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Behavior of chitosan gel beads in a fluidized bed reactor

[1]Hanieh M. Gholizadeh, [2]Hoda Khesali, [3]Samaneh Sanjari, [4]Farzaneh Vahabzadeh

Chemical Engineering Department, Food Engineering and Biotechnology Group, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran

h_m.gholizadeh@aut.ac.ir

Abstract

Chitosan as natural and biodegradable biopolymer has attracted considerable attentions because of its commercial applications in many different industrial fields and the reports mainly have focused on the cell immobilization subject. Hydrodynamic properties of solid particles in a liquid suspension are important in design and control of the reactor. The aim of the present work was to study hydrodynamic behavior of chitosan beads in a liquid-solid fluidized bed reactor (FBR). With considering the relationships between the three forces of gravity, buoyancy and drag acting on moveable particles in liquid phase, terminal settling velocity ($U_{t,s}$) and drag coefficient ($C_{D,s}$) as usual fluidization data were calculated for chitosan gel beads using appropriate mathematical expressions (i.e. bulk density of fluidized suspension affects particles buoyancy). Further experiments were performed to quantitatively determine the dependency of superficial liquid velocity on bed expansion (a measure of fluidized bed porosity). The minimum fluidization velocity (U_{mf}, as a measure of fluidization onset and the particles being fluidized) also was measured and data prediction was confirmed using Ergun equation in which, Reynolds number for start of the fluidization has been defined in relation to Archimedes number, indicative of fluidized bed characteristics. Additionally, the results of $U_{t,s}$ were discussed in terms of operative friction force (particle-particle, particle-wall).

Keywords: Chitosan gel beads, Fluidized bed reactor, Hydrodynamics.

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[1]Master’s student

[2]Research assistant

[3]Assistant professor

[4]Professor

1. Introduction

Transformation of fine solid particles in a gas or liquid stream, into a fluidlike state is the main operation in a FBR. The smooth, liquidlike flow of solid particles in FBRs leads to continuous control and ease of handling of the operations. Also the rapid mixing of fluidized solid particles contributes to nearly isothermal conditions throughout the reactor and as a result the operation can be controlled simply and reliably. Liquid-solid fluidization has received much attention for its utilization in various process industries such as food technology, biochemical processing, and water treatment. As the fluid flow upward through the bed varies, different fluidization regimes are observed (Fig. 1). At low flow rates, the fluid moves slowly through the void spaces between particles, thereby the solid particles stay stationary (Fig.1a). At a higher fluid flow, a point is reached when the drag and buoyancy forces between a particle and the fluid counterbalances the weight of the particle (Fig. 1b, d). The superficial liquid velocity at which the bed is just fluidized, is known as the minimum fluidization velocity. Increasing the fluid velocity, in liquid-solid systems, leads to progressive expansion of the bed and no large-scale bubbling or heterogeneity (Fig. 1c) [1].

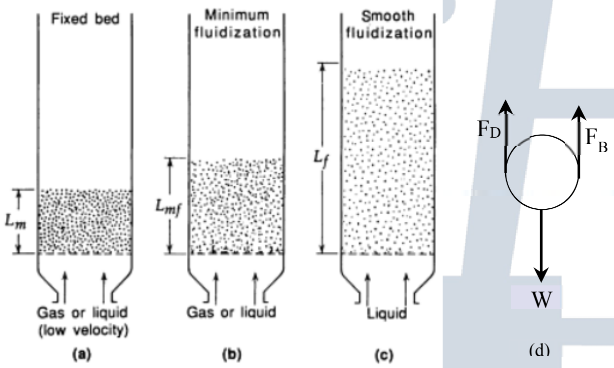

Fig. 1. (a, b, c): Different fluidization regimes at various fluid flows (Kunii and Levenspiel, 1991),

(d): Drag (F_D), buoyancy (F_B) and gravitational (W) Forces acting on a fluidized particle

Investigation of the hydrodynamic behavior of fluidized particles is essential in order to control the operating conditions of FBRs. For instance, the amount of minimum fluidization velocity for any kind of particles informs the operator of the minimum fluid velocity needed to keep the bed of particles fluidized.

Chitosan is a natural nontoxic biopolymer derived by deacetylation of chitin, which is an abundant polysaccharide in nature. Chitosan biopolymer matrix has been used as the entrapment material in many cell immobilization studies [2].

In present work some hydrodynamic characteristics of fluidized chitosan gel beads in a liquid-solid FBR are studied. Drag coefficient, minimum fluidization velocity and bed expansion are measured and Ergun equation is used to predict the amount of minimum fluidization velocity [3].

2. Materials and Methods

2.1. Preparation of Chitosan Gel Beads

Chitosan solution (2%, w/v) was prepared by dissolving chitosan powder in the aqueous solution of acetic acid (2%, v/v). The mixture was dropped into sodium tripolyphosphate (TPP) solution (1%, w/v) through a syringe needle and gel beads of 1.8 mm diameter were obtained. The density of gel beads was determined by dividing the average weight of particles by the volume of a particle.

$$\rho_p = \frac{m_{avg}}{\frac{\pi}{6} d_p^3} \qquad (1)$$

2.2. Configuration of the Liquid- Solid FBR

Figure 3 illustrates the FBR constructed and applied for fluidization experiments. The FBR consisted of a jacketed glass column with diameter and height of 1.5 and 12 cm respectively. Temperature was controlled at 20ºC by a recirculating water bath. Water, as the liquid phase, was pumped upward through the bed by a peristaltic pump. A perforated screen was located at the top of the reactor to prevent the elutriation of fluidized gel beads at high liquid velocities.

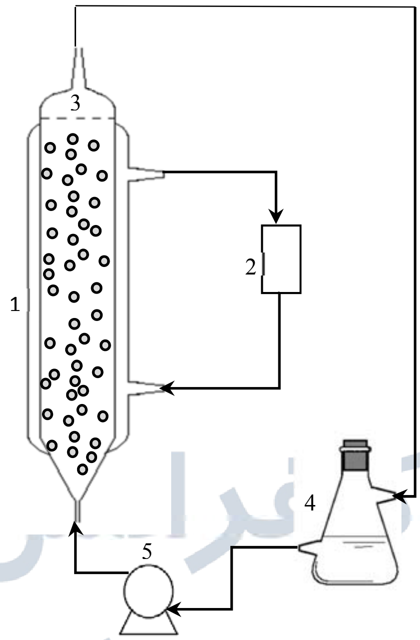

Fig. 3. Schematic diagram of the apparatus for the liquid-solid fluidization: (1) jacketed FBR column, (2) recirculating water bath, (3) perforated plate, (4) liquid reservoir, (5) peristaltic pump.

2.3. Bed Expansion

According to Sarrouh et al. [4] fluidized bed expansion is defined as:

$$\varepsilon = \frac{V_b - V_p}{V_b} \qquad (2)$$

Total volume of the gel beads (V_p) was determined by measuring the volume change when the beads were added to a graduated cylinder containing a specific volume of water and (V_b) was the fluidized bed volume.

Thereby, fluidized bed expansion at different liquid velocities was calculated by measuring the height of fluidized bed of chitosan gel beads in the FBR.

2.4. Minimum Fluidization Velocity

The minimum upward fluid velocity needed to keep the particles fluidized is known as the minimum fluidization velocity. In order to measure this significant parameter gel beads were first fully fluidized throughout the FBR. Then the liquid flow rate was gradually reduced till the gel beads settle and form a packed bed. By increasing the liquid flow rate, variation of the bed height was recorded. The liquid flow rate at which the bed height just started changing was considered as the apparent minimum fluidization velocity ($U_{mf,app}$). According to Wu et al. [3] $U_{mf,app}$ was determined at a point that a sharp change was observed in the slope of the relationship between the liquid superficial velocity and bed expansion (fig. 4).

2.5. Terminal Settling Velocity and Drag Coefficient

Drag coefficient, which represents the amount of force needed to keep a particle suspended in a liquid [4], is defined as:

$$C_{D,S} = \frac{4(\rho_p - \rho_f)gd_p}{3\rho_f U_{t\infty,s}^2} \qquad (3)$$

The equation above is obtained when the sum of all vertical forces acting on a suspended sphere is zero. The force of gravity on the solid acts in the direction of fall, and the buoyancy and drag forces act in the opposite direction (Fig. 2). At the aforementioned steady state point the falling sphere reaches a constant velocity, known as the terminal settling velocity. In order to determine the terminal settling velocity of chitosan gel beads, a single bead was let to descent through a segment in the middle of the reactor and 1 cm away from the top and bottom of the reactor to avoid end effect on particle motion.

Since in laboratory-scale reactors wall effects, which is the friction due to the walls' surface area, is significant, the terminal settling velocity of a sphere in an infinite fluid ($U_{t\infty,s}$), where the wall effects are neglected, is calculated using eq. 4.

$$\frac{U_{t,s}}{U_{t\infty,s}} = \left(\frac{1 - \frac{d_p}{D}}{1 - \frac{0.475\, d_p}{D}}\right)^4 \qquad (4)$$

The equation above is applied when the fluid flow is in the laminar regime [3, 4].

3. Results and Discussion

3.1. Bed Expansion and Minimum Fluidization Velocity

The influence of liquid superficial velocity on the bed expansion is shown in Fig. 4. The breakpoint in this log-log graph represents the onset of fluidization and corresponding liquid superficial velocity is considered as the apparent minimum fluidization velocity ($U_{mf,\,app}$).

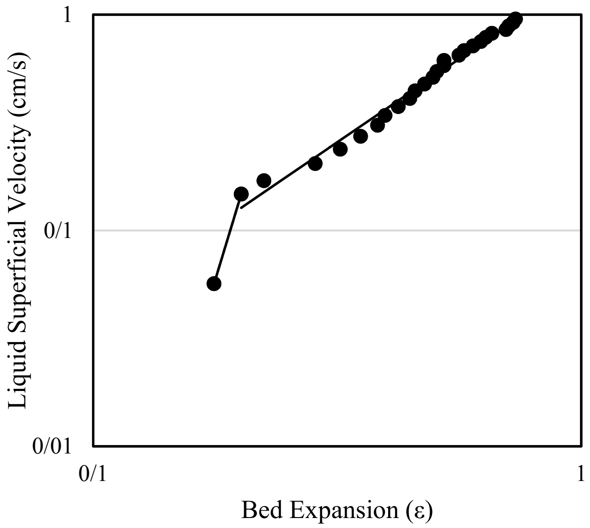

Figure 4. Liquid superficial velocity as a function of bed expansion for chitosan gel beads.

The predicted amount of minimum fluidization velocity was also calculated using Ergun equation (eq. 5) [3, 4].

$$\frac{1.75}{\varepsilon_{mf}^{3}.\, \emptyset_s} Re_{mf}^{2} + \frac{150(1-\varepsilon_{mf})}{\varepsilon_{mf}^{3}.\, \emptyset_s{}^{2}} Re_{mf} = A_r \qquad (5)$$

$$A_r = \frac{\rho_f.\, d_p^3.\, (\rho_p - \rho_f).\, g}{\mu_f^2} \qquad (6)$$

Since the gel beads were spherical, the sphericity (Φ_s) in eq. 5 was assumed to be one. The 18% relative error (eq. 7) between the measured and predicted values for minimum fluidization velocity (Table 1) indicated suitable prediction of U_{mf} for fluidized chitosan beads by Erqun equation according to similar reports for PVA gel beads [3].

$$\text{Relative error} = \frac{|\text{Value}_{exp} - \text{Value}_{cal}|}{\text{Value}_{exp}} \times 100 \qquad (7)$$

Table 1. Physical and hydrodynamic characteristics of chitosan gel beads

d_p (cm)	ρ_p (g/cm³)	$C_{D,s}$	$U_{t,s}$ (cm/s)	$U_{t\infty,s}$ (cm/s)	$U_{mf,\,app}$ (cm/s)	$U_{mf,\,pred}$ (cm/s)
0.18	1.516	19.75	1.88	2.48	0.1216	0.0996

3.2. Terminal Settling Velocity and Drag Coefficient

The difference between amounts of $U_{t,s}$ and $U_{t\infty,s}$ (Table 1) can indicate the presence of friction forces in the reactor. Wall effects depend on the particle-to-reactor diameter ratio and can be highly significant for laboratory-scale experiments and using particles with larger diameters can intensify these effects [3, 4, 5].

The estimated amount for $C_{D,s}$ represents the force needed to keep the particles fluidized [2008] and is related to the roughness and surface properties of gel beads[6].

4. Conclusions

Some hydrodynamic characteristics of chitosan gel beads were evaluated in a liquid-solid FBR. Bed expansion, minimum fluidization velocity, terminal settling velocity and drag coefficient were measured and Ergun equation was applied to predict the minimum fluidization velocity and the obtained result was quite reasonable according to similar previous studies on PVA gel beads [3].

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