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Feasibility of Miniaturized Viscosity Sensors for the Characterization of Suspensions

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Abstract

For many applications the viscosity of a complex fluid sample is interesting to control the process and reactions. These fluids can for instance be suspensions of different types of microorganisms, e.g., bacteria or fungi. Macroscopic viscosity measurement systems would only be able to measure the global, averaged viscosity. Miniaturized TSM resonators, however, are probing only a very thin fluid film (typically only a few µm thick, depending on frequency and viscosity) on their surface. Earlier investigations with water-in-oil micro-emulsions have shown that the influence of water droplets in oil is dependent of their size. In this paper we focus on a similar effect, i.e. the influence of the surface roughness. It turns out that the sensor behaves differently if the dimension of the inclusions or particles is in the order of the surface roughness.

Viscosity; suspension; TSM;

1. Introduction

In industries such as biochemistry of food industry, biochemical processes are very important. To increase the efficiency and to guarantee the quality of the products, processes need to be controlled. For this purpose various parameters have to be measured e.g. the concentration of different fluids, the density, and also the viscosity of the fluid yields additional information about the actual process conditions.

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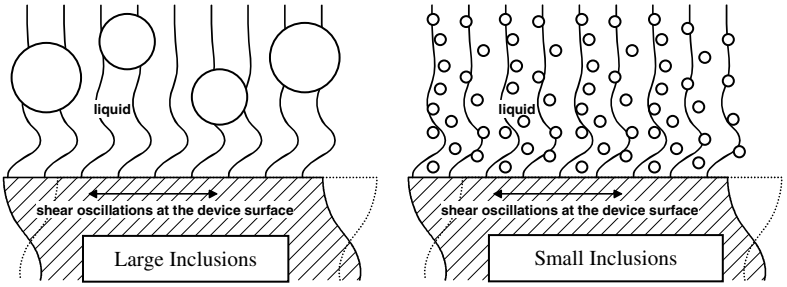

Fig. 1. A shear vibrating surface excites strongly damped shear waves in an adjacent liquid. If as suspension or emulsion is sensed, the measurement results will be different from the macroscopically apparent viscosity if the size of the inclusions is comparable or even larger than the penetration depth of the wave (see also [3]).

The viscosity in suspensions and emulsions is different from the viscosity of a single phase fluid. On a macroscopic scale, the various components (e.g., particles) affect the viscosity but this is not valid for microscopic measurement systems. Miniaturized viscosity sensors based on the interaction of a shear-vibrating surface with an adjacent sample liquid are probing only a very small layer of liquid (due to the strongly damped shear waves excited into the liquid) and therefore the bigger particles of the emulsions will not interact with the measurement device [3]. The penetration depth of the excited shear wave is given by $\delta = \sqrt{2\eta / \rho\omega}$ (η, ρ, ω denote viscosity, density and oscillation frequency) [5]. The effect of particles on viscosity sensors has been demonstrated using a thickness shear mode resonator (TSM see also below) for emulsions [3] but also for cantilever based sensor and suspensions [4].

In this paper, we are particularly addressing the influence of the surface structure of the sensor. As an example for a miniaturized viscosity sensor, we consider the above TSM resonators.

2. Measurement Setup

The used resonators feature a resonance frequency of about 6 MHz. One of them has a rough and the other a polished surface (see Fig. 2). The measurements were performed with an Agilent 4294A Precision Impedance Analyzer. For the sensor setup the resonator is placed upright into the sample liquid (suspension) to prevent the particles from accumulating on the surface of the resonator. The container of the fluid has to be large enough to suppress perturbations from the walls. The used cylindrical containers are 5 cm high, have an inner diameter of 2 cm, and feature a cap. The TSM resonator holders are glued into the cap using epoxy resin allowing easy removal and cleaning. To perform the measurement the capped container is turned upside down such that the resonator disk is completely immersed in the sample.

In preparing the samples, we used a viscosity standard silicon oil (calibration oil for laboratory viscometers) to minimize spurious effects (e.g., due to conductivity). At room temperature the viscosity of the oil was 18.61 mPas yielding a penetration depth of δ=1.08 μm. Each sample contains 7 ml of viscosity standard oil and is mixed with a certain amount of particles.

Each sample series features different concentrations (given in terms of weight ratios) of two glass sphere mixtures covering different size ranges (diameter range 0.5-10 μm and 70-110 μm obtained from Kisker , see Fig. 4 and 5).

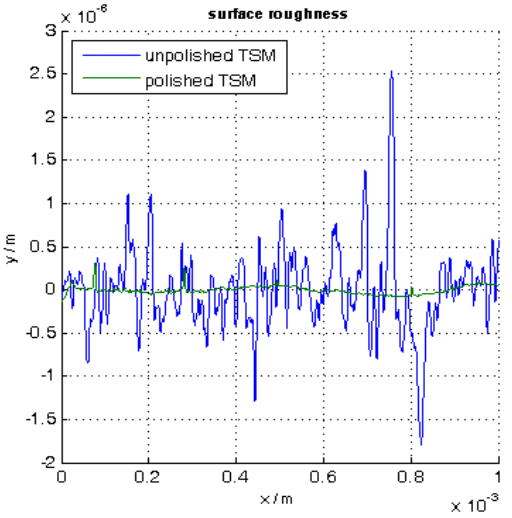

Fig. 2. Surface roughness of the two TSM resonators

3. Experimental Results

For the measurements it is very important to maintain the homogeneous distribution of the particles because they tend to sediment. Therefore the measuring time has to be kept as short as possible. Care has to be taken during the mixing process to not generate air bubbles in the fluid. For each sample and each TSM resonator, an impedance spectrum has been measured. The parameters of the electrical equivalent circuit have been extracted by fitting. According to theory, they are connected to the viscosity and the mass density of the fluid [5].

The influence of the surface roughness of the TSM resonator in case of simple liquid loading (i.e. no complex liquids such as suspensions) has been shown [5] and [6]. In case of suspensions, we expect that when the roughness is in the region of the particle size, the interaction of the surface of the TSM and the particles increases because the particles get caught in the valleys of the surface. Therefore the rough TSM should show a stronger dependency on the particle density than the polished one. Fig. 2 shows the surface roughness of the unpolished and the polished TSM resonator measured with a surface profilometer. The unpolished device features a roughness in the µm range and the polished one in the region of 10 nm. Figs. 3 and 4 show the influence of particle concentration for the smaller particles on the measured impedance spectra of the immersed device close to resonance. It can be seen that only the small particles cause a significant change on the measured characteristics. Fig. 5 shows the fitted equivalent circuit parameter ΔR^2 (the square of the loss resistance which is related to the fluid's viscosity) plotted versus the mass ratio (i.e. the total particle mass fraction) of the suspension for the rough TSM resonator. Also here, a clear dependence on the mass ratio can be seen for the small particles while the ΔR^2 scarcely changes for the samples featuring bigger particles. On the contrary, for the polished TSM resonator a significant dependence on the mass ratio can be seen neither for the small nor for the bigger particles (Fig. 6).

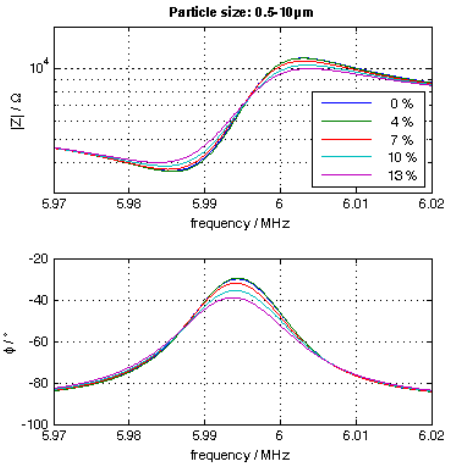

Fig. 3. Resonance curves of rough TSM

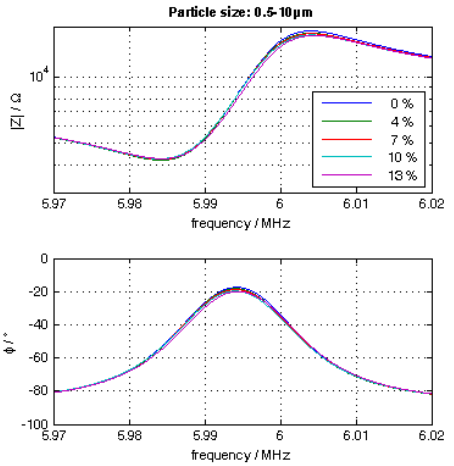

Fig. 4. Resonance curves of polished TSM

4. Conclusions

In this paper we presented the results of our investigations on the characterization of suspensions with different particle sizes and TSM resonators featuring a different surface roughness. It has been shown that the influence of the particles on the sensor characteristics was only clearly recognizable when the particle size was in the order of the surface roughness. For the present configuration, the penetration depth was at the lower end of the used particle size distribution such that, according to earlier work, the effect of the particles on the sensed viscosity should be scarcely recognizable, which is consistent with the present results if the observed interaction is interpreted as consequence of the interaction with the rough surface.

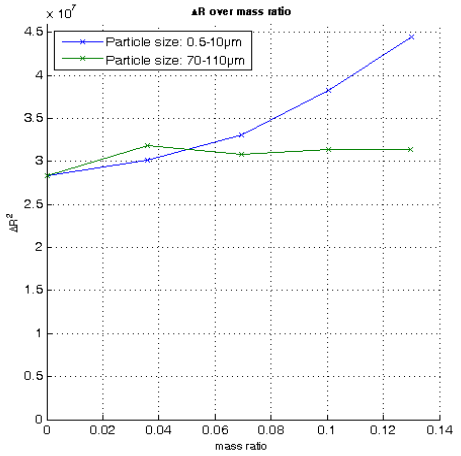

Fig. 5. Fit results for ΔR^2 of the rough TSM

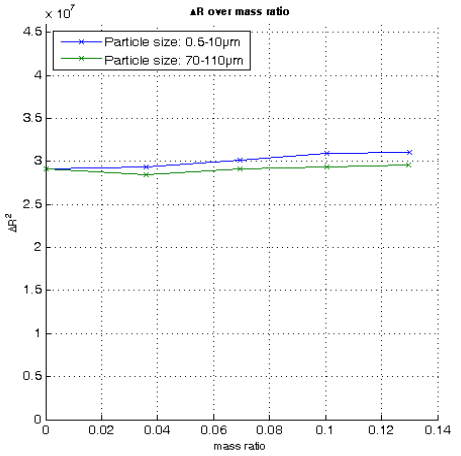

Fig. 6. Fit results for ΔR^2 of the polished TSM

Acknowledgements

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