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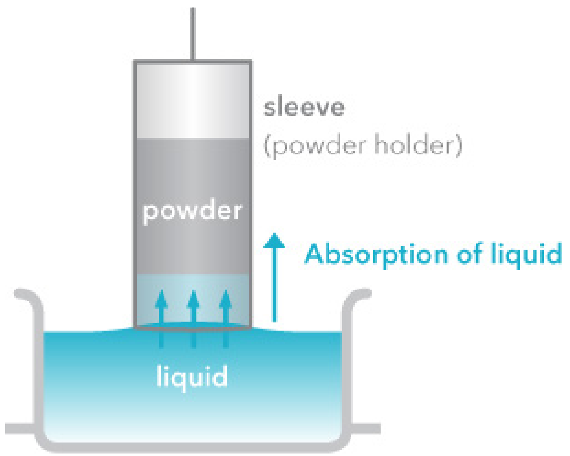
The Washburn method

This technology note reviews the Washburn method and how it can be utilized to study powder wettability.

Introduction

Direct contact angle measurements have become a standard experiment when dealing with planar solid surfaces or cylindrical materials, like fibers. Such direct approaches cannot be used on finely dispersed solid materials, like powders. Usually a method called capillary rise or Washburn method is utilized. The Washburn method can be done by using a force tensiometer and a special type of powder holder [1]. The measurement set up is shown in Figure 1. The powder holder, with small holes in the bottom, is immersed into the liquid and the amount of liquid absorbed into the powder bed is measured against time.



[Figure 1]: Schematic of the Washburn method

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The capillary rise method is based on the Poiseuille law related to the liquid flow through a capillary:

$$v = \frac{R_D^2}{8\eta}\frac{\Delta P}{l} \qquad (1)$$

In the equation (1), v is the kinetics of flow, RD the mean hydrodynamic radius of the capillary, η the viscosity of the liquid, l the length of the capillary and ΔP the pressure difference. ΔP can be expressed as a sum of a capillary pressure and a hydrostatic pressure. Thus equation (1) can be written:

$$\frac{dh}{dt} = \frac{R_D^2}{8\eta h}\left[\frac{2\gamma_l \cos\theta}{R_S} \pm \rho g h\right] \qquad (2)$$

where h is the liquid front height, g the gravitational constant, R_S the mean static radius of the capillary, and ρ the liquid density. Now if hydrostatic pressure is neglected and we suppose that $r = R_D^2/R_S$, integration of the equation (2) with boundary condition h=0 when t=0 gives:

$$h^2 = \frac{r\gamma_l \cos\theta}{2\eta} t \qquad (3)$$

Equation (3) is called Washburn equation. The porous bed is considered as a bundle of parallel capillaries of constant radius. The use of this equation would require a visual observation of the moving liquid front. Since this is much more difficult to do than measuring the gained weight, the weight w is related to the height in the cylinder by:

$$w = \varepsilon \rho \pi R^2 h \quad (4)$$

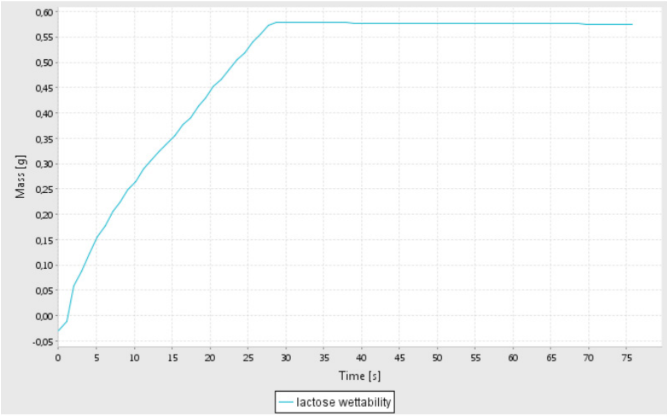
where ε is the porosity of the packed powder column, ρ the density of the liquid, and R the inner radius of the tube. Finally combining the equations (3) and (4):

$$w^2 = (r\varepsilon^2(\pi R^2)^2)\frac{\rho^2\gamma_l cos\theta}{2\eta}t \quad (5)$$

which leads to:

$$w^2 = c\,\frac{\rho^2\gamma_l cos\theta}{2\eta}t \quad (6)$$

Equation (6) is often referred as modified Washburn equation. The term c is a geometric factor and is constant as long as packing and the particle size remains similar [2]. It has to be experimentally determined to each type of packing and powder combination. Precise and accurate determination of the constant c is critical for the correct application of the Washburn equation. In practice, to solve the material constant the measurement has to be done first with the completely wetting liquid such as hexane, heptane or octane. The contact angle can thus be assumed to be zero (cos0 =1) and the material constant c can be calculated if the properties of the liquid are know. After definition of the material constant the contact angle measurement with the liquid of interested can be done. A powder packing method has to be repeatable and carefully controlled since it is not possible to measure the material constant and then re-use the same powder for actual contact angle measurement. A typical powder wettability curve is presented in Figure 2. Washburn method has also been utilized to study of other materials like fabrics [3], soil [4] and carbon fibers [5,6].



[Figure 2]: Typical curve obtained with the Washburn method.

References:

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