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Abstract

Real-Time Tracking of the Dynamic Viscosity of Bitumen with Piezoelectric MEMS Resonators †

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Abstract: This work demonstrates lab-scale monitoring of the dynamic viscosity of bitumen with piezoelectric MEMS resonators over a period of 120 h at an elevated temperature of 100 °C in air. The aluminium nitride-based MEMS resonator is excited in a high-order roof-tile-shaped mode to provide high-quality factors while immersed in bitumen. The results demonstrate the robustness of the MEMS sensor, as it is capable of performing at elevated temperatures continuous measurements for a long time even in harsh environments like bitumen.

Keywords: piezoelectric MEMS resonator; bitumen; dynamic viscosity; density

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1. Introduction

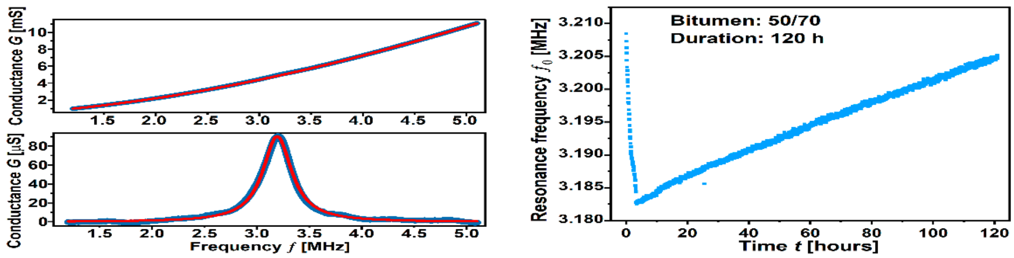
Monitoring of fluid properties such as viscosity (μ) and density (ρ) in real time with low sample volumes is important for many industrial and medical applications. In this context, the determination of μ and ρ of fluids, by measuring the resonance frequency (f_0) and the Q-factor (Q) of mechanically elastic micro-structures such as beams, has been reported [1]. To overcome the viscous damping in high-viscosity liquids, roof-tile shaped (RTS) vibrational modes were introduced for piezoelectric microplate-type resonators [2]. This class of modes features high Q-factors even in highly viscous liquids like bitumen and is a promising approach for an integrated monitoring of fluid properties.

2. Materials and Methods

The reported work in this paper is based on the same temperature-controlled setup and a similar MEMS sensor, as reported in [3]. Bitumen 50/70 is placed on the surface of the sensor and subsequently annealed at 80 °C to immerse the whole device in bitumen. After placing the device into the climate cabinet, the MFIA excites the sensor in the RTS mode 1B at 100 °C and measures the conductance for a period of 120 h. After the baseline is removed, the conductance of an LCR circuit is fitted to the data, and f_0 and Q are extracted. Using six standard high-viscosity test liquids, the sensor is calibrated, and μ is calculated from Q, given a measured bitumen density of 0.977 g/cm^3 [3].

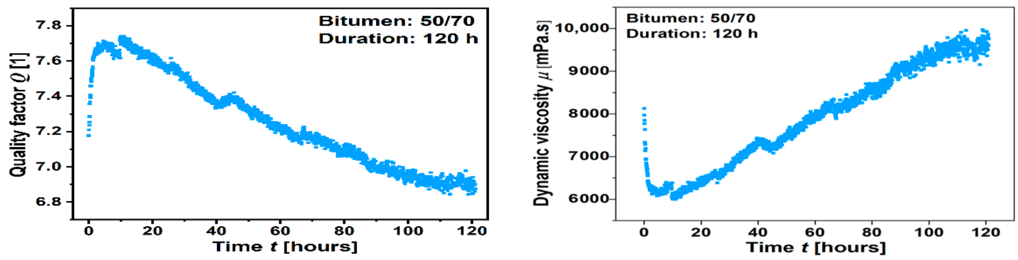
3. Discussion

Figure 1a top and bottom show the conductance spectrum as raw data, including baseline, as well as the conductance spectrum after baseline correction, respectively. Given the expected low Q, the fit of the LCR conductance spectrum to the measured data is regarded as excellent. Figure 1b shows f_0 as a function of time. In Figure 2a, Q over time is shown, where an initial increase in Q is observed, followed by a decrease. Figure 2b shows the evolution of μ with time, indicating a continuous increase of μ during bitumen aging. This is reasonable, as bitumen commonly exhibits an increase in the dynamic shear modulus with aging, which in turn results in an increase of μ [4].



(**a**) (**b**)

Figure 1. (**a**) Top and bottom images show the raw and corrected conductance with fitted LCR conductance, respectively; (**b**) f_0 as a function of time for submerged sensor in bitumen.



(**a**) (**b**)

Figure 2. (**a**,**b**) Q and μ as a function of time for immersed sensor in bitumen, respectively.

4. Conclusions

To the best of the authors' knowledge, MEMS sensor have never been used to monitor the μ of bitumen for 5 days. Measured values range up to 10,000 mPa·s in bitumen at 100 °C.

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