**Choosing the most Suitable Theory in Laser Diffraction**

**Mie or Fraunhofer?**

The inventor of Laser Particle Size Technology

**PARTICLE SIZE AND SHAPE ANALYZERS**

**Introduction**

Particle size analysis is based on the inversion of a diffusion matrix, the resolution of which is based on theories stemming from the equations of Maxwell.

The Fraunhofer approximation and the Mie theory enable particle size distributions between several tens of nanometres and several thousands of micrometres to be calculated.

The differences between these two models are explained in various ISO standards that serve as bases during particle size analyses.

**Description of the standards**

The reference standard for particle size analysis is the ISO 13320-1 Standard [1], which deals with the general principles of particle size analysis by laser diffraction.

In particular, the standard describes the measurement principle and the characteristics of the apparatus used, but also recommends the procedures to use for the preparation of the samples and sets the reference values for the repeatability and reproducibility measurements.

The ISO 9276 Standard Parts 1 to 5 is a description of the mathematical and statistical methods that enable the particle size distribution to be calculated.

**What is stated in the ISO 13320-1 Standard**

The ISO 13320-1 Standard recommends the use of the Mie and Fraunhofer theories for spherical particles. It is also recommended to adapt the concentration of the measurement medium in order to avoid the phenomenon of multi-diffusion by adjusting the concentration in order to separate the particles of at least 40 times the wavelength of the incident light.

The diagram shown in figure 1 enables the most suitable theory to be chosen as a function of the parameters available to the operator. If he or she does not know the refractive index of the material or if the size of the particles is above 50 µm, the user can use the Fraunhofer theory. In other cases, the Mie theory will give the best results.

**Figure 1**: Guide for choosing the most suitable theory as a function of the material

F and M correspond to the use of the Mie or Fraunhofer theories.

np/nm corresponds to the ratio of the refractive indices between the material and the solvent.
Influence of the choice of the theory on the appearance of the particle size distributions

Case of glass beads

In this example, glass beads with a diameter certified by the supplier (Whitehouse Scientific) were measured while applying the Mie and Fraunhofer theories.

The particle size distributions shown in figure 2 have a similar appearance whatever the theory applied.

However, when the Fraunhofer theory is used, we observe the presence of a population of particles, the size of which is between 1 and 5 µm. This population is not present when the Mie theory is used with a complex refractive index of the material equal to \( n = 1.529 - 0i \).

Direct observation of the sample by optical microscopy makes it possible to check for the presence or not of this population of particles. The captured images, an example of which is given in figure 3, were analysed using ExpertShape image analysis software developed by CILAS.

Observations made by optical microscopy on the sample of glass beads enabled the corresponding particle size distribution (figure 2) to be drawn. It is similar to that obtained when the Mie theory is applied.

The population present between 1 and 5 µm when the Fraunhofer theory is used thus has no physical reality. This population is uniquely generated by the limit of the model applied.

Figure 3: Optical microscopy photograph of glass beads (10x magnification)
Case of quartz particles

The quartz particles measured have an average diameter less than 50 µm. As may be observed in figures 4 and 5, the particle size distributions have a similar appearance whatever the mathematical model used.

For this type of particle, the choice of the theory applied has an influence on the position of the D10, D50 and D90 values. These values are systematically lower when the Mie theory is applied (table 1).

As indicated in the ISO 13320-1 Standard, the Fraunhofer approximation underestimates the populations of the smallest particles, the size of which is below 50 µm.

The use of the Mie theory then makes it possible to have relevant information on these populations and should be used in so far as the refractive indices of the material and the solvent are known.

The choice of the Fraunhofer theory for the small particles leads to a significant error of around 35% on the D50 value. An estimation of the refractive index enables this error to be limited.

<table>
<thead>
<tr>
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<th>D10 (µm)</th>
<th>D50 (µm)</th>
<th>D90 (µm)</th>
</tr>
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<tbody>
<tr>
<td>Mie</td>
<td>0.50</td>
<td>1.29</td>
<td>2.89</td>
</tr>
<tr>
<td>Fraunhofer</td>
<td>0.80</td>
<td>1.74</td>
<td>3.55</td>
</tr>
</tbody>
</table>

Table 1: Specific diameter values for quartz using the Mie and Fraunhofer theories

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Conclusions

The results of this document show, in the case of small or transparent particles, that the use of the Fraunhofer approximation leads to an error in the size measurement. The presence of populations that are actually absent or a shift in the particle size distribution towards larger particles are the main consequences of the limits of use of this model.

On the other hand, if the powder to be analysed is composed of several phases, of particles whose diameter is greater than 50 µm, or instead in the case where the complex refractive index is not known, the Fraunhofer theory is a good alternative for determining the particle size distribution.

The combined analysis of the size by laser diffraction and the analysis of images obtained by optical microscopy makes it possible to obtain a complete characterisation of the material and may be a useful aid in choosing the most suitable theory.

References

Laser diffraction methods – Partie 1: General principles