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The importance of surface energy in the dispersion behaviour of talc particles in aqueous media

Laurence Galet [*], Carol Goalard, John Allan Dodds

Ecole des mines d'Albi-Carmaux, UMR CNRS 2392, Campus Jarlard 81013 Albi cedex 09, France

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ABSTRACT

The dispersion of powders in liquids is an operation used in many industries, which depends on parameters involving both the process (stirring power, temperature and reactor geometry) and the material (the powder, the liquid and the powder/liquid interface). Even though dispersion operations have been the object of several investigations, the importance of the various parameters and especially the physicochemical properties is rarely treated. This paper presents an experimental study of the kinetics of talc dispersion in water based on prior determination of powder properties (particle size, density, surface area and surface free energy), which are used to calculate the different work functions involved in dispersion (adhesion, immersion and spreading). Experiments are presented using an optical fibre sensor to determine the dispersion kinetics of talc in water as a function of stirring power and powder concentration. These results are found to correlate with the energy calculated to be required to cross the liquid–gas interface.

1. Introduction

The literature on dispersion is not extensive. Schubert [1] investigated the subject when considering the instantisation of powdered food products. The wetting of instant powdered milk was studied on the basis of parameters such as the effect of the fat content of the milk on the rate of wetting. The effect of agglomeration was also discussed and related to the change in the wetting characteristics. In previous papers, we have studied the dispersion behaviour of powders (cocoa and talc) and the influence of powder modifications by wet granulation on dispersion [2–4].

A paper published by Buckton [5] on the wetting of a powder by a liquid defined different aspects of the work involved. He divided the process of wetting an individual cubic particle into the following three stages: (1) Adhesion of the powder, which is related to the interaction between the two phases coming into contact. (2) Immersion where the powder particles crosses the vapour/liquid interface. (3) Spreading of the powder through the liquid, which is the detachment of the particle from the interface.

These considerations are used in the study reported here for which talc has been chosen because it is widely used in many industrial sectors such as paper, paints, ceramics, cosmetics and pharmaceutics. Moreover, talc is an insoluble and hydrophobic powder, which is hard to disperse in water. Three samples of talc with different particle sizes have been chosen in order to understand the influence of particle size and specific area on the kinetics of dispersion and above all on the powder/liquid interactions. After determination of the physical properties of these three talc samples, we present the experimental study of dispersion kinetics and examine influence of stirring power and powder concentration.

2. Materials and methods

2.1. Talc particles

Talc, chemical formula $Mg_3Si_4O_{10}(OH)_2$, is a hydrated magnesium sheet silicate with a lamellar structure. Fine talc powders with tight particle size distributions are generally made by jet milling using an integral turbo classifier [6]. As grinding can change the surface properties of particle we have used a single type of talc mined in France (Talc 00 from Talc de Luzenac, France) separated into size fractions by means of an Alpine 50 ATP turbo classifier. The particle size distributions of the talc powders obtained in this way have been determined using a Malvern Mastersizer 2000 (dry dispersion in air), Fig. 1. The true solid density of the powder was obtained using a Micrometrics AccuPyc 1330 helium pycnometer. The BET specific area was determined using a Micromeritics Asap 2010 with argon. Talc properties are collected in Table 1. A SEM picture of Talc 1 is shown in Fig. 2.

2.2. Surface free energy and work of dispersion

As mentioned in the Introduction, it is important to have very good data on the surface properties, and in particular the surface

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[*] Corresponding author.
E-mail address: laurence.galet@enstimac.fr (L. Galet).

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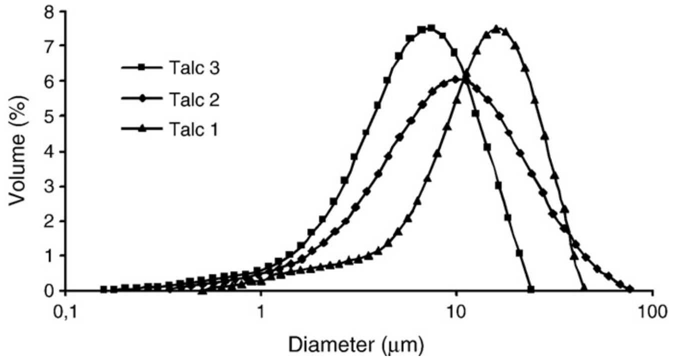

Fig. 1. Size distributions of the talc powders.

energy of a powder, to quantify the work necessary to wet the particles. The methods used for this were: Steven's immersion method, sessile drop measurements with an extrapolation using Zisman's method, capillary rise analysed using the Washburn equation, and dynamic vapour sorption (DVS). These methods have shown that the three samples of talc have the same surface energy values, confirming that the separation did not modify the surface properties of the talc [7].

We report here the results of dynamic contact angle measurements with pure water (performed with a tensiometer ILMS-GBX). The capillary rise method involves measuring the rate of penetration of liquid into a powder bed. The Poiseuille and Laplace equations are combined to form the Washburn equation:

$$\frac{m^2}{t} = C\frac{\rho^2\gamma\cos\theta}{2\eta} \tag{1}$$

where: m = mass of liquid (kg), t = time (s), C = constant (m^5), ρ = liquid density (kg m^{-3}), γ = liquid surface tension (J m^{-2}), θ = contact angle (°), η = viscosity (Pa s). The surface energies of the liquids used were measured at 20 °C. The liquid mass that penetrated the powder bed as a function of time was recorded using a Kruss K12 tensiometer. The value of the “constant C” is obtained by using a perfectly wetting liquid and the value of $\cos\theta$ determined from Eq. (1).

These contact angles are used to calculate the work of dispersion, consisting in the variation of the free energy between the final and the initial states of the talc particles (Fig. 3). Using the Young equation Eq. (2), the work of dispersion W_{dis} Eq. (4) depends on the surface tension of the liquid dispersion and the contact angle between the liquid and the solid. The values of θ and so with the work of dispersion, are identical for the three size of talc (Table 1).

$$\gamma_{\mathrm{SV}} = \gamma_{\mathrm{SL}} + \gamma_{\mathrm{LV}}\cos\theta \tag{2}$$

$$W_{\mathrm{dis}} = \gamma_{\mathrm{SL}} - \gamma_{\mathrm{SV}} \tag{3}$$

$$W_{\mathrm{dis}} = -\gamma_{\mathrm{LV}}\cos\theta \tag{4}$$

2.3. Measurement of dispersion kinetics

Table 1
Talc samples properties and talc/water interactions

Classifier speed (rpm)	$d(0.5)$ (µm)	Density (g/cm^3)	Surface area (m^2/g)	Contact angle (°±1)	Work of dispersion (mJ/m^2±1.3)
Talc 1 (7000)	13.1	2.79	3.1	88	−2,5
Talc 2 (9000)	8.7	2.79	4.5		
Talc 3 (11000)	5.9	2.79	5.2		

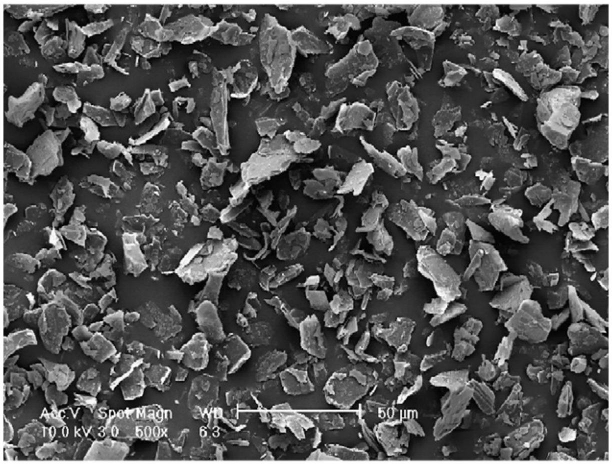

Fig. 2. SEM photograph of Talc 1.

The dispersion experiments of talc powder in water were performed in a 4 baffled stainless steel reactor (15 cm diameter) with a 6 cm diameter dispersion stirrer. A fibre optic sensor was used to measure the rate of dispersion of talc in water. This device was developed at Polytech'Marseille for the measurement of particle concentrations [8]. The technique is based upon the back-scattering of light by the particles. The fibre optic sensor comprises a bundle of seven fibres. The central fibre brings light from a LED source and the six other fibres are used to detect the backscattered light (Fig. 4). The fibre optic sensor is used in conjunction with a signal conditioner and a PC with Labview® data acquisition software (Fig. 5). The volume analysed by the sensor depends on the suspension concentration, 5 to 10 ml. Preliminary studies show that the position of the sensor in the reactor have no influence on a relative study of the dispersion kinetics. In our experiments the sensor was located 2 cm from the bottom of the reactor. The linearity of sensor response with solid concentration was validated and the sensor calibrated to determine the response to a given concentration of powder. The response when the powder is fully dispersed is required in order to be able to normalise results as fractional dispersion values. The calibration of the captor was therefore made at the maximum stirrer speed. The response obtained from the calibration curve for a given mass concentration powder is considered to be the maximum response for that concentration as the agitation power was at a maximum. This maximum response is referred to as R_∞. During the dispersion of the powder in a liquid, the response of the powder R is merely an arbitrary voltage and must be related to the concentration of dispersed particles if the dispersion profile is to be developed. The extent of dispersion, $X(t)$ is defined as:

$$X(t) = \frac{R(t)}{R_\infty} = \frac{C(t)}{C_\infty} \tag{5}$$

$$X(t) = A(1-\exp(-kt)) \tag{6}$$

$X(t)$ gives an extent of dispersion based on the response of the powder relative to the theoretical maximum response. The experimental curves can be fitted to a two parameter exponential model given in Eq. (6): were k (s^{-1}) represents the dispersion rate of the

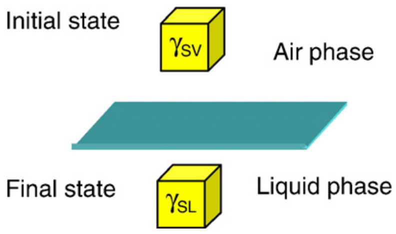

Fig. 3. The final stage of solid particle is characterised by γ_{SL}.