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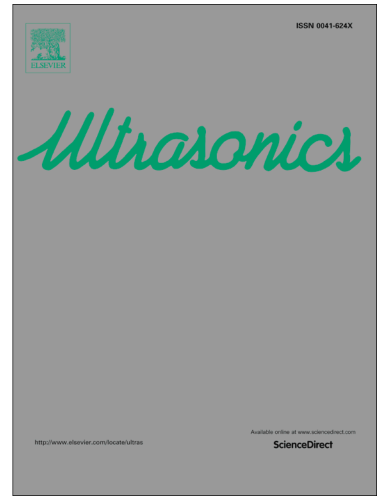

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Ediguer E. Franco, Flávio Buiochi

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Ultrasonic measurement of viscosity: signal processing methodologies

Ediguer E. Franco[a,*], Flávio Buiochi[b]

[a] *Engineering Faculty, Universidad Autónoma de Occidente, Cali, Valle del Cauca, Colombia.*
[b] *School of Engineering at the University of São Paulo, São Paulo, SP, Brazil.*

Abstract

This work deals with two alternative methodologies for data post-processing resulting from the ultrasonic shear-wave reflectance method used for liquid viscosity measurement. In the shear-wave reflectance method, the measurement principle is the small transference of energy to the liquid when the wave strikes a solid-liquid interface, causing a detectable change in the reflection coefficient. A measurement cell that uses mode conversion for the generation of the shear waves was employed and samples of five different substances were tested, covering a viscosity range of three orders of magnitude. Ultrasonic results were compared to the values obtained by conventional viscometry. Despite the wide range of viscosity and the different nature of the liquids, Newtonian behavior was observed with all samples at the working frequencies. This can be concluded from the coincidence between the values obtained by ultrasound and by the rotational viscometer. However, the viscosity values show an oscillating behavior when calculated for different frequencies along the band of the transducer. This oscillating behavior induces big errors when the viscosity is calculated at a single frequency, forcing the development of alternative methodologies. Two methodologies that calculate the reflection coefficient in a frequency band instead of a single frequency were analyzed, showing more accuracy and precision.

Keywords: Viscosity, ultrasound, shear waves, reflection coefficient.

1. Introduction

The propagation of shear waves in a liquid is directly affected by its rheological properties. In general, it is established that liquids cannot sustain shear waves because the attenuation is high and the waves travel very small distances, making it difficult for directly measuring the liquid properties [1]. This problem can be circumvented by two approaches. In the first, the shear wave is transmitted through a thin layer of liquid sample trapped between two solids [2], but this technique is only useful for fluids of high viscosity. The second approach uses the reflection of the shear waves at a solid-liquid interface, where the small transference of energy to the liquid can be detected in the reflection coefficient [3].

The reflectance technique has some important advantages. The most remarkable is the ability to perform real time and in-situ monitoring. It can be used with relatively light liquids, such as edible oils [4, 5]. The liquids can be static, for example a polymeric resin curing in a mold cavity [6], or in movement, such as a fluid flowing in a pipe [7] or stirred as the lubricant in an engine [8]. This is possible because the sensing element is a solid surface that can be embedded in the pipe or mold wall. Although measurements can be done in a wide range of pressure and temperature, changes in these physical properties, specially temperature, during the test are problematic. This is an unsolved issue that requires additional research to allow out-of-laboratory applications.

When the shear-wave propagating in a solid reaches the solid-liquid interface a small portion of the energy is transmitted to the liquid, causing a change in the magnitude and phase of the reflection coefficient. The experimental measurement requires a calibration fluid, with air being the most used fluid because the large mismatch in the acoustic impedances generates a complete reflection. The comparison between the signals obtained with air and with sample is carried out in the frequency domain.

The measurement sensitivity depends on the acoustic mismatch between solid and liquid interface [9]. The magnitude and phase of the reflection coefficient are related to changes in the amplitude and arrival time, respectively, of the signals. The experimental determination of the reflection coefficient magnitude is a relatively easy task with viscous liquids. As the sample viscosity

*Corresponding author