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Tissue-mimicking Materials for various kind of Phantoms

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***Abstract*—We present a tissue-mimicking material for the phantom of medical diagnostic instruments. Accurate testing of an instrument by phantoms requires a tissue-mimicking material that has the acoustic velocity, density, and attenuation defined in the International Electrotechnical Commission (IEC) standard, and furthermore the tissue-mimicking material must be stable over time. To achieve the material with the desired acoustic velocity, density, and attenuation, we have developed a new swollen segmented polyurethane gel. To realize the gel with low attenuation, we have discussed liquid composition of the gel. Acoustic properties of binary mixtures of tetraethylene glycol dimethyl ether with 1-ethyl-3-methylimizazolium dicyanamid, 1-butthyl-3-methylimizazolium dicyanamide, and 1-ethyl-3-methylimizazolium thiocyanate have been experimentally investigated.**

Keywords—tissue-mimicking material, phantom, swollen segmented polyurethane gel, ionic liquid, 1-ethl-3-methylimizolium dicyanamide, 1-buthyl-3-methylimizolium dicyanamide

I. INTRODUCTION

Phantoms have been used for the acceptance testing, quality assurance testing, and clinical calibration of diagnostic ultrasound equipment. Accurate testing of an instrument by phantoms requires a tissure-mimicking material (TMM) that has the acoustic velocity, density, and attenuation defined in the International Electrotechnical Commision (IEC) standard [1], and furthermore the tissue-material must be stable over time. Various phantoms have been developed using hydrogels made from agars or organogels of oil-in-gelatin [2], [3]. The conventinal gel materials have disadavntages such as a change in quality by bleeding water or oil as a dispersion medium. It has been reported that the weight stability of gelatin gel is 30 wt % . At surrounding air temperatures of 277 and 293K over 10 days [4]. In addition, hydrogel or oil-gel is is fragle, so they naturally change quality over time.

We have adopted a new permanent gel as a TMM to solve the above problems. The gel originates from one component, segmented polyurethane gel (SPUG), and it is reported that the long-term quality of the material has been maintained [5]. The gel is swollen SPUG (S-SPUG), in which liquids exist among SPUG network as dispersion media to acquire the low attenuation. To achieve the SPUG with desired acoustic velocity and density, a binary mixture of tetraethylene glycol dimethyl ether (TETRAGLYME) with 1-butyl-3-methylimidazolium thiocyanate ([BMIM][SCN]) [6].

However, the weakness of [BMIM][SCN] is high attenuation. To solve the problem we have searched the ionic liquids with lower attenuation.

II. MATERIALS AND EXPERIMETAL RESULTS

In this study, our aim is to develop a new TMM with the acoustic velocity, density, and attenuation defined in the IEC standard [1]. The parameters of TMM defined in the IEC standard are shown in Table I.

TABLE I. PARAMETERS OF TMM SPECIFIED IN IEC STANDARD. f IS THE ACOUSTIC FREQUENCY (HZ)

Acoustic velocity	(1540 ± 15) ms^{-1}
Characteristic acoustic impedance	$(1.60\pm0.16)\times10^{6}$ kgm^{-2}s^{-1}
Attenuation	$(0.5\pm0.05)\times10^{-4}\times f$ dBm^{-1}Hz^{-1}

We have synthesized a permanent gel that originates from one component, with SPUG with liquid [6]. The gel consists of

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a swollen SPUG (S-SPUG), in which liquid TETRAGLYME exists among SPUG network as dispersion media. The physical properties of the S-SPUG are shown in Table II.

TABLE II. PHYSICAL PROPERTIES OF S-SPUG AT THE TEMPERATURE 295.0 K.

Acoustic velocity	1427 ms^{-1}
Density	1.030×10^{6} kg m^3

As shown in Table III, the acoustic velocity of S-SPUG is nearly depend on that of TETRAGLYME.

The material with the acoustic velocity and density defined in the IEC standard had been achieved by dispersing PMMA particles of 20 wt% in S-SPUG [7]. However, the attenuation constant of the material is larger than the value defined in the IEC standard.

In order to solve the problem, we have developed the new S-SPUG with the desired acoustic velocity and lower attenuation constant.

We have search the ionic liquid with lower attenuation constant. We have noted the that the attenuation of liquid is depend on the viscosity [8].

We have found the ionic liquids with lower viscosity that are commercially available. The acoustic velocities and viscosities of the ionic liquids and the ethylene glycol dimethyl ethers measured by us are shown ion Table III.

TABLE III. Experimental densities, acoustic velocities and viscosities for the pure liquids at the temperature 295.0K.

Materials CAS RN	**Physical Properties**		
	Density (g/cm^3)	*Acoustic velocity (m/s)*	*Viscosity (mPa.s)*
DIGLYME[1] 111-96-6	0.9424	1291	1.083[8]
TRIGLYME[2] 112-49-2	0.9831	1359	2.26
TETRAGLYME[3] 143-24-8	1.0097	1396	3.73
[EMIM][DCA][4] 370865-89-7	1.1024	1797	14.67
[BMIM][DCA][5] 448245-52-1	1.0606	1742	32.60
[EMIM][SCN][6] 331717-63-6	1.1168	1869	25.42
[BMIM][SCN][7] 344790-87-0	1.0687	1771	58.10

[1] Diethylene glycol dimethyl ether
[2] Triethylene glycol dimethyl ether
[3] Tetraethylene glycol dimethyl ether
[4] 1-ethyl-3-methylimizazolium dicyanamide
[5] 1-buthyl-3-methylimizazolium dicyanamide
[6] 1-ethyl-3-methylimizazolium thiocyanate
[7] 1-buthyl-3-methylimizazolium thiocyanate
[8] Measurement of viscosity by Ubbelohde viscometer

The acoustic velocities, densities, and viscosities of binary mixture of ethylene glycol dimethyl ethers with [EMIM][DCA], [BMIM][DCA], [EMIM][SCN], and [BMIM][SCN] at the temperature of 295.0 K have been measured.

The relation between acoustic velocity and ionic liquid concentration of binary mixtures of the TETRAGLYME with the ionic liquids were measured by the sing -around system. The relation between viscosity and ionic liquid concentration of the binary mixtures were experimentally obtained. The examples of measured results ae shown in figure 1 and 2.

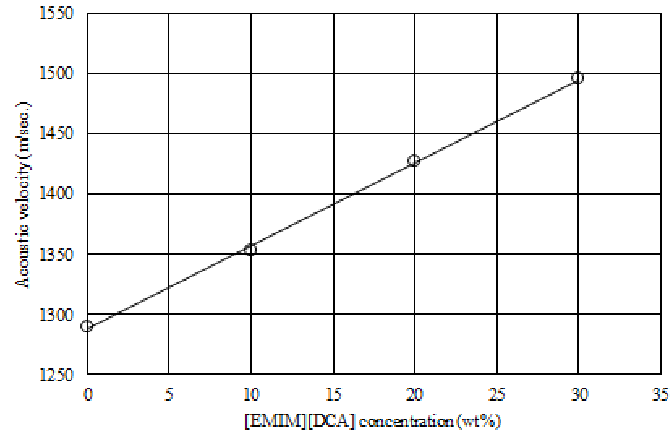

Fig.1 The acoustic velocity of the S-SPUG as a function of concentration of [EMIM][DCA]. The liquid dispersed in S-SPUG is a binary mixture of TETRAGLYME with [EMIM][DCA].

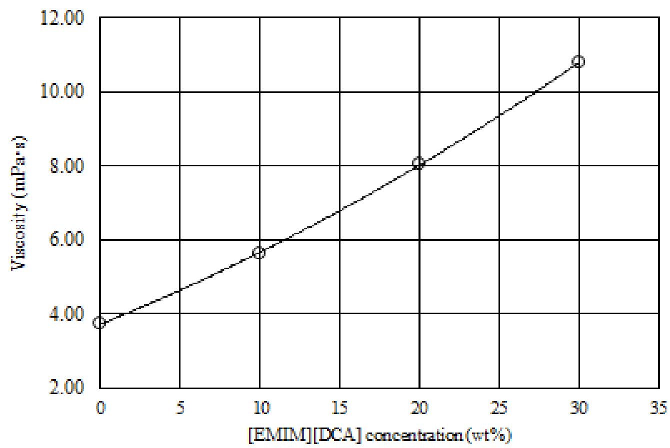

Fig.2 The viscosity of the S-SPUG as a function of concentration of [EMIM][DCA]. The liquid dispersed in S-SPUG is a binary mixture of TETRAGLYME with [EMIM][DCA].

On the measured results, the relations between the acoustic velocity and viscosity of binary mixtures of the ethylene glycol dimethyl ethers with the ionic liquids are summarized in Figure3.

Figure 4 indicates that the binary mixture of DIGLYME and TETRAGLYME with [EMIM][DCA] may result in minimum viscosity at the region from 1400 to 1500 m/s.

The S-SPUG dispersed the binary mixture of TETRAGLYME with [EMIM][DCA] has been manufactured. The S-SPUG is shown in Figure 5. The S-SPUG with PMMA particles is shown in Figure 6.

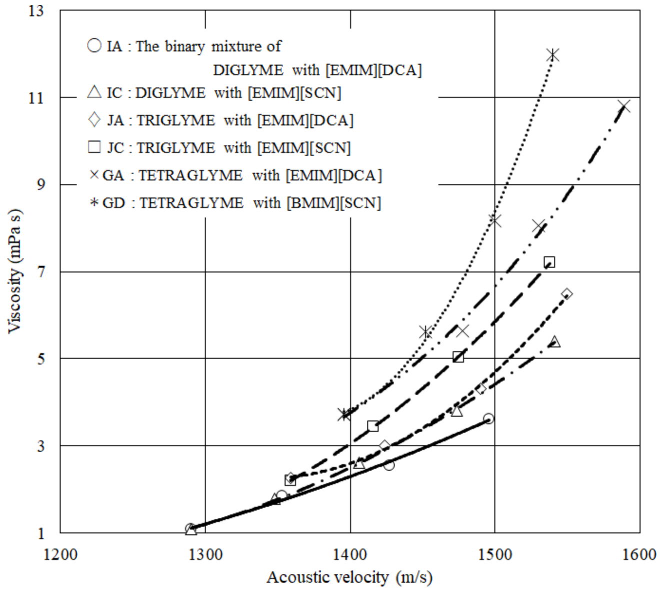

Fig.3 The relation between the acoustic velocity and viscosity of binary mixtures of the ethylene glycol dimethyl ethers with ionic liquids.

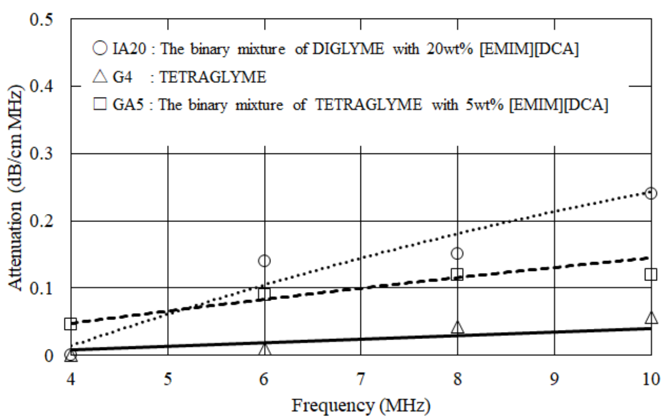

Fig. 4 The attenuation of the S-SPUGs as a function of acoustic frequency.

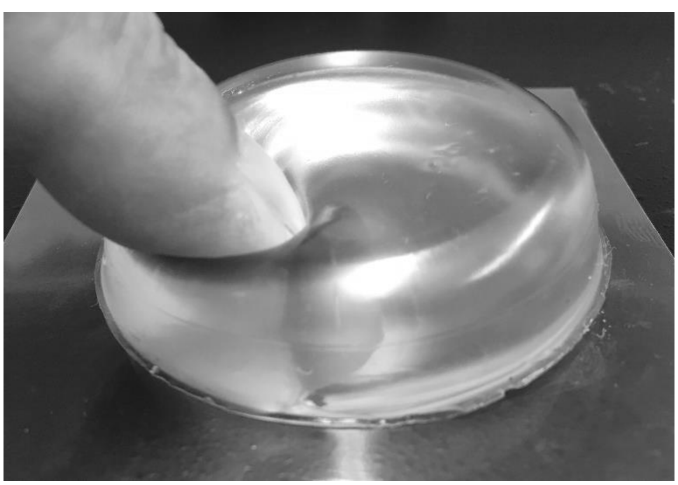

Fig. 5 The external view of S-SPUG.
PMMA particles are not dispersed in the gel.

Fig.6 The external view of a cell for acoustic velocity and attenuation measurement of S-SPUG. The S-SPUG is dispersed PMMA particles.

III. Conclusion

We have a new TMM with low attenuation. The material has been achieved by the S-SPUG with a binary mixture of TETRAGLYME and [EMIM][DCA] and PMMA particles.

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