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Aleš SLÍVA*, Jiří ZEGZULKA**

INTERPARTICLE FORCES OF POWDER PARTICLES AND THEIR COATING PROCESS

INTERPARTIKULÁRNÍ SÍLY PRÁŠKOVÝCH ČÁSTIC A JEJICH POVRCHOVÁ MODIFIKACE

Abstract

Coating is a process, by which fine particles in nano-range are connected to a powder particle material. During the initial phases of coating, surface of powder particle material is sprinkled by nano-particles and thus a lot of powder material properties can be directed and changed especially. A lot of method of surface coatings processing are discovered via commercial devices, and also there are a lot of pioneer devices working without basic knowledge of coating mechanism in laboratory background. The main advantage of the coated material is the possibility to changing the basic properties e.g. wetability, conductivity, electric and electronic properties, rheological properties, flowability, magnetic properties etc. It has been observed that only a few percentages (%W) are enough to ensure a property change and a property direction.

In the paper, the coating mechanism and forces involved in coating processing are investigated and mathematical modeling of dry coating is initiated.

Abstrakt

Povrchová modifikace je proces, při kterém jemné částice v nano měřítku jsou spojovány k částicím práškového materiálu. V průběhu celého procesu povrchové modifikace je povrch práškového materiálu pokryt nano částicemi a to je příčinou, že mohou být řízeny a především změněny vlastnosti práškového materiálu. Celá řada metod nanášení povrchovou modifikací je již ve světě používána a realizuje se na komerčně vyráběných přístrojích. Také existuje celá řada amatérských zařízení pracujících bez větších znalostí povrchové modifikace v laboratorních podmínkách.

Hlavní výhoda povrchově modifikovaného materiálu je možnost změnit základní vlastnosti materiálu-voděodolnost, vodivost, elektrické a elektronické vlastnosti, reologické vlastnosti, tekutost, magnetické vlastnosti apod. Pouze několik procent hmotnosti jemného materiálu v nano měřítku stačí, aby mohly být vlastnosti práškového materiálu změněny a řízeny.

V příspěvku je prozkoumán mechanismus modifikace včetně působících sil při modifikačním procesu. Celý proces je popsán v rámci matematického modelování a následně objasněn a vysvětlen na několika partikulárních systémech .

1 INTRODUCTION

Powder is an assembly consisting of particles varied by size, shape, porosity, hardness, elasticity, etc. Therefore, its properties depend on a lot of factors, such as mechanical-physical properties (size distribution, shape, porosity and so on), environmental conditions (temperature, external pressure, moisture, etc.) and actual conditions among particulates (electrostatic and chemical changes, Van der Walls forces, mechanism of growth created agglomerates from individual particulates, etc.).

* doc. Ing. Ph.D., Institute of Transportation, Faculty of Mechanical Engineering, Laboratory of Bulk Materials, VŠB-Technical University of Ostrava, 17. listopadu 15, 708 33 Ostrava-Poruba, tel. (+420) 59 732 5110, e-mail ales.sliva@vsb.cz

** prof. Ing. CSc., Institute of Transportation, Faculty of Mechanical Engineering, Laboratory of Bulk Materials, VŠB-Technical University of Ostrava, 17. listopadu 15, 708 33 Ostrava-Poruba, tel. (+420) 59 732 5110, e-mail jiri.zegzulka@vsb.cz

These properties are often unpredictable and their dependence on a lot of factors mentioned above. By using surface modification various coating techniques, for example, a lot of difficulties changeable properties improved. Utilization of the "concept of microfabrication" is to many industrial fields, e.g. foods, cosmetics, dental materials, ceramics, cements, inks, detergents, metallurgy, pharmaceuticals, paintings, etc.

An essential property especially during storage, handling and processing of a particulate material is flowability in vessels, bunkers, and silos.

The flowability as a property influences the creation of falls, such an arching, piping, ratholing, sudden avalanching in a storage transport system. In addition, flowability more notably depends on environmental factors mentioned above and is often constantly changing so that the powder behavior is not often predictable.

Elimination of the phenomena, for example by using air pumps and vibrators for existing storage system, is mechanically very ineffective and time consuming. Moreover, these mechanical tools are often expensive and inefficient due to additional attachments to case these storage systems. Coating by a small amount of additive, and thereby decreasing the angle of internal friction, is one way of improvement flow properties of storage particulate materials. Although flow property improvement of a particulate material is achieved, issues such as the applicability for food industry and quantifying how much coating batch is necessary for optimal storage and transport conditions still remain.

2 COATING PROCESS EXPLAINED VIA HAMAKER CALCULATION FOR TWO BODY PARTICLE SYSTEM

Mutual inter-particle interactions can be expressed by the energy background via the total energy (V_t) of London-van Walls attractive energy (V_A), Coulomb electrostatic repulsive or attractive energy (V_E), and short-range Born repulsive energy [1] (V_B) by consideration of two size various particles of a sphere shape [1,7,11] (see Fig 1):

$$V_t = V_A + V_E + V_B \tag{1}$$

2.1 London-van der Walls energy V_A

The London-van der Walls energy of a powder particle with radius *a* and fine particle in nano-range is characterized by radius *b* given [1,2]

$$V_A = V_{A1,2} + V_{A2,2} \qquad (2),$$

where

$$V_{A1,2} = -\frac{A_{1,2}}{6}.\left[\frac{2ab}{D^2-(a+b)^2} + \frac{2ab}{D^2-(a-b)^2} + \ln\frac{D^2-(a+b)^2}{D^2-(a-b)^2}\right] \tag{3}$$

and

$$V_{A2,2} = -\frac{NA_{2,2}}{12}.\left[\left(1-\frac{b^2}{2D^2}\right).\ln\left(1-\frac{b^2}{D^2}\right)+\left(\sin^2\frac{\theta_0}{2}-\frac{b^2}{2D^2}\right)\ln\frac{\sin^2\frac{\theta_0}{2}}{\left|\sin^2\frac{\theta_0}{2}-\frac{b^2}{D^2}\right|}\right] \tag{4}$$

In equation (4) number of fine particles in nano-range is determined as [4]

$$N = x.\frac{\rho_{1,1}}{\rho_{2,2}}\left(\frac{a}{b}\right)^3 \qquad (5),$$

where x is the mass fraction of fine particles in nano-range, and $\rho_{1,1}$ denotes density and $\rho_{2,2}$ is density of powder particles.

The angle θ created between the center of the powder particle and the two centers fine particles in nano range (Fig. 1) is defined as

$$\theta_0 = \frac{2b + l'}{a + b + l} \tag{6},$$

where

l (l') is inter-particulate gap between powder and fine particle(s) in nano-range.

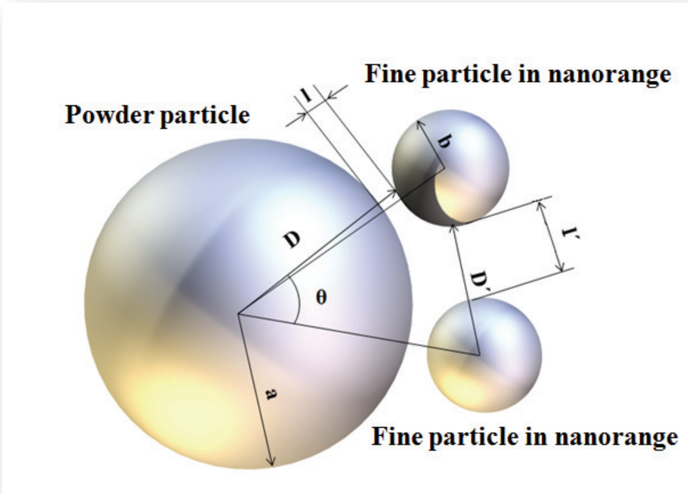

Fig. 1 Schematic model for calculation of the energy between powder particle and fine particle in nano-range in a vacuum/air [1,2]

Hamaker constants [3,6] for individual powder particle and fine particle system [10,11] modelled by particulates are either usually expressed by tabular data for individual materials with size distribution [5] or measured and compared with various measuring methods [7,8,9] used in laboratory observation conditions.

2.2 Electrostatic interactive energy V_E

The interactive electrostatic energy of powder particle$_{1,2}$ and fine particle$_{2,2}$ in nano-range is a function of electrostatic charge Q, the total number of fine particles N, distance between centers of powder and fine particle in nano-range $D=a+b+l$ is given [1,7,11]

$$V_E = V_{E1,2} + V_{E2,2}, \tag{7},$$

where

$$V_{E1,2} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{-Qq}{D} \tag{8}$$

and

$$V_{E2,2} = \frac{2\pi D^3 \sigma_e^2}{\varepsilon_0 N}\left(1 - \sin\frac{\theta_0}{2}\right) \tag{9}$$

ε_0 is dielectric constant of the vacuum and q is electric change of coating particle and charge per unit on the sphere becomes

$$\sigma_e = \frac{Nq}{4\pi D^2} \tag{10}$$

2.3 Born molecular interaction V_B

The Born repulsion involves molecular interaction to their electron-orbital overlapping, which acts at very short separations and affects the potential as well.

The Born repulsive energy is derived by following equitation [1,7,11]

$$V_B = \frac{\sqrt{A_{1,1}.A_{2,2}}.\sigma^6}{7560}.\left[\frac{8\left(\frac{ab}{a+b}\right)+l}{(2\frac{ab}{a+b}+l)^7} + \frac{6\left(\frac{ab}{a+b}\right)-l}{l^7}\right] \quad (11),$$

where

σ - collision parameter (dimension of length proper to the solids).

3 THEORETICAL TOTAL INTERPARTICLE ENERGY OF THE COATED MATERIALS

Total interparticle energy expressed by London van der Walls force, Born repulsion molecular interaction, and electrostatic energy for system of a cornstarch coated by 1% of 20 nm, 600 nm and 2 microns silica are depicted in Fig. 2.

Although values from Fig. 2 display theoretical results of interparticle result energies for the particular system, it is very easy to recognize difference between 20 nm, 600 nm and 2 microns coated cornstarch. A complete evaluation and interpretation of the theoretical results seems to be the important contribution to cornstarch coating of a 20 nm fumed silica in comparison with almost identical 600 nm and 2 microns coated cornstarch. Taking into account every coated silica curves, the curves approximate to zero energy level after a 10 Angstroms. The theoretical phenomenon explains energetic balance of fluidized materials due to more separation of coated particulates (coating effect). Flowability of the fluidized coated materials (Fig. 2) may be improved and silo falls (arching, piping, rat holing etc.) can be eliminated, too. The silo falls are typical for pure uncoated cornstarch, which is characterized by high Initial shear stress. The Initial shear stress is visible as very high value of the total energy of 6 Angström curve of the pure cornstarch in comparison with silica coated curves in Fig. 2.

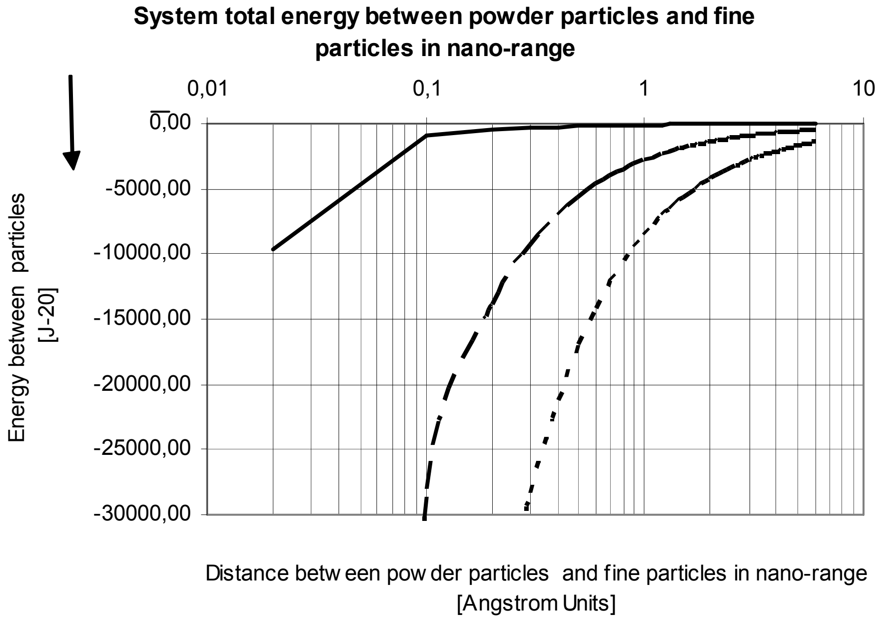

Fig. 2 Graph of the theoretical total interparticle energy of systems

(____ system: 14 microns cornstarch coated by 1% of 20 nm silica, ---- system: 14 microns cornstarch coated by 1% of 600 nm hydrophilic silica, ….. system: 14 microns cornstarch coated by 1% of 2 microns hydrophilic silica)

4 CONCLUSIONS

The equations (1-11) explain theoretical approach to interparticle interaction calculation, especially for coated material in a vacuum/air (system: powder particle Vs. fine particles in nano-range). The depicted Bergström's calculation [5] executes the endeavor to generalize the dependence for some inorganic material. Although the approach to Hamaker constant estimation on behalf of only three characteristics optical and frequency parameters has limited the refractive index, there is possibility to determine Hamaker constants for unknown material by knowing the parameter only. The Hamaker constant covers van der Walls interaction and explains very well the interparticle expression as one parameter, which characterizes the interparticle influence. Accurate estimations of the Hamaker constants are important for fine-particle investigations and phenomenon description.

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