Evaluating mean particle size in concentrated dispersions

- Static Multiple Light Scattering (SMLS) -

GENERAL

Introduction

Particle size measurement in native dispersions is of high interest in a wide range of industries (e.g. food, health, chemical and pharmaceutical industries). Many techniques allow to achieve particle size measurements, but most will require measurement conditions such as shear stress (e.g. centrifugation or filtration) or dilutions (e.g. dynamic light scattering, laser diffraction or microscopy) that may alter the original state of the dispersion. Turbiscan technology based on Static Multiple Light Scattering (SMLS) allows to overcome these limitations by providing an evaluation of the particle size even at high concentration and without denaturing the sample. This note provides theoretical explanations of particle size evaluation with static multiple light scattering (SMLS) technique.

KEY **BENEFITS**

NO DILUTION

ANALYSIS AT REST

ACCURATE

Reference

Mengual, O., Meunier, G., Cayré, I., Puech, K., & Snabre, P. (1999). TURBISCAN MA 2000: multiple light scattering measurement for concentrated emulsion and suspension instability analysis. Talanta, 50(2), 445-456.

Reminder on the technique

A monochromatic infrared light source (wavelength λ=880nm) is propagating in a dispersion (particles dispersed in a continuous phase) contained in a cylindrical glass cell. Two sensors collect the light scattered by the particles in the dispersed phase.

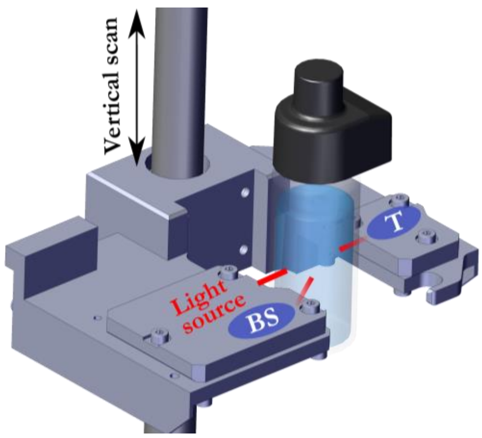

Figure 1: Schematic representation of the SMLS principle

One sensor is located at an angle of 0° from the incident light (i.e. in front of the source) and collect **the transmitted light T**. The second sensor is located at an angle of 135° from the incident direction and allows to collect the **backscattered light BS**.

The transmitted signal T is expressed by the **Lambert-Beer law**:

$$T = T_0 \exp\left(\frac{-2r_i}{l}\right) = T_0 \exp\left(\frac{-3r_i \phi Q_e(d)}{d}\right) \qquad (1)$$

With T_0 the transmitted signal of the continuous phase, l the mean free path (average distance travelled by a photon between two particles), r_i the internal radius of the cell, d the particle mean size, ϕ the volume fraction and Q_e the extinction efficiency.

Q_e depends on the particles size d, refractive indices n_p and n_f of the dispersed and continuous phases and the wavelength λ, and is calculated thanks to the **Mie theory.**

The **backscattered signal BS** is approximated by:

$$BS = \alpha \sqrt{\frac{1}{l^*}} + \beta = \alpha \sqrt{\frac{3\phi(1-g(d))Q_e(d)}{2d}} + \beta \qquad (2)$$

α and β are the gain and offset of the experimental setup which are defined during the manufacturing of the Turbiscan device.

The transport mean free path $l^* = l/\left(1 - g(d)\right)$ is the distance for which the photon direction is randomized, i.e. the distance travelled by the photon before it "forgets" its initial direction. It can be assimilated to the penetration distance of the light into the sample. l^* depends on g the asymmetry factor that quantifies the anisotropy of the light scattered by the particles.

As shown by equations (1) and (2), the transmitted T and backscattered BS signals are directly linked to the fundamental properties of the dispersed phase, i.e. **the volume fraction $\boldsymbol{\phi}$** and **mean size $\boldsymbol{d}$**. By knowing one of these dispersion properties (d or ϕ), the other one can be estimated (ϕ or d) thanks to root-finding algorithms.

Concentration dependence

Figure 2 shows the evolution of **T** and **BS** signals with the particle volume fraction ϕ for silica beads with diameter $d = 100nm$ in water.

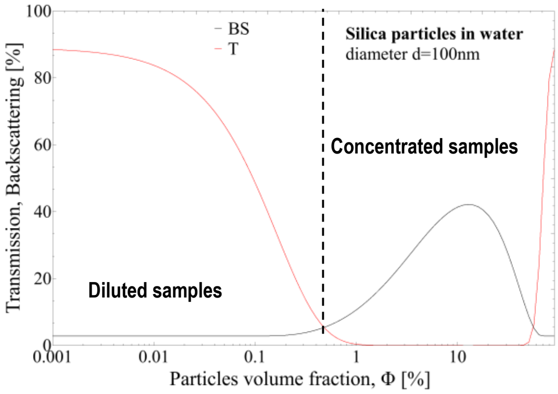

Figure 2 Variation of the T and BS signals with particles volume fraction ϕ for silica beads (d=100 nm) in water.

These signals are exploitable over the whole concentration range. Hence, SMLS provides a characterization of the dispersed phase for a wide range of concentration, typically from $\boldsymbol{\phi} = \mathbf{0.0001}\%$ to $\boldsymbol{\phi} = \mathbf{95}\%$ depending on the sample properties.

Size dependence

Figure 3 illustrates the dependence of both the transmitted T and backscattered BS signals with the mean particles size d for TiO_2 particles in water with a volume fraction fixed at 0.1%. When one signal (T or BS) is constant or null, the other one (BS or T) is sufficiently sensitive to estimate the mean particle size. Thus, with SMLS **particles size ranging from $\mathbf{10}\boldsymbol{nm}$ to $\mathbf{1000}\boldsymbol{\mu m}$** can be estimated**.**

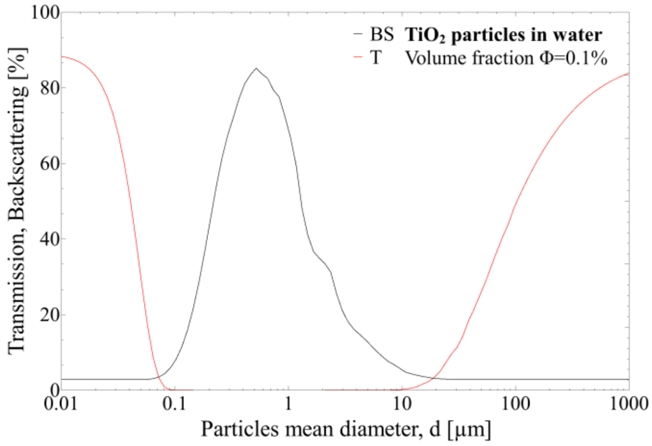

Figure 3: Variation of the T and BS signals with particles mean diameter d for TiO_2 particles in water.

CONCLUSION

The SMLS technique allows to estimate the particle size in a dispersion over a wide range of concentrations ($\boldsymbol{\phi} = \mathbf{0.0001}\%$ to $\boldsymbol{\phi} = \mathbf{95}\%$) and sizes ($\mathbf{10}\boldsymbol{nm}$ **to** $\mathbf{1000}\boldsymbol{\mu m}$) from scattered light measurements. This is possible thanks to the use of the transmitted signal for diluted dispersions and the backscattered signal for the concentrated ones. This method has already proved its interest and accuracy for various type of dispersions (emulsions, solid particles, bubbles…).