillatory nature and damping of the voidage variations is observed. However, wall effect effectively impact on local voidage over the cross section of the bed due to low aspect ratio $D_i / d_p \approx 4.3$. In order to exhibit flow distribution as a function of voidage, the individual voidage at sites No. 1, 2, 3, 4 and 5 were calculated to be 0.4366, 0.637, 0.256, 0.448 and 0.798, respectively.
3.2. Flow distribution

In order to know the effect of wall effect, local velocity at expected locations were measured in various height of bed and flow rate. Experimental results shown that the local velocity distribution were affected by voidage, indicated in dimensionless radial coordinate (Fig. 4). Next to the wall, where the velocity is significantly higher than the mean. This behavior evidenced the role of wall effect on flow distribution in the packed bed. The non-uniform velocity profile was reduced with small total flow rate.

In the high bed (H = 400 mm and H = 200 mm), local velocity and voidage variation are similar. However, this agreement is broken in the short bed (H = 50 mm and H = 20 mm). As this consequence, the height of bed and flow rate need to be reduced to obtain an equable velocity profile.

Radial velocity can be expressed by Fahien and Stankovich equation, which is shown in brief relation concerning with radial coordinate: $u = a + b.x^c - c.x^e$. The measured velocities were fitted to this model. It considers that the column radius, $R_c$, of the bed was replaced to the hydraulic radius, $R_h = \frac{\varepsilon D}{6(1-\varepsilon)}$. The obtained parameters were summarized and presented in following table.

| H, mm  | Flow rate, L.min$^{-1}$ | $a$  | $b$  | $c$  | $\alpha$ | $\beta$ | $R^2$  |
|-------|-------------------------|------|------|------|-----------|---------|-------|
| 400   | 0.6                     | 0.21 | -52.4| 52.5 | 2.10$^{-3}$| 3.64×10$^{-5}$ | 0.929  |
|       | 1.0                     | 0.45 | -79.56| 79.93| 4.10$^{-3}$| 3.57×10$^{-5}$ | 0.930  |
|       | 2.0                     | 0.38 | -97.88| 98.89| 6×10$^{-3}$ | 3.56×10$^{-5}$ | 0.933  |
| 200   | 0.6                     | 0.16 | 26.22| -26.04| 10×10$^{-5}$ | 3.76×10$^{-3}$ | 0.562  |
|       | 1.0                     | 0.32 | 51.78| -51.37| 2×10$^{-5}$ | 5.5×10$^{-3}$ | 0.496  |
|       | 2.0                     | 0.61 | 33.31| -32.47| 63×10$^{-5}$ | 10.3×10$^{-3}$ | 0.546  |
Based on the obtained velocities from the 400 mm of bed height, the fitting of Fahien and Stankovich model was in good compatibility, cases else are opposite. Velocity related to void fraction as a function. However, there is large oscillation of voidage in the short bed [11]. Therefore, the Fahien and Stankovich model is useful for simulation of the high bed. For a packed bed reactor, radial uniformity of velocity distribution is once of important parameters that affect to reaction efficiency.

4. CONCLUSION

In packed bed with low column-to-particle diameter ratio, wall effect must be considered to voidage and velocity characterization. Structure of pellet bed was exhibited by voidage that affected on velocity pattern. Radial velocity oscillately varied in the similarity of voidage variation. It found that radial velocity tend to uniformity with reducing of flow rate and bed height. Parameters in the Fahien and Stankovich model was established by fitting with experimental results in 400 mm of bed height. However, the model is not suitable for description of velocity profile in shorter bed height.

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NOMENCLATURE

- $a$, $b$, $c$: constants
- $D_c$: column diameter (mm)
- $d_p$: particle diameter (mm)
- $d_{eq}$: volume-equivalent sphere diameter (mm)
- $R$: correlation coefficient (-)
- $r$: radius (mm)
- $R_h$: hydraulic radius (mm)
- $x = \frac{r}{R_h}$: dimensionless radial coordinate (-)
- $u$: velocity (m/s)

Greenk symbols

- $\alpha$, $\beta$: exponential coefficients (-)

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