ASSESSMENT OF FLUID CONTAMINATION BASED ON VISCOSITY MEASUREMENTS USING A LONGITUDINALLY VIBRATING PLATE

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Abstract- Contamination in a fluidic system can be extremely detrimental especially in biomedical applications. In this study, a longitudinally vibrating disk method is investigated for the measurement of dynamic viscosity as a means of monitoring in line fluid contamination. The device for monitoring contamination in flowing fluids according to the present study comprises electronics for determining frequency and amplitude of oscillations of a transducer, which are functions of the variations of viscosity and density of the monitored fluid. Further, this method helps lowering the costs for system maintenance.

Keywords- Dynamic Viscosity, Fluids, Resonance, Contamination, Moving Coil transducer, Dynamic Sensor.

I. INTRODUCTION

Contamination in a fluidic system may stem from several different sources. Manufacturing and maintenance malpractices, wear and chemical reactions in the system may cause contaminants to be present in a fluid. The contaminating materials can be organic, metallic or non-metallic solid particles, other types of organic or inorganic fluids, water and gases, such as air. Although solid particles such as tiny particles of Orings, gaskets, hoses, bare metal particles and plating materials (e.g., silver and chromium), dust, and silicates, are serious contaminants, they are not the main subject of this study, and they are usually prevented by fine inline filtering of the fluid. Dissolved air and water contamination can adversely affect the properties of a fluid. Dissolved, emulsified water may result in the formation of ice or oxidation or corrosion products of metallic surfaces. Foreign fluid contamination may be the result of incorrect fluid inadvertently introduced into the system. Physical parameters of the fluid are all influenced, and the effects of such contamination depend on the contaminant, and its amount. Although determination of the purity and contamination of a fluid can be accomplished using various types of physical inline measurements, this study considers viscosity measurements technique. There are numerous possibilities of measuring dynamic viscosity of fluids in line. The principle of operation for a class of viscometer is based on resonance or vibrational techniques. These are essential for measuring viscosity of fluids in a production process. Continuous monitoring provides spontaneous information on product variations, which increases the consistency of products. In-line viscosity measuring and monitoring instruments can be used with non-Newtonian fluids, such as gels. Most common of these on the industrial scale is known as flexural mode operating type measuring instruments. Such an instrument consists of a laterally oscillating “finger” within the fluid of unknown dynamic viscosity [1-4]. In this study, however, an alternative type of measuring system, so called longitudinally vibrating disk method is investigated. The dynamic viscosity (η) of the fluid is measured as a product of ($\rho\eta$) and the relative change of the power input of the immersed vibrating disk into the fluid. The viscometer is calibrated at 25°C in air and distilled water. The device for monitoring contamination in flowing fluids according to the present study comprises means for determining frequency and amplitude of oscillations of a transducer, which are functions of the variations of viscosity and density of the monitored fluid. Further, this solution helps lowering the costs for system maintenance.

II. THEORY

2.1. Derivation of Equations

Let a thin plate with surface area S, fixed on a long bar with a total mass m, undergoes laminar harmonic vibrations due to the harmonic force F, in a limitless liquid with viscosity and density. The system is affected by the inertia where x is instantaneous displacement from the position of equilibrium; is the displaced liquid mass [2],
The second term in (1) characterizes the contribution to the inertia due to the part of liquid set in sinusoidal motion near the plate. The equation of motion of the suspended system will be The complete solution of this differential equation has the form where A0 initial amplitude, initial phase of natural vibrations of the suspended system which are determined from the original conditions; in particular, they can vanish or can have any arbitrary value reasonable for experiment conditions, and is the natural frequency of free vibrations of the suspended system.
In the steady state, the motion of the plate will be described by the second term only. The suspended

system undergoes harmonic vibrations at the vibration frequency of the excitation force with amplitude and the phase angle

For low viscosities, when 1 and the phase shift is 90o, the formula is simplified as Thus, in order to determine the viscosity, it is necessary to determine the peak amplitude of vibrations. The constant terms , are determined during the calibration tests using a liquid with known density and viscosity values with amplitude of vibrations,

or,

2.2. Electrical Equivalent Model of a Moving Coil Transducer:

An electrical equivalent circuit synthesis and realization for moving coil transducers can be performed using a model based circuit topology. In this work, we present the results of our laboratory measurements on a moving coil transducer (loudspeaker -driver-), and describe the method of obtaining its equivalent circuit parameters.

The moving coil (dynamic) transducer is a translational type, and a dynamic or permanent magnet loudspeaker is a typical moving coil transducer. A permanent magnet establishes a radial magnetic field in an annular air gap, the moving coil consists of a few turns of fine wire wound on a light form and supported in the air gap; it is attached to a light and stiff cone supported by a flexible suspension which keeps the cone and coil in place without restricting the axial motion [5].The current in the coil develops a force which is transmitted to the cone which produces a displacement. For small signal analysis, this can be simplified by using a two parts equivalent circuit model of a driver, as shown in Fig. 1. In the first part (electrical part), coil resistance and inductance are represented. The second part (mechanical part) consists of elements that represent the effect of cone suspension, inertia effects and the loading effect of medium. At low frequencies the effective mass of the cone presents a large mechanical admittance and velocity is reduced. To facilitate analysis of equivalent circuit, all mechanical quantities are referred to the electrical side.

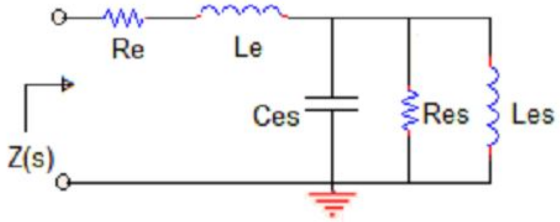

Fig.1. Electrical equivalent circuit for a dynamic transducer.

Note that, this circuit can be analyzed as a driving point impedance. In this model, so called Thiele/ Small parameters [6-8] are represented as follows:

Re=Minimum resistance value of driver coil,

Le=Inductance of coil,

Les=Compliance of suspension,

Ce=Mass of diaphragm,

Res=Mechanical damping,

f0= Resonance frequency of transducer, in Hz.

The maximum voltage drop occurs at the resonance frequency, f0 of the transducer, Magnitude of impedance at two bandwidth determining frequencies on either side of the resonance frequency are the same, The quality factor for the mechanical part is given by the following equations; where BW stands for bandwidth. Here, the angular resonance frequency term is Since are the measured parameters, and using (1) - (5), Using (5), At f=10 kHz, the impedance of the transducer helps to calculate electrical (coil) inductance,

III. EXPERIMENTAL

All measurements were conducted taking the temperature effects into account and registering ambient temperature and moisture during experiments using a thermo-hygrometer (TFA Dostmann, Wertheim, Germany). Fluid temperature values were measured using a mercury glass type thermometer (Sinar, Turkey). Distilled water was obtained from physics department (metrology lab). A wide-band digital true rms multimeter (Brymen BM907), and a signal generator with frequency counter (Tabor 8020) were used in these measurements. An oscilloscope (GwInstek GDS-2102) was used in addition to DMM for verification of the readings. The moving coil transducer used in these experiments is a 1W, 4Ω speaker. Fluid samples are contained in a slightly conical polystyrene cup. Besides the studies using distilled water, the fluid used is diluted ketchup in water solution which contains some xanthan gum. Equivalent circuit parameters were obtained by measuring and recording the impedance versus frequency data in different fluids. All measurements were conducted around 24℃. A voltage divider circuit is set up using a 10 Ω resistor and the driver. The voltage divider is fed by the signal generator through the resistor. A current is adjusted to flow through the voltage divider by setting the signal generator output voltage at 3 V (peak-to-peak) and 50 Hz. The voltage readings on two voltmeters are recorded. Then, the frequency output of signal generator is varied between 50Hz-10 kHz, (in 10Hz intervals between 50Hz-300Hz, 100Hz intervals between 300Hz-1000Hz, and 1kHz intervals between 1kHz-10kHz). The frequency output of signal generator at maximum impedance value is the resonance frequency. We measured minimum impedance magnitude and calculate Res. Then, R, Bandwidth, Ces, Les and Le parameters are determined using equations (15) - (23).

IV. RESULTS

By performing air and water calibration measurements with empty polystyrene cup in place, various tests were run. Fig 2 displays driving point impedance vs frequency graph for transducer one end of which is attached to driver cone while other end with a spindle and circular disk (plate) dipped in fluid contained in a polystyrene cup (the same cup used in all experiments). All experiments that were performed using fluid samples always employ the same cup at the same filling level.

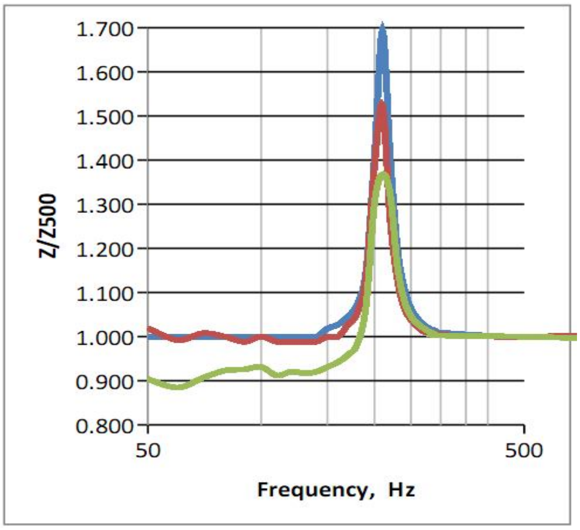

Fig.2. Scaled spectra of different media. Resonance frequency is 210 Hz for each value of peak signal generator voltage 5V. V1: Air (blue), V2: Water (red), V3: Diluted xanthan gum in water simulating the effect of a contaminant.

V. DISCUSSION AND CONCLUSIONS

There is a strong evidence that electrical (driving point) input impedance changes when the transducer operates in different media, that can be an argument for the use of impedance based vibrational analysis technique using a moving coil transducer, in contrast to existing methods. As a result of initial experiments, it is noted that, there is only a slight difference between measured and calculated vibration magnitude spectral results. The small difference is the observed slight peak at f = 3 kHz in measured magnitude spectra, which does not appear in computationally obtained spectra. Preliminary results obtained during these measurements suggest that the proposed method can

be useful in practice. However, more quantitative studies are required to assess the method, in depth. Here only the qualitative results are presented. Quantifying measured results needs to be done. We try to find an empirical relationship between observed impedance values and sample viscosities. Following are the points to consider for future improvements and modifications for this method: Signal generator output voltage may be set at a higher

level. Note that we used 3Vpp output level throughout our study due to our pre-fixed protocols, however it can be suggested that an increased voltage level may result in more accurate viscosity values. Provision of Standard Viscosity oil samples will greatly improve quantitative studies. Comparative viscosity measurements of standard

materials as well as other test samples by using an existing other type of (e.g., rotational) viscometer will significantly help to realize the intended vibrational viscometer, by benchmark analyses. We noted throughout our experiments that temperature is an important factor in this kind of measurement. Therefore, an empirical equation will be more reliable with the addition of temperature dependence parameter. This can be advantageous to re-scale the equipment for viscosity measurements performed at different temperatures.

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