NON-INVASIVE FLUID PROPERTY MEASUREMENTS USING ACOUSTIC METHODS

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ABSTRACT

Properties of a fluid are normally determined using invasive methods. These methods lead to possible contamination and/or consumption of the fluid sample. When only very small amounts of a valuable sample exist, non-invasive measurement methods are preferred.

Acoustic Wave Response Analysis is such a preferred measurement method. This technique analyzes known relationships between fluid properties in order to deduce additional characteristics of the fluid sample. In this presentation, we describe a technique involving excitation of the surface of the fluid and the measurement of its response. An acoustic transducer is used to excite and monitor the surface of a liquid sample. Using this technique, the surface tension and viscosity are measured. Concentration of the solution is determined by analyzing the relationship between these measured characteristics.

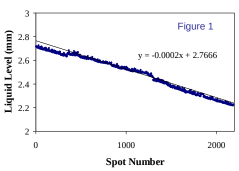
We employ this microfluidic technique in determining the concentration of DMSO and water in solution in 1536 wellplates for this poster presentation.

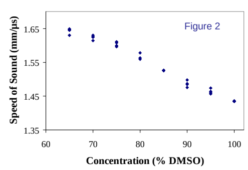
HYPOTHESIS

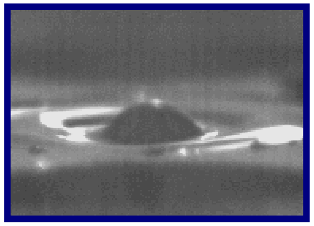
Acoustic Wave Response Analysis is based upon the idea that a fluid can be excited with acoustic energy and the response can be measured using an acoustic measurement technique. When a fluid is placed in a microtiter plate it occupies a roughly cylindrical volume. The surface of the fluid can be described as a circular membrane. The oscillation modes of a circular membrane have been studied extensively. These modes of oscillation can be summarized as symmetric and asymmetric modes. If the circular membrane is excited in the center, the symmetric modes are excited, and the asymmetric modes remain quiet.

When the circular membrane is stimulated, several symmetric modes of vibration begin to oscillate. The lowest frequency mode is known as the (0,1) mode. The frequency of this oscillation is dependent on the diameter of the well and the surface tension of the fluid in the well. The higher the surface tension, and the smaller the well diameter, the higher the frequency of oscillation. The (0,2) and (0,3) modes also contribute to the symmetric oscillation of a circular membrane. The (0,2) mode oscillates at 2.295 times the frequency of the (0,1) mode. The (0,3) mode oscillates at 3.598 times of the (0,1) mode's frequency.

Similarly, when these three modes are stimulated the amplitudes will decay in a short time. How fast these oscillations decay is partially dependent on the viscosity of the fluids on both sides of the membrane—the air and the fluid in the well.







Acoustic Pressure Applied – Mound Forms

MATERIALS AND METHODS

LIQUID LEVEL MEASUREMENT

The amount of liquid in a well can be measured by a sonar technique. A small burst of acoustic waves is directed toward the surface of the liquid. The sound waves travel through a coupling fluid, the bottom of the well plate, and through the liquid. The waves reflect off the surface of the fluid and back toward the source. Using the speed of sound of the liquid, one can use the difference between the time when the burst is generated and when it's reflection is received to calculate the depth of the liquid in the well.

SPEED OF SOUND MEASUREMENT

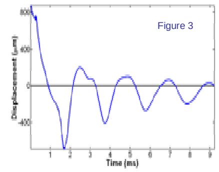
The distance measured is equal to the speed of sound times the time the burst takes to traverse the distance. Therefore, the speed of sound for the material can be measured if the volume of the fluid and the shape of the container are known. By using several wells filled to a known level and measured several times, a very reasonable measurement of the speed of sound can be determined.

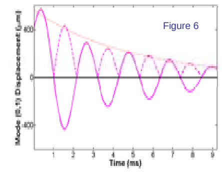
SURFACE STIMULATION MEASUREMENT

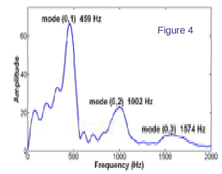
Producing a focused acoustic wave of significant duration, stimulates the surface of a fluid. When the surface of the fluid is stimulated, the surface begins to rise. If the surface is stimulated long enough, a drop of fluid can be ejected from the surface of the fluid. However, if less energy is used, and a drop of fluid is not forced to be ejected, the surface will simply be raised. If the focused acoustic wave ceases to stimulate the surface, the surface will continue to rise until the force of the surface tension counters the momentum of the surface.

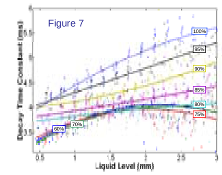
Once the surface of the fluid has been stimulated, its movement can be measured. This is accomplished by measuring the position of the surface at regular intervals. The surface is measured by using a standard sonar technique. A short burst of sound is transmitted and the reflections from that short burst are timed. Based on the speed of sound through the different materials, the distance can be calculated. If a short burst and pause are generated and the reflections are detected, the distance can be measured over and over as the surface is moving. The result is a sample of the position of the surface after each measurement.

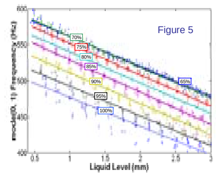
Once the oscillation of the surface has been detected, a Fast Fourier Transform (FFT) is used to separate the three different modes of oscillation by frequency. An Inverse Fourier Transform is then performed on the separated frequencies, yielding three decaying waveforms.

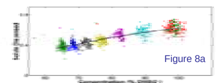


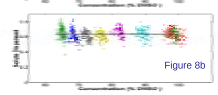












ATS-100

Acoustic Transfer System

RESULTS

LIQUID LEVEL MEASUREMENT

The sensitivity of our liquid level measurement can be demonstrated by draining a well. A well is drained by ejecting a drop of a known volume from the same well over and over again. Before each drop ejection, the level of the liquid in the well is measured. By graphing the liquid level measured for each drop on the y-axis and the number of the drop on the x-axis, we can show how repeatable the measurement can be (Figure 1).

SPEED OF SOUND MEASUREMENT

Similarly the speed of sound is measured by putting a known amount of a fluid in a well. The time for the pulse to reflect off the surface of the fluid is then determined. By measuring the time several times, a very good determination of the speed of sound for a fluid can be measured.

The speed of sound of a DMSO/water solution was measured at several concentrations (65% - 100%). The fluid is placed in a well to slightly overflowing. A glass cover is then placed over the well displacing the fluid and preventing any air from being trapped. In this situation, the depth of the well is known precisely based of the construction of the wellplate. The travel time of the pulse is then measured and the speed of sound for each concentration is measured (Figure 2).

SURFACE TENSION MEASUREMENT

The surface tension can be determined by stimulating the surface of the fluid, continuously measuring the position of the surface, and detecting the oscillation (Figure 3). The frequency of the oscillation is related to the tension of the membrane or surface of the fluid. In general, three modes of oscillation are excited when the surface is stimulated. A Fast Fourier Transform (FFT) is performed on the data (Figure 4) and the values of the three frequencies are extracted.

A wellplate is filled with different DMSO concentrations at different liquid levels. Data is taken at each well location, and the oscillation frequency of the (0,1) mode is determined for each well. The relationship between the depth of fluid in the well, the concentration of DMSO/water solution, and the frequency of oscillation are shown (Figure 5).

VISCOSITY MEASUREMENT

Similarly, viscosity can be determined by measuring the dampening of the oscillation. By selecting the data in the FFT plot around the (0,1) frequency peak, the time domain data can be reconstructed using an Inverse Fast Fourier Transform (IFFT). The result is a reconstructed (0,1) waveform extracted from the data using the IFFT (Figure 6). The absolute values of the peaks are fitted to an exponential function. The decay time constant is plotted for different DMSO/water concentrations (viscosities between 1-4 cP) as a function of liquid level (Figure 7).

SUMMARY

Acoustic Wave Response Analysis measures fluid properties to a high certainty. This microfluidic method has been integrated into EDC Biosystems' ***True Non-Contact Technology™*** for liquid dispensing. As source DMSO solutions absorb or evaporate water, the system is able to alter the volume dispensed in order to transfer the proper amount of solute to the target. This is demonstrated with the use of florescence dissolved in 100% DMSO. Water has been added to the solution to produce various concentrations of DMSO and water. The difference between non-compensation and compensation is shown (Figure 8).

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