
Application of Ultrasound Spectroscopy to Complex Applications

Ultrasonic Spectroscopy (USS) is the characterisation of the ultrasonic response of a material to the propagation of a low energy ultrasonic wave. Ultrasonic Spectroscopy can measure the absolute frequency dependant velocity and attenuation of liquids and soft solids. Ultrasonic waves propagate through a medium as a mechanical wave. Due to the nature of the Ultrasound wave the method has a number of inherent and useful features:

- Non-destructive, Non-Intrusive and in-situ
- Can be used on opaque samples allowing use at high concentration and strong colours
- Can be used on both liquids and soft solids
- Simple sample handling with no requirement for manual intervention
- Able to operate over a wide range of length scales from nanometres to millimetres

The interaction of the wave with the material is a function of the material structure including hydrodynamic and the thermo-elastic properties. Therefore Ultrasonic Spectroscopy data can be used to characterise any process which modifies these parameters including the process kinetics, solids concentration, rheological behaviour and changes in particle size or material structure.

Unlike optical methods, Ultrasound is not limited by the opacity of the sample and is hence able to work at high concentration or in coloured liquids such as pigments. The technique is sensitive to changes in particle size over a wide range of mean particle sizes approximately 10nm to 1mm

The ITS U2s is a unique product, a single multipurpose ultrasound spectroscopy platform which can be applied to a wide range of materials from pure liquids to soft solids over a wide range of operating conditions. It has been specifically developed to provide a solution to in-situ process characterisation needs and can provide real-time information of on the micro-structure of industrial materials.

- Use of fast measurement methods
- Specifically developed for in-line/in-situ applications.
- Modular design for customisation to process needs
- Able to measure both the forward (Transmission) and reverse (reflected) signals

The use of fast transient methods allows data collection in real time allowing the use of the system on dynamic and rapidly evolving applications, such as crystallization. The system can operate in pipes for diameters of 8mm to 100mm or vessels from 500ml up in applications with operating temperatures of 10-120C. The sensor itself is custom designed to match the application, and avoids the need to move the transducers during measurements allowing a more robust and process compatible sensor. The sensor can either be a flow through cell for pipes or a dip in probe for reactors and large vessels.

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The U2s can be configured to operate in a number of different methods to best match the application

The probe or pipe method: Low concentration liquids and colloids very fast measurements

The Coded transmission method: low concentration and High concentration liquids and colloids, moderate update rate.

The reflectance method, extremely highly attenuating materials almost solid.

The Ultrasonic Spectroscopy data can be used to characterise a range of material or process properties and behaviours including:

Measurement of density and or concentration of discrete phases mixed liquids or slurries

Rheological characterisation of liquids and soft solids through phase velocity

Indicative changes in attenuation spectra due to changes in material structure including particle size of colloids both slurries and emulsions through changes in

Relaxation phenomena in biomaterials and soft solids

The characterisation of liquids containing bubbles

Liquids: 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 where the average density and bulk modulus are calculated using mixing equations.

Emulsions: Ultrasound is scattered by emulsion droplets due to the differences in the thermodynamic properties between the continuous and disperse phases. At dimensions smaller than the wavelength the ultrasound wave compresses the volume of the material leading to small changes in the dimensional and thermal conditions of the droplets. This change results in changes in attenuation and phase of the wave. These changes are indicative of the droplet size, distribution and volume concentration.

Aerated Materials: The structure of bubbles is maintained by surface tension cavity. When ultrasound encounters a bubble the structure vibrates with a frequency content proportional to bubble size. This response is resonant and has a high Q therefore signature of the bubbles will focus the energy and dominate the response. Therefore in an aerated sample the liquid and other disperse characteristics are obscured by the bubble response. Hence it is possible to only measure bubble characteristics. The method is also not able to determine the gas fraction as the magnitude of the response is very non-linear and hence cannot be determined analytically.

Slurries: Particles absorb and diffract ultrasound energy and hence the change in ultrasound energy of a wave in a slurry or emulsion is a function of the particle size. Particle size determination from the ultrasonic attenuation spectra is based on a first principles model. Significant information is needed in order to accurately determine the particle size and distribution even in relatively simple applications. Complex or multimodal particle size distribution requires significant effort to develop robust solutions. However whether a particle size model is used or not the change in ultrasonic spectra reflects change in particle size. In a process situation use of the spectra is sufficient to control the process.