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Effects of Material Viscosity on Particle Sizing by Ultrasonic Attenuation Spectroscopy

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Abstract

Ultrasonic spectroscopy is becoming a promising particle measurement technique for the characterization of emulsions and suspensions over a wide range of particle size and concentration especially in the petrochemical, pharmaceutical, adhesives, food and other industries. Compared with other competitive methods like laser diffraction, dynamic light scattering and image analysis, the approach of ultrasonic attenuation spectroscopy possesses significant superiority in the highly-concentrated particulate two-phase flow measurement even in the optical opaque medium, due to the high penetrability of ultrasonic waves through medium, as well as in situ non-invasive measurement and low cost but endurable apparatus. Typically, the overall process by which the particle size distribution of a suspension is measured using ultrasonic attenuation spectroscopy can be divided into two parts: the measurement of frequency-dependent ultrasonic attenuation in two-phase system, and the inversion calculation based on the prediction of mathematical model. The modeling process relies on the fundamental relationship between attenuation spectrum and physical properties, where viscosity could be a critical and complex property because its quantity can influence the ultrasonic attenuation seriously and ultimately the inversion calculation of the resultant particle size distribution. In this paper, a variable viscosity experimental system has been established through changing the concentration of aqueous glycerol solutions or the temperature of glycerol solutions. For the sample of micron-sized glass beads, a series of experiments have been carried out to obtain the attenuation spectrum, which were predicted and interpreted using the ECAH (Epstein, Carhart, Allegra and Hawley) model simultaneously. Hence, the particle size distribution of the glass beads can be retrieved through the inversion calculation.

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Keywords: Ultrasonic; Attenuation spectrum; Viscosity; Particle size distribution

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1. Introduction

In recent years, ultrasound technique has gained considerable attention for particle measurement, offering advantages with respect to more extensively accepted analytical methods such as optical and electrical techniques. Characteristics like the availability to optically opaque, undiluted and high/non-conducting dispersions and the non-intrusive nature of the acoustic transducers promote its applications for the rapidly and on-line monitoring of a wide field such as petrochemical, pharmaceutical, and food industries [1].

Furthermore, ultrasound attenuation spectroscopy has been validated to be applicable to the characterization of particles over several orders of magnitude in size (10 nm to 1 mm) at very high concentrations (volume fraction from 0.1% to 50%) [2]. By making use of a rigorous and fundamental theoretical model, particle sizing with ultrasound spectroscopy deeply relies on the assumption that the fundamental relationship between attenuation spectrum and requisite physical properties, where viscosity could usually be a significant and complicated property because its quantity can influence the ultrasonic attenuation seriously by direct sound absorption of continue media and viscos loss occurred in the interaction between sound and media, and ultimately the inversion calculation of the resultant particle size distribution. While, Frank Babick *et al* focused on the dependence of ultrasonic attenuation on the material properties and illuminated which material properties have to be obtained with high accuracy and which can be estimated [3]. As Patricia Mougina *et al* have studied the sensitivity of particle sizing by ultrasonic attenuation spectroscopy to material properties [4].

In this study, we investigate the influence of viscosity on the ultrasonic attenuation coefficient and particle size distribution of micron-sized glass beads in glycerol solutions or aqueous glycerol solutions with different temperature and volume concentration, respectively. We also consider the implications of the viscosity-dependence of the ultrasonic properties of suspensions for utilization of the ultrasound technique for characterizing suspensions. In Section 2, a brief introduction to the physical background of ultrasound technique as well as associated fundamental model are presented. Then in Section 3, a simple presentation to the materials and experiments and an analytical derivation of the dependence of obtained measured and calculated results from viscosity are given. After that, the analytical results are verified and discussed by calculating particle size distributions of measured attenuation spectrum with different sets of material properties changing with viscosity in Section 4, followed by a final conclusion. In particular, the study aims to characterize and compare dispersions with different volume concentrations and different temperature in order to demonstrate the possible ways in which the change of viscosity of dispersion can change the original ultrasonic attenuation spectrum of the dispersion. The study brings the conditions in which ultrasonic attenuation spectroscopy is capable of explaining that the change of viscosity of a dispersion will change original particle size of the disperse medium.

2. Theoretical basis

2.1. Physical background of ultrasonic attenuation spectroscopy

In a homogeneous medium, sound waves, similar to light, propagate straight from the source, thus steadily losing part of their energy during sound absorption in the dispersed medium. In heterogeneous media, such as in suspensions or emulsions, the redirection of acoustic energy away from the incident beam can be observed in sound propagation [5]. Sound scattering is a general wave phenomenon that the sound waves are refracted, reflected and diffracted on the dispersed phase in such a way that each particle acts as a sound source, radiating sound waves in all directions. Against light scattering, sound scattering could be strongly affected by thermal and mechanical coupling effects between the continuous and dispersed phase. That's the physical characteristic of sound waves, which are nothing less than propagating compressional equilibrium disturbances, consistent to temperature fluctuations. The thermal and mechanical coupling effects impact the sound propagation in two ways: they vary the scattering profile, and they are of a dissipative nature hence decreasing the total amount of acoustic energy through sound absorption. The magnitude of the scattering effect depends on the physical properties of the involved phases and the particle size [6].