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Improvement of estimation method for physical properties of liquid using shear horizontal surface acoustic wave sensor response

横波型弾性表面波センサ応答を用いた液体の物性値推定法の改善

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1. Introduction

On-line measurement of liquid properties is required in industrial fields, such as automobiles, chemistry, pharmaceuticals and petrochemicals. Shear horizontal surface acoustic wave (SH-SAW) sensor has advantages of simultaneous detection of liquid mechanical and electrical properties. Also, the SH-SAW liquid-phase sensor is high sensitivity, small size and low cost. In the previous study[1], we proposed the determination method of viscosity and density. However, bulk modulus of liquid was assumed as constant. The estimated results didn't match the literature values[2]. The constant of bulk modulus is considered to be the major cause. In order to improve the accuracy, we derived and considered the bulk modulus in addition to density and viscosity. Glycerol solution and ethanol solution were measured with SH-SAW sensor. And the estimation results were compared with the literature values.

2. SH-SAW sensor

The SH-SAW sensor consists of input and output interdigital transducers (IDT) fabricated on 36ºYX-$LiTaO_3$ (**Fig 1**). When an electrical signal is applied to the IDT, the SH-SAW is excited. It propagates on the substrate and is reconverted into the electric signal by the output IDT. When a liquid is placed on the SH-SAW propagating surface, the phase and amplitude of it are perturbed. By detecting phase and amplitude, it is possible to determine the properties of liquid, that are density, viscosity and bulk modulus.

The center frequency of SH-SAW sensor we used was 51.5 MHz. Reference liquid was water. Velocity change $\Delta V/V$ and attenuation change $\Delta\alpha/k$ were calculated from the phase difference and the amplitude ratio from the reference, respectively.

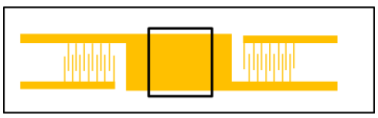

Fig 1　SH-SAW sensor

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3. Improvement points of estimation method

Density and viscosity are related to bulk modulus. As they increase, the bulk modulus also increases. If three parameters increase, the velocity and attenuation of the SH-SAW increase. For example, we consider the case when the bulk modulus of the sample is larger than it of water. Since the bulk modulus of water is smaller than the actual value of a sample, the estimated values of density and viscosity becomes larger. Therefor, it is necessary to increase the bulk modulus because the density and the viscosity increase. To approach the bulk modulus to the actual value, it is calculated by using the average of estimated value and it of water. The specific procedure is written in the following.

1) Density ρ and viscosity η are derived using the previous method[1)]. The bulk modulus K of a sample is assumed as the same with water.

2) The average of the derived value and water is expressed as ρ' and η'. Then, using ρ' and η or ρ and η', K is changed in an arbitrary range to obtain data of $\Delta V/V$ and $\Delta\alpha/k$.

3) To find optimum value of K which minimizes the difference D between the value obtained in 2) and the value obtained from the measured value, using the following formula.

$$D=|\{(\Delta V/V)-(\Delta V/V)_m\}/(\Delta V/V)_m|+|\{(\Delta\alpha/k)-(\Delta\alpha/k)_m\}/(\Delta\alpha/k)_m|$$

The bulkmoduls derived from ρ' and η or ρ and η' are expressed as $K1$ and $K2$, respectively. Note that $K1$ obtained on average with water is expressed as $K1_1$.

4) The average of $K1$ and $K2$ becomes K and it is substituted into the method used 1) to derive ρ and η again.

Process from 1) to 4) is the first loop to determine liquid properties.

5) For the second and subsequent loops, the average

of ρ' and η' obtained at the previous loop are used to calculate liquid properties in the same way.

6) The loop ends in five times. The final values are estimated values.

4. Re-delivery from literature values

$\Delta V/V$ and $\Delta\alpha/k$ were determined from the literature values[2] of glycerol solution using conventional forward problem analysis method[3,4]. Then, the re-derived values were compared with the literature values. The temperature was 20°C. The results are shown in **Table 1**. From the results, it was found that $K1_1$ is close to the literature value. Viscosity has a large influence on bulk modulus, so it may not be averaged. Although the reason is not clear, since $K1_1$ was effective, it was also compared with the case using $K1_1$. From Table 1, it can be seen that the physical property values can be well estimated. Physical property values can be better estimated by using $K1_1$ than finally obtained K.

Table 1 Re-delivery from literature values

Bulk modulus [Pa]

	5wt%	10wt%	30wt%	50wt%
Literature	2.286E+09	2.38E+09	2.791E+09	3.258E+09
Estimated(K)	2.276E+09	2.361E+09	2.768E+09	3.397E+09
Difference	−0.42%	−0.80%	−0.84%	4.26%
Estimated(K1)	2.283E+09	2.373E+09	2.785E+09	3.363E+09
Difference	−0.12%	−0.30%	−0.23%	3.24%

Density [kg/m^3]

	5wt%	10wt%	30wt%	50wt%
Literature	1.010E+03	1.022E+03	1.072E+03	1.125E+03
Estimated(K)	1.015E+03	1.033E+03	1.085E+03	1.053E+03
Difference	0.56%	1.10%	1.21%	−6.46%
Estimated(K1)	1.011E+03	1.026E+03	1.075E+03	1.070E+03
Difference	0.14%	0.39%	0.31%	−4.93%

Viscosity [Pas]

	5wt%	10wt%	30wt%	50wt%
Literature	1.127E−03	1.291E−03	2.458E−03	6.040E−03
Estimated(K)	1.120E−03	1.276E−03	2.439E−03	6.470E−03
Difference	−0.63%	−1.13%	−0.75%	7.13%
Estimated(K1)	1.125E−03	1.286E−03	2.462E−03	6.364E−03
Difference	−0.20%	−0.42%	0.17%	5.38%

5. Estimation from measured values

The results obtained from measured values are shown in **Table 2**. The finally obtained K is close to the literature value, but the density and viscosity are greatly distant. When $K1_1$ is used, the bulk modulus is more distant but the density and the viscosity are closer. Although not shown here, it was same in the case of ethanol solution. Even if the bulk modulus was accurately derived, the density and the viscosity could not be derived with high accuracy. The reason is considered that the temperature is not accurate and the liquid pool is slightly inclined. Therefore, it was found that more accurate measurement is necessary to estimate the physical property.

Table 2 Estimation from measured values

Bulk modulus [Pa]

	5wt%	10wt%	30wt%	50wt%
Literature	2.286E+09	2.380E+09	2.791E+09	3.258E+09
Estimated(K)	2.230E+09	2.350E+09	2.770E+09	3.334E+09
Difference	−2.44%	−1.26%	−0.78%	2.33%
Estimated(K1)	2.089E+09	2.229E+09	2.514E+09	3.150E+09
Difference	−8.60%	−6.35%	−9.94%	−3.30%

Density [kg/m^3]

	5wt%	10wt%	30wt%	50wt%
Literature	1.010E+03	1.022E+03	1.072E+03	1.125E+03
Estimated(K)	9.022E+02	9.304E+02	8.609E+02	8.965E+02
Difference	−10.65%	−8.92%	−19.67%	−20.34%
Estimated(K1)	1.011E+03	1.002E+03	9.972E+02	9.877E+02
Difference	0.14%	−1.93%	−6.95%	−12.24%

Viscosity [Pas]

	5wt%	10wt%	30wt%	50wt%
Literature	1.127E−03	1.291E−03	2.458E−03	6.040E−03
Estimated(K)	1.420E−03	1.659E−03	4.155E−03	9.113E−03
Difference	25.98%	28.52%	69.05%	50.88%
Estimated(K1)	1.296E−03	1.539E−03	3.568E−03	8.260E−03
Difference	14.99%	19.22%	45.14%	36.77%

6. Conclusion

In this paper, we derived and considered the bulk modulus to improve the estimation method for physical properties of liquid using SH-SAW sensor response. It was possible to estimate from literature values. However, the estimation accuracy from the measured values was low. In the future, in addition to improving the estimation method, it is necessary to make more accurate measurements.

References

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