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Proceedings of Symposium on Ultrasonic Electronics, Vol. 34 (2013) pp. 319-320
20-22 November, 2013

Blood Mimicking Fluid Using Polyethylene Glycol Aqueous Solution and Their Physical Properties

ポリエチレングリコール水溶液による疑似血液とその物性

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1. Introduction

The measurement of blood flow by the use of Doppler ultrasound is based upon the phenomenon that the frequency of ultrasound is changed when reflected from moving particles of blood within the blood flow. This change of frequency is called the Doppler shift and is proportional to the velocity of blood flow. The performance of Doppler ultrasound equipment can be evaluated with various test objects. To make tests meaningful, the acoustic properties of the main components (tissue-mimicking material and blood-mimicking fluid) of the phantom should closely match those of the corresponding human tissues. The properties of the blood-mimicking fluid (BMF) should also correspond to those of human blood.

The acoustic properties of a BMF for flow phantoms are defined in the international standard[1)] documented by the International Electrotechnical Commission (IEC). We developed a new BMF satisfied in the IEC standard and the details were reported. The viscosity of the BMF defined the IEC is $4 \cdot 10^{-3}$ (Pa s) and the value is independent in the velocity of a BMF flow. On the other hand the viscosity of human blood ranges from 2 cP to $2 \cdot 10^{2}$ cP depended on the shear rate of the blood. The typical experimental data is shown in **Fig.1**[2)].

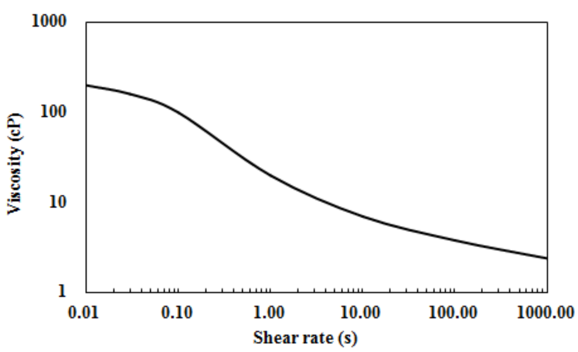

Fig.1 Relatonship between shearrate and viscosity of human blood.

In the experiments adopted flow phantoms with vessels of various diameters the BMF with the different viscosity from IEC standard is desired.

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The BMF developed by us is adopted water -soluble silicone oil and glycerin-aqueous-solution dispersed polystyrene particles[3)]. In the newly developed BMF the glycerin-aqueous-solution has been exchanged polyethylene glycol aqueous solution. The viscosity of polyethylene glycol is depended on its molecular weight, but the density and acoustic velocity are practically not depended on the molecular weight. We have taken the advantage of the futures of polyethylene-glycol and developed the new BMF.

2. Method

In this study, our aim is to develop a BMF with the acoustic velocity and density defined in the IEC standard[1)] and the arbitrary viscosity.

To achieve the new BMF, we proposed that water-soluble silicone oil and polyethylene-glycol -aqueous-solution dispersed polystyrene particles be adopted in the BMF.

To develop a liquid for the new BMF, we have adopted a new method for designing experiments with a mixture that has been devised by Scheffé[18)]. In a three-components system, a general polynomial model[19)] that expresses a response, η, as a function of components x_1, x_2, and x_3 is

$$\eta=\beta_1x_1+\beta_2x_2+\beta_3x_3+\beta_{12}x_1x_2+\beta_{13}x_1x_3+\beta_{23}x_2x_3+\beta_{123}x_1x_2x_3,$$

$$x_1+x_2+x_3=1, \qquad (1)$$

where β_1, β_2, β_3, β_{12}, β_{13}, β_{23}, and β_{123} are constants.

In the nomenclature proposed by Scheffé, seven equations with seven coefficients exist, where the seven coefficients are unknown. We now have seven equations containing seven unknowns. The experimental data η for seven sets of values of x_1, x_2, and x_3 can be used to design the BMF.

The response of η to components of x_1, x_2, and x_3 are given by the experimental data shown in **Table I**. With the substitution $\eta = C_0$ or $\eta = \rho_0$, the general equation given by eq. (1) can be rearranged. The values of ρ_0 and C_0 for different sets of values of x_1, x_2, and x_3 are given by the experimental data shown in Table I, where ρ_0 and C_0 are the density and velocity of the samples, respectively, and x_1, x_2, and x_3 are the components of water, water-soluble results shown in Table I give the values of ρ_0, C_0, x_1, x_2, and x_3 in eq. (1).

Table I. Composition physical properties of polyethylene-glycol (#400) and water soluble silicon oil (KF-642) aqueous solutions. (temperature:22.0C°)

Water (wt %)	Silicon Oil (wt %)	Polyethylene-glycol (wt %)	Acoustic Velocity (m/s)	Density (10^3 kg/m^3)
100.0	0.0	0.0	1492.5	0.998
60.0	20.0	20.0	1577.0	1.050
40.0	30.0	30.0	1572.5	1.072
80.0	10.0	10.0	1548.6	1.024
90.0	0.0	10.0	1542.3	1.016
80.0	0.0	20.0	1608.3	1.034
90.0	5.0	5.0	1516.6	1.016

$\beta_1=0.998$

$0.6\beta_1+0.2\beta_2+0.2\beta_3+0.12\beta_{12}+0.12\beta_{13}+0.04\beta_{23}$
$+0.024\beta_{23}=1.050$

$0.4\beta_1+0.3\beta_2+0.3\beta_3+0.12\beta_{12}+0.12\beta_{13}+0.09\beta_{23}$
$+0.036\beta_{23}=1.072$

$0.8\beta_1+0.1\beta_2+0.1\beta_3+0.08\beta_{12}+0.08\beta_{13}+0.01\beta_{23}$
$+0.009\beta_{23}=1.024$

$0.9\beta_1+0.1\beta_3+0.09\beta_{13}+0.09\beta_{23}=1.016$

$0.8\beta_1+0.2\beta_3+0.16\beta_{12}=1.034$

$0.9\beta_1+0.05\beta_2+0.05\beta_3+0.045\beta_{12}+0.045\beta_{13}$
$+0.062\beta_{23}+0.00225\beta_{23}=1.016$

Solving the seven equations simultaneously, which is possible since the number of equations is equal to the number of unknown parameters, we can determine β_1, β_2, β_3, β_{12}, β_{13}, β_{23}, and β_{123}. The density ρ_0 and acoustic velocity C_0 of the solution with three components, i.e., water, water-soluble silicon oil, and polyethylene-glycol can be given. An optimum mixing ratio of the aqueous solutions was decided on the method.

3. Experimental

We obtained the following experimental results on the acoustic velocity, density, and viscosity of polyethylene-glycols.

Table II. Acoustic properties and viscosity of polyethylene-glycols. (temperature:22.0 C°)

Molecular weight (M)	200	400	600
Acoustic velocity (m/s)	1612	1604	1598
Dnesity (10^3 kg/m^3)	1.126	1.126	1.126
Viscosity (cSt)	50.3	94.7	141.0

From the experimental data show in **Table II** it is concluded that polyethylene-glycaols are practically not depend on their molecular weight. The viscosity of polyethylene-glycols largely increases with their molecular weight. The experimental results on the viscosity of polyethylene glycol aqueous solutions are shown in **Fig.2**. The results indicate that the viscosity of the BMF can be adjusted by mixing the appropriate molecular weight of polyethylene glycol.

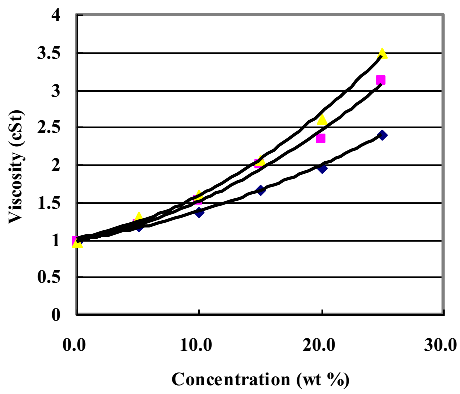

Fig.2 The relationship between the viscosity and concentration of polyethylene glycol aqueous solutions. (temperature:22.0 C°)

In the BMF made from water, water-soluble silicon oil, and polyethylene-glycol the acoustic velocity and density are not depended on the molecular weight, but the viscosity is depended on the molecular weight. On the characteristics related above we have realized the BMFs with the optimum viscosity for the experiments.

4. Conclusion

We have developed the BMF with the acoustic velocity and density defined IEC standard and the various viscosity

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