Application Note

m3000u

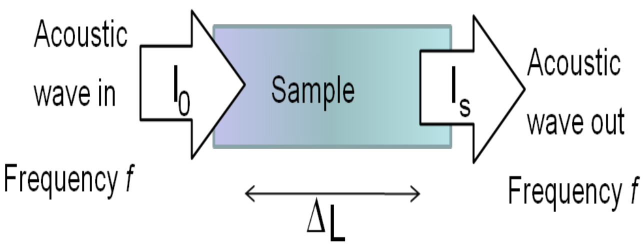
Ultrasound Spectroscopy

Ultrasound Spectroscopy

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.

The basic principle is the measurement of the change in the amplitude and phase of a ultrasound wave which has passed through a known length of material.

Ultrasonic Spectroscopy can measure the absolute frequency dependant velocity and attenuation of mainly liquids over a wide range of frequencies.



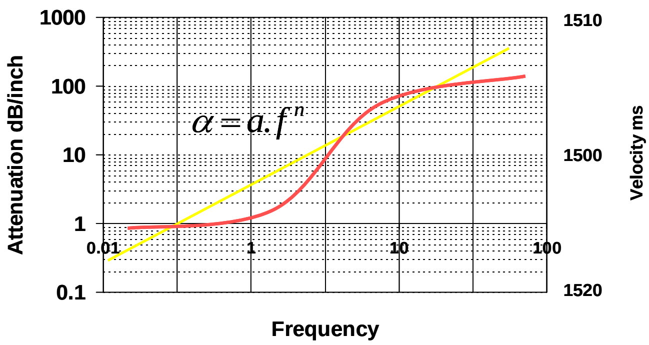


Figure 2: Typical spectra from a material exhibiting ultrasound dispersion such as a colloid

All Ultrasonic methods have a great advantage over optical methods in that they are not limited by the opacity of the material. Therefore they make ideal process sensor technologies as they are not affected by fouling of windows or sample opacity. Hence, there has been significant interest in the use of Ultrasonic Spectroscopy for the characterization of concentrated materials (which is taken to mean concentrations of greater than 1% since laser diffraction is limited to <0.1% for most applications) in particular the:

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

This application concentrated on determination of the particle size of the API's through some results suggest that there would be the possibility of using ultrasound to monitor the concentration of surfactant.

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Particle Sizing

Particle size and concentration determination from the ultrasonic attenuation spectra [1],[4],[5],[6],[7] is based on a first principles model ([8],[9]. The model 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 conversation of mechanical energy to heat and scattering is similar to light scattering in which a wave if diffracted by the particles. As in the laser diffraction method the ultrasonic spectroscopy method is an ensemble method.

Hence the complete model of the interaction requires knowledge of the properties relating to thermal, mechanical, and intrinsic ultrasonic properties. 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*

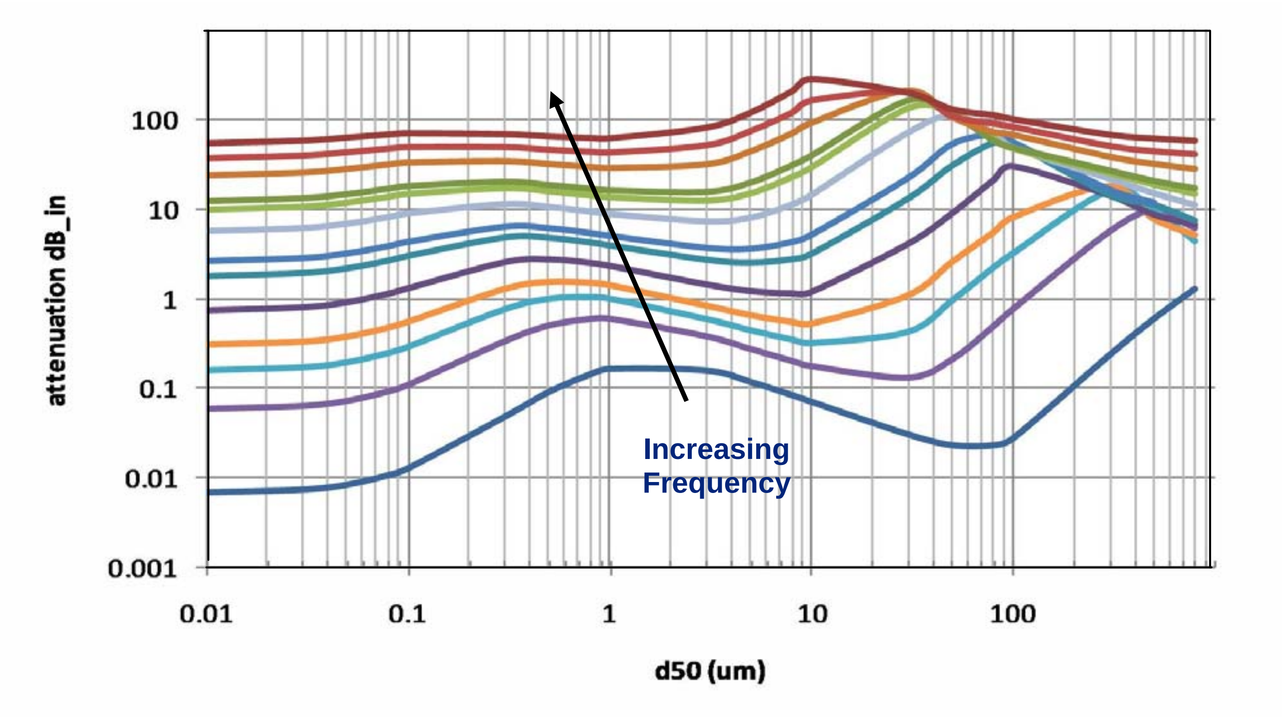

Figure 2: Visualisation of the attenuation of Glutamic Acid in Water for a range of mean particle sizes

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These can be found from a variety of sources including manufacturers data sheets and references sources [2],[3].

However, the influence of each of the mechanisms and hence the importance of the physical properties is dependent on the size of the particles and the type of particles. Large dense particles are dominated by geometric scattering which occurs at high frequencies, while particles sub 100nm only exhibit thermodynamic absorption. Between 100nm and 100um particles exhibit a resonance in the visco-dynamic mechanism related to the ability of the continuous phase to entrain them.

Concentration

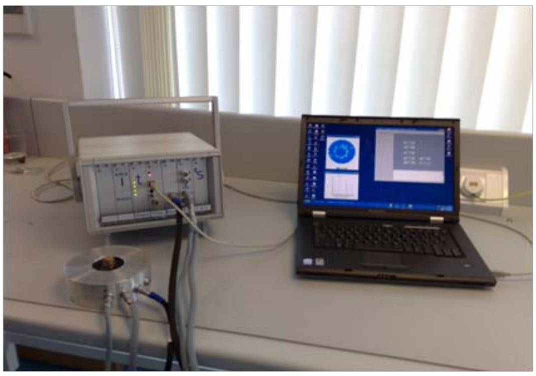
The acoustic velocity of a liquid is dependent on the density and bulk modulus where density defines the mass per unit volume which must be acted upon by the mechanical force and bulk modulus is a measure of the resistance to that movement. Since density and bulk modulus are temperature dependant the velocity is also temperature dependant The theoretical velocity can be determined from the Wood equation. If the liquid is a mixture of two liquids it is possible to determine the concentration of the two liquids using a modified version of the wood equation were the average density and bulk modulus are calculated using mixing equations.

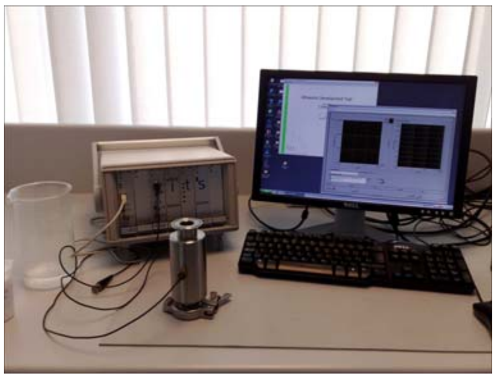
m3000u Instrument

ITS has developed an ultrasound system based on its m3000 multimodal measure system known as the m3000u. The m3000u provides both ultrasonic spectroscopy and tomography measurement methods. Tomography images the sample at a macroscopic scale allowing the identification of separate phases and the interfaces between . Spectroscopy as discussed above probes the microstructure of the material.

The spectroscopy modality is designed to operate in transmission mode using two ultrasonic transducers. The transducers covert the electrical signal to an ultrasonic wave and vice versa under the control of the a measurement control system The measurement control system generates the signal and detects the response. The ultrasonic transducers are fitted to a custom sensor cell.

The m3000u ultrasound spectroscopy system (USS) is a broad band system operating at a centre frequency of 10MHz with sample volumes as small as 1ml. The measurement method uses a wideband signal source to generate a transient signal, which unlike traditional electrical, optical and ultrasound spectrometry systems which generate a sequence of single frequencies and measure the response to each individual frequency. The advantage of the transient method is in dramatically shorter measurement times.





Images of m3000u

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INDUSTRIAL TOMOGRAPHY SYSTEMS plc

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Ultrasound Spectroscopy

Specification

Diameter	Max 200	mm
	Min 5	mm
Sound Speed	Max 3000	m/s
	Min 300	m/s
Attenuation	Min 0.05	dB/cm
	Max 100	dB/cm
Temperature	**Standard**	
	Max 50	C
	Min 0	C
	Extended	
	Max 120	C
	Min -10	C (non-aqueous)
Frequency Range	Min 3	MHz
	Max 32	MHz
Measurement Time	30	seconds

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