

## m3000u

### Ultrasonic Spectroscopy and the determination of physical Properties

#### Ultrasonic Materials Characterisation

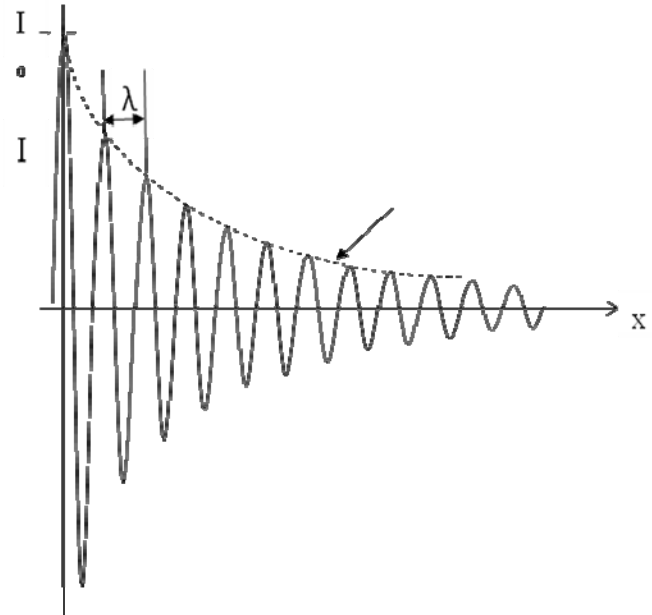
Ultrasound is the propagation of a mechanical wave through the molecular, microscopic and macroscopic structure of a material or materials. Ultrasonic Spectroscopy is the measurement of the frequency dependant ultrasonic response of a material. It is closely related to rheology however operates at higher frequencies and shorter length scales.

Since with all waves it can be described by a characteristic propagation wave number containing frequency dependant phase and magnitude changes. The interaction of the wave with the material is modifies the wave character through exchange of energy with through a range of physical process.

While all materials exhibit absorption processes which attenuate the wave, in pure liquids there is little or no dispersion and hence the propagation velocity is independent of frequency while colloids and solids exhibit thermo elastic, visco-elastic and scattering absorption process and frequency dependant dispersion phenomena which produces phase velocity. . In liquids only the longitudinal (compression) wave is supported over distance while solids support both longitudinal and shear waves. In addition ultrasonic waves are reflected, refracted and diffracted by interfaces, voids and changes in physical properties.

Ultrasonic Spectroscopy can measure the absolute frequency dependant velocity and attenuation of mainly liquids over a wide range of frequencies. As it is a non optical methods is not limited by the opacity of the material. It is an ideal process sensor technology as it is not affected by fouling of windows. Hence, there has been significant interest in the use of Ultrasonic Spectroscopy for the characterisation of materials in particular:

- Measurement of density in solids and in pure/mixed liquids
- Determination of thermal properties of liquids
- Rheological characterisation of liquids and soft solids through phase velocity
- Particle Sizing of colloids using attenuation
- Relaxation phenomena in biomaterials and soft solids



$$P = Z \cdot \omega \cdot A \cos\left(\omega t - \frac{\omega x}{c}\right) \quad [Pa]$$

The m3000u provides the capability of complimenting the information obtained from spatial tomography measurements with spectroscopic information.

This allows probing of not only the macro structure of the material but the microscopic structure and function.

The ITS ultrasound spectroscopy is based on the use of either pulsed or chirp measurements and hence can obtain and process data in real time. This allows the use of the technique on dynamic and rapidly evolving applications.

A wide range of models and techniques are available which can be used to interpret the spectroscopy data [refs]

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There is particular interest in ultrasound methods for the determination of the particle size of colloids. The advantages of the USS method of particle sizing over other more traditional techniques (i.e. laser diffraction) are seen as wide size range, ability to operate at high particle concentrations and turbid samples.

In this method the ultrasonic attenuation is used to back calculate the particle size from frequency dependant absorption. The absorption is a function of the mechanical interaction of the acoustic wave with structure of the material. These mechanism can be categorised as, visco-dynamic, thermodynamic, or scattering.

Visco-dynamic relates to the losses due to the mechanical movements of the particle in the liquids, thermodynamic relates to conversion of mechanical energy to heat and scattering is similar to light scattering in which a wave is diffracted by the particles.

As in the laser diffraction method the ultrasonic spectroscopy method it is an ensemble method.

Hence the complete model of the interaction requires knowledge of the properties relating to thermal, mechanical, and intrinsic ultrasonic properties. This for a two phase system requires a knowledge of 14 physical properties. For each phase the following properties are required:

- Density
- Sound speed: Ultrasonic group velocity
- Thermal Expansion Coefficient
- Thermal Conductivity
- Heat Capacity
- Shear Modulus: Young's Modulus, solids only
- Viscosity: Liquids only
- Attenuation: Ultrasonic attenuation coefficient

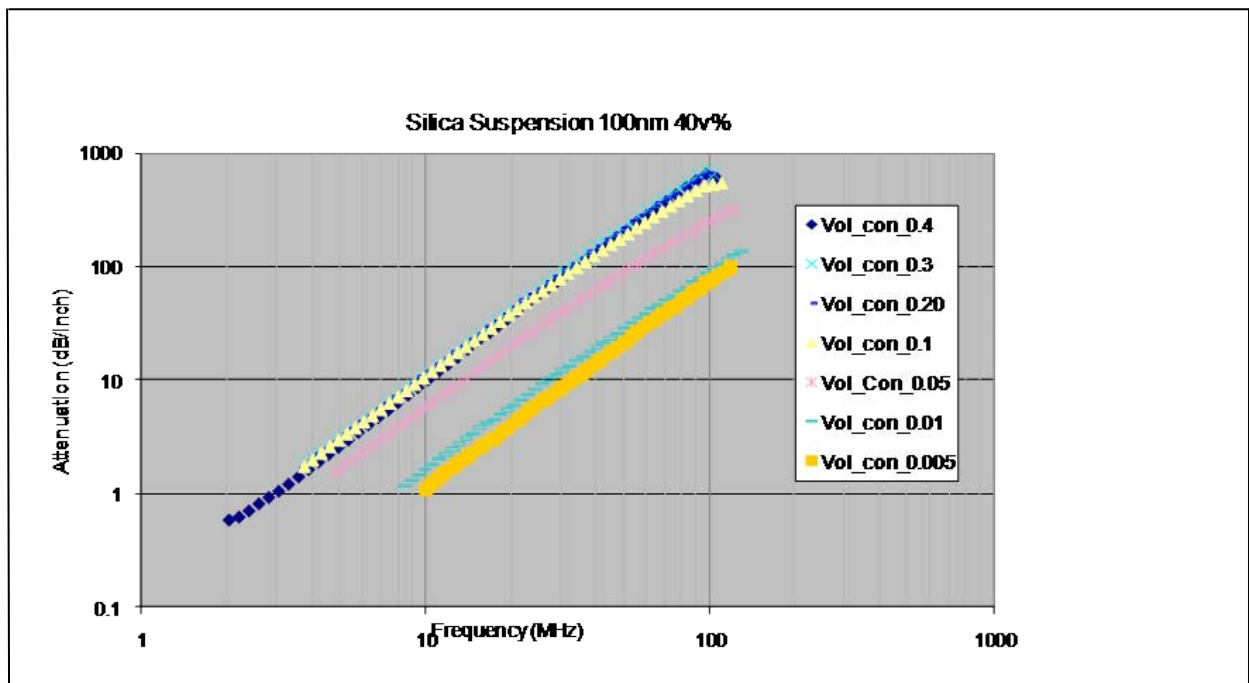


Figure 2: Data obtained from Ultrasonic Spectroscopy Measurements of 40v% 100nm silica as part of collaborative project with Leeds University

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As can be seen from above, the physical properties required depends on the material state of the individual phases. For the discrete phase, the state can either be a solid (particles) or a liquid (emulsion). However, continuous phase (medium) can only be a liquid. For liquids the attenuation and velocity can be measured using the sensor.

There is an implicit assumption that the user will know some information about the particles and continuous phase, it is unusual for there to be no information on the material. There are extensive knowledge bases on physical properties including Kaye and Laby, NPL, NIST and these are the first source of information, the second is to calculate values from other properties using basic chemical principles, the third option is to measure using appropriate techniques and finally the last option is to use a knowledge of the application coupled with the quality of the results to adjust a set of properties from known and similar material to provide accurate results.

All of these approaches require review of the results and refining of the input parameters

Most suspensions and emulsions use water as the suspending medium, in which case the properties are from Povey:

Property	Value	Temp	Units
Density	998	20C	kg.m <sup>-3</sup>
Sound speed	1482	20C	m.s <sup>-1</sup>
Thermal Expansion Coefficient	0.00021	20C	K <sup>-1</sup>
Thermal Conductivity	0.591	20C	W.m <sup>-1</sup> .K <sup>-1</sup>
Heat Capacity	4182	20C	J.kg <sup>-1</sup> .K <sup>-1</sup>
Viscosity	0.001	20C	Pa.s
Attenuation	0.4	20C	Np m

It is worth emphasising that no properties of the suspension or emulsion as a whole are necessary; only the properties of each individual phase are important for the correct operation of the instrument. If the physical properties are obtained in different units the most common conversions are given below.

#### Density

This is the mass per unit volume of the particle or medium. There are several methods by which this can be measured, most of which involve accurately weighing a known volume of the material of interest

#### Sound speed

This refers to the rate at which sound travels through the pure particle sample or the medium. The sound speed in liquids can be measured using a pure sample of the continuous phase. The sound speed in a liquid can also be calculated using the bulk modulus and density. The sound speed in solids can be calculated if the density and elastic modulus of a material are known.

#### Thermal Expansion Coefficient

Expansion Coefficient refers to the change in volume of a substance as the temperature increases, and can be calculated from the temperature dependence of the sample density

#### Thermal conductivity

Rate of transfer of heat through a material by conduction and can be calculated from the density, specific heat at constant pressure and the thermal diffusivity.

#### Heat capacity

Specific heat is the amount of energy required to raise the temperature of a unit mass of material by 1°C. at constant pressure.

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#### Shear Modulus

The shear modulus or the second lamé constant is for solids. And can be calculated from Young's Modulus and Poisson's Ratio

#### Viscosity

Relates to the dynamic viscosity of a liquid and requires a rheometer to measure. It can also be calculated from the kinematic viscosity using density of the liquid

#### Attenuation coefficient – Factor and Exponent

The attenuation is a measure of the reduction in amplitude of a sound wave as it passes through a sample. Its value is frequency dependent, thus the attenuation ( $\alpha$ ) is often represented by the following function:

$$\alpha = x \cdot f^y$$

where x is the attenuation coefficient or factor, f is frequency and y is the exponent which describes the frequency dependency. The exponent for water is 2 and the data for most liquids is expressed as a function of frequency squared.

For liquids the attenuation can be measured. Once the attenuation spectrum of the sample has been measured, the line of best fit can be calculated

For solids and liquids it is possible to calculate the value from the heat capacity, thermal conductivity and bulk modulus. However these values need to be used cautiously as especially in liquids they do not account for all attenuation mechanisms.

#### References:

Kaye & Laby, Tables of Physical and Chemical Constants and Some Mathematical Functions, Longman 16th Edition ISBN-13: 978-0582226296

<http://www.kayelaby.npl.co.uk/>

<http://www.library.manchester.ac.uk/subjects/eps/chemistry/cpcp/>

Povey, Ultrasonic Techniques for fluids characterisation Academic press ISBN-0-12-563730-6

For more information contact:

Richard Tweedie  
Industrial Tomography Systems Plc  
Phone: +44 (0) 161 832 9297  
Fax: +44 (0) 161 839 5195  
Email: [richard.tweedie@itoms.com](mailto:richard.tweedie@itoms.com)