Dissipative QCM

Application Example

MONITORING BULK VISCOSITY

Introduction

The change in bulk viscosity can be used as a parameter to signal for example the beginning or end of a reaction, gelation or swelling process. Furthermore, viscosity of human body fluids is used as a predictor of certain diseases. In the latter case, a requirement of the measurement protocol is that it can handle very small sample volumes. For this reason, the Dissipative QCM is highly interesting for monitoring viscosity changes when compared to the traditional techniques such as rotational, capillary or tuning-fork viscometers. The QCM-Dissipation requires only a fraction of a milliliter compared to several to tens of milliliters for the traditional techniques.

The aim of this example is to demonstrate the usefulness of the Dissipative QCM (QCM-Dissipation) for monitoring viscosity changes of liquids and its suitability for measurements in highly viscous (damped) systems.

Results

Figure 1 shows the frequency change of a 5 MHz gold-coated crystal in contact with different glycerol solutions measured with the Dissipative QCM compared to the frequency change predicted by the Kanazawa equation.

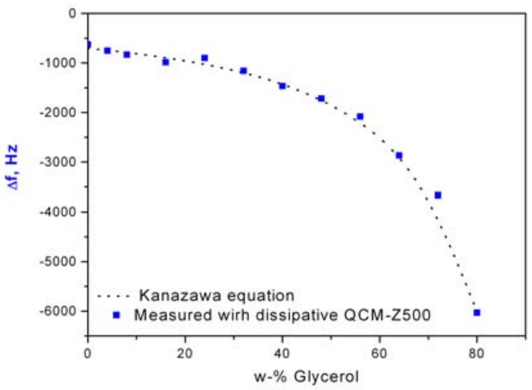

Figure 1

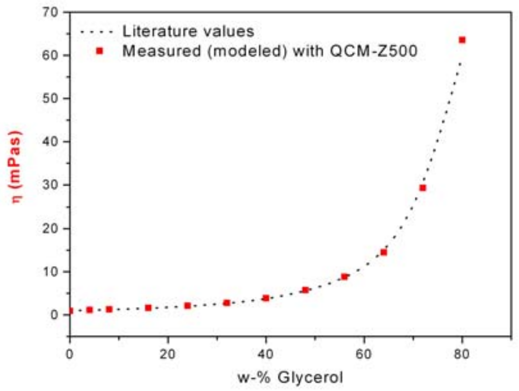

Figure 2

Kanazawa et al (Anal. Chem. Vol. 57 (1985) p. 1770) was the first to show that the decrease in frequency of a resonator in contact with a (Newtonian) liquid is related to the viscosity of the liquid i.e.

$$\Delta f = -f_u^{3/2} \left[(\rho_L \eta_L) / (\pi \times (\rho_q \mu_q))\right]^{1/2} \qquad (1)$$

Δf = measured frequency shift, f_u = resonant frequency of the unloaded crystal in air, ρ_L = density of liquid in contact with the crystal, η_L = viscosity of liquid in contact with the crystal, ρ_q = density of quartz, 2.648 g/cm^3, μ_q = shear modulus of quartz, 2.947×10^{11} g/cm$\times$s^2.

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This relationship has later also been confirmed by other authors who used a more detailed and elaborate theoretical treatment (IEEE Trans. Ultrason. Ferroelec., and Freq. Control, vol 45 (1998), and Anal. Chem. vol. 71 (1999) p. 2205).

Figure 2 shows the calculated (modeled) viscosity values compared to the literature values. The good correlation between theoretical and experimental values is clearly illustrated in Figures 1 and 2, which confirms that the Dissipative QCM(QCM-Dissipation) is an excellent technique for evaluation of fluid bulk viscosities or viscosity changes, especially in cases where the amount of sample liquid is small. Furthermore, the correlation of the measured viscosity with literature, especially in the highly viscous regime also clearly demonstrates the excellent suitability of the for measurements on highly damped systems.

The effect of increasing viscosity can be clearly seen in plots of admittance (= 1 / impedance) or phase against frequency. Figure 3 shows admittance versus frequency for a range of glycerol concentrations in contact with a 5 MHz polished gold-coated crystal. While Equation 1 clearly shows that the resonance frequency is dependent on viscosity, Figure 3 also illustrates the broadening of the admittance peak, which is another effect of viscous damping.

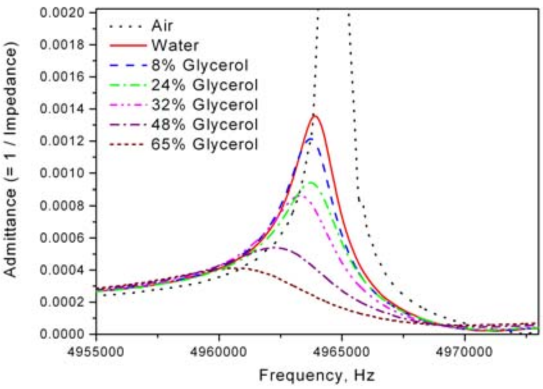

Figure 3

Conclusion

Dissipative QCM is an excellent technique for measuring bulk viscosity in highly damped systems, particularly in cases where the available sample volume is too small to measure with traditional techniques. The direct measurement of dissipation and related parameters allows different models to be applied for determining viscosity, thereby increasing the reliability of the measurement.