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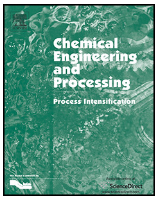

The influence of surface hydrophobicity in fluidization of ultrafine Al_2O_3 particles

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ABSTRACT

A new approach is hereby presented to study the influence of surface properties on ultrafine alumina (Al_2O_3) particles towards a fluidized performance by changing the ultrafine particles (Al_2O_3) surface hydrophobic degree. A number of variables that affects fluidization performance of ultrafine particles (Al_2O_3), including hydrophobicity has been studied. The minimum full fluidization velocities (U_{mff}), average bed pressure drop (ΔP_a), standard deviation in pressure drop (σ_p) and so on, has been found to depend on the hydrophobic degree, which is a function of the ultrafine particles (Al_2O_3) surface properties. After treatment of the ultrafine particles (Al_2O_3) with a surfactant, the liquid-solid contact angle on the ultrafine particles (Al_2O_3) raises, thus changing the interaction between the ultrafine particles (Al_2O_3) and also between the ultrafine particles (Al_2O_3) with the micro-fluidized bed wall surface. Furthermore, some changes in important parameters such as particle size (simple agglomerate size), bulk density, flow function plots, maximum wall friction angle, BET parameters and so on were also evaluated. The fluidization of ultrafine particles is attractive, if the interaction forces between the ultrafine particles (Al_2O_3) and also between the ultrafine particles (Al_2O_3) with the micro-fluidized bed wall surface can be artificially controlled. Moreover, it is possible to achieve a better fluidization performance on the ultrafine particles (Al_2O_3). However, more investigation is required to improve the fluidization performance of the ultrafine particles.

1. Introduction

With the rapid growth of powder applications in industry, fluidization processes is widely used for its good mixing and continuous handling ability. Therefore, powder fluidization has become more and more important. The quality of fluidization is strongly related to physical properties of the powder, e.g. size and density, and also their surface characteristics. With respect to fluidizing characteristics, particles are classified into four groups (C, A, B, and D) by Geldart [1]. Geldart group C particles, which are also called ultrafine particles in this paper, usually show very poor fluidization performance.

But with the deepening in research specific to this area, some kinds of ultrafine particles such as WC (tungsten carbide) [2], Ni, Si_3N_4, SiC, Al_2O_3, TiO_2 [3] and Cu/Al_2O_3 aerogel [4] have been reported to achieve smooth fluidization in agglomerate bubbling fluidization (ABF) or agglomerate particulate fluidization (APF) behavior respectively [5]. Subsequently Valverde and Castellanos described solid-like to fluid-like to elutriation (SFE) behavior and solid-like to fluid-like to bubbling (SFB) behavior to further improve the fluidizing behavior in classical Geldart type C particles [6].

The above development notes that it is possible to achieve ultrafine particles fluidized as agglomerates. The high surface-to-volume ratio and the small distance between ultrafine particles cause strong cohesive forces between them, which easily lead to extreme agglomerates. If the superficial gas velocity in fluidization process is high enough to make the agglomerates break, that will cause entrainment far beyond terminal velocity of the single ultrafine particles.

The most basic and common forces [7] between the ultrafine particles are: van der waals, electrostatic attraction, liquid bridge and solid bridge force. In addition there are forces between surface active point and mechanical meshing forces between the concave and convex parts on the rough surface. In general, air atmosphere intra-particle cohesion mainly originates from liquid bridge force that may be ten times or several times of the van der waals force (Fig. 1). In very dry air atmosphere (liquid bridge force does not exist in that case), intra-particle cohesion is mainly produced by van der waals force. Moreover, the electrostatic force between

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Nomenclature

r_1	Radius of curvature of neck of liquid bridge between particles (m)
σ	Surface tension of liquid ($N\,m^{-1}$)
Δp	Pressure difference across gas-liquid interface (Pa)
A	Hamaker constant, dimensionless
d	Particle radius (m)
h	Distance between particles (m)
W_s	Mass of particles in bed (kg)
g	Contact acceleration of gravity ($m\,s^{-2}$)
A_T	Cross-sectional area of bed (m^2)

ultrafine particles is much smaller. Thus, the most important forces between ultrafine particles are: the liquid bridge and the van der waals forces.

According to conventional theory explanation [8], liquid bridge force (F_{LB}) is dominated by surface tension (F_{ST}), and pressure difference (F_{DP}) between the inside and outside of the bridge (Eq. (1)). From this equation and Fig. 2 it can be shown that the liquid bridge force (F_{LB}) is a function of the bridge volume. With the increase in bridge volume, the forces between particles become greater and the separation distances before the bonds rupture become greater [9].

$$F_{LB} = F_{ST} + F_{DP} = 2\pi r_1 \sigma + \Delta p \pi {r_1}^2 \tag{1}$$

The van der waals force (F_{vdw}) [10] is an omnipresent attraction between particles (Fig. 3), in the scope of action about 1 nm. The independent particles composed of a large number of molecules, though the van der waals force is weak. The synergistic van der waals forces play a significant role in the range of 100 nm, meanwhile for solids the closest contact distance is 0.4 nm. When there is no water molecules on the particle surfaces, van der waals force becomes particularly important in the dominance of interparticle cohesion. From Eq. (2), it can be shown that when the particle radius and distance are fixed, van der waals force (F_{vdw}) is a function of the Hamaker constant A, which has the variation law [11] of metal > nonmetal > polymer.

$$F_{vdw} = Ad/24\,h^2 \tag{2}$$

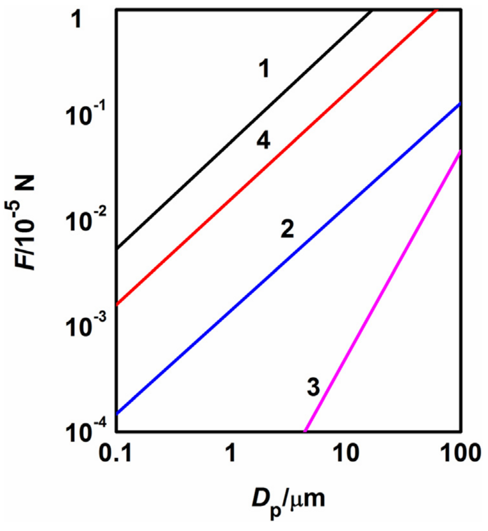

Fig. 1. Relationship between particle force and particle size [7]: 1. Liquid bridge force 2. Electrostatic force of conductor particles 3. Electrostatic force of insulator particles 4. Van der waals force.

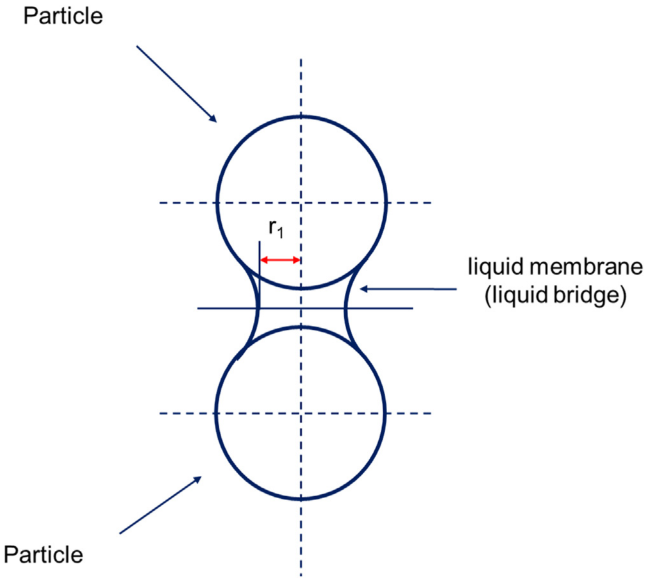

Fig. 2. The liquid bridge force model between the particles.

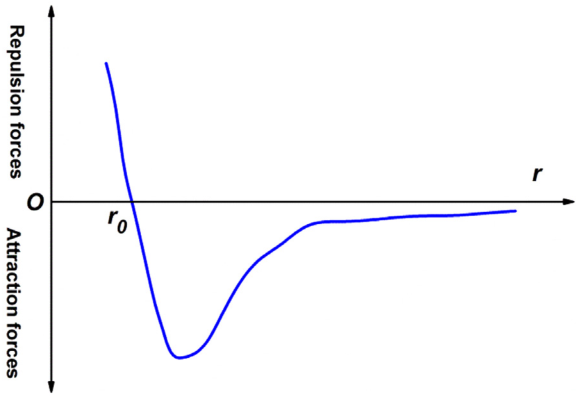

Fig. 3. The van der waals force between the particles.

It is known from Es. (1) and (2) that both the liquid bridge force (F_{LB}) and the van der waals force (F_{vdw}) are influenced by the particle surface hydrophobicity, which can affect the value of r_1 in the liquid bridge force (F_{LB}) and the Hamaker constant (A) in the van der waals force (F_{vdw}). Therefore, it is important to examine how hydrophobicity changes on the surface of ultrafine particles can affect the most important forces between the ultrafine particles, such as the liquid bridge and the van der waals forces, and then study the influence of that on fluidization performance of ultrafine particles.

2. Experimental

2.1. Hydrophobic treatment approach of the Al_2O_3

Scheme 1 shows the treatment approach for preparation of the hydrophobic Al_2O_3. The surfactant of sodium dodecyl sulfate (SDS) was coated on Al_2O_3 to obtain a hydrophobic Al_2O_3 in order to make the surface of the Al_2O_3 into hydrophobic. After treatment of the surfactant, the liquid-solid contact angle of the particles raises (from 12° to 36°, Scheme 1). Given that the surfactant treated particles show hydrophobicity, this property maybe advantageous for the fluidization performance.