ISSN: 2456-8473
International Journal of Chemistry, Pharmacy & Technology
Vol. 2, No.5, pp-220-231, 2017

A NEW BLOOD MIMICKING FLUID USING PROPYLENE GLYCOL AND THEIR PROPERTIES FOR A FLOW PHANTOM TEST OF MEDICAL DOPPLER ULTRASOUND

Ammar A. Oglat[1*], MZ Matjafri[1], Nursakinah Suardi[1], Mohammad A. Oqlat[2], Ahmad A. Oqlat[3] and Mostafa A Abdelrahman[3]

[1] Department of Medical Physics and Radiation Science, School of Physics, Univirsti Sains Malaysia, 11800 Penang Malaysia

[2] Department of Biological Sciences, School of Science, Yarmouk University, Irbid Jordan

[3] Faculty of Medicine, J.U.S.T University, Irbid Jordan

Corresponding Author: ammar.oglat@yahoo.com

Received 15-04-17; Revised & Accepted: 25-05-17

ABSTRACT

The most common scattering particle materials for preparation of Blood Mimicking Fluid (BMF) are the nylon (Orgasol) and the polystyrene. These scatters particle materials density must be equal with mixture fluid density during preparing BMF. In this research study, low cost and less consuming time of a new proper ternary mixture fluid for the preparation of BMF was used to be suitable for the nylon (Orgasol) or the polystyrene density as a scattering particle material, for keep neutrally buoyant. This BMF proper for utilizing in Doppler flow phantom or test objects. The polystyrene and nylon particles were used for suspension in a mixture fluid base of three items, distilled water, propylene glycol and glycerol. The diameter of polystyrene particles is 30 µm, where its density 1.050 g/ml. While the diameter of nylon particles is between 5-15 µm, where its density depends on the type of nylon. Both the acoustical (speed of sound and attenuation) and physical (density and viscosity) properties of the mixture fluid or BMF were measured and agreed with draft International Electrotechnical Commission (IEC) requirements and values.

Keywords: Physical properties, acoustical properties, Propylene glycol, Blood Mimicking Fluid (BMF), Urick formula.

INTRODUCTION

Applying Doppler ultrasound mechanism for measuring the blood flow in vessels relies on the variation of ultrasound frequency waves which are reflected from movable scattered particles of blood during the blood flow. The changes of frequency known as the frequency shift or Doppler shift and rise with rising the speed of blood flow [1]. The implementation of Doppler medical ultrasound equipment can be estimated with various test objects [2][3][4][5]. This test object can also be called as flow phantom which has been utilized in the research field. The tissue-mimicking material (TMM) and blood mimicking fluid (BMF) should have suitable acoustical and physical properties that nearly match with the human tissue and blood to allow the examination more meaningful.

The International Electrotechnical Commission (IEC) utilized as a standard and fixed amounts of the physical and acoustical properties of Blood Mimicking Fluid(BMF) for test object or flow phantoms (see table 1). There are several diversities of Blood Mimicking Fluids (BMF) that have been reported in several studies [6-10]. However, various types of scattered particles materials which used as a suspension particles in Blood Mimicking Fluid (BMF) to produce and create scattering influence.

Classical BMFs have included materials acting as a scattered particles such as starch, Sephadex, nylon powder (Orgasol), silicon powder, and polystyrene microspheres in the fluid to compose BMF which applied for different targets. The densities of these scattered particles material are displayed in Table II. However, the densities of the scattered particles materials must be matched with the densities of the liquid mixture, to avoid both the float or deposit down of the scattered particles items, and to permit preserve neutrally buoyant of those particles inside this liquid. For example, the densities of Orgasol (nylon) particles are different according to their types, like nylon (2001UDNAT1, 2001EXDNAT1, and 2002DNAT1) have density of 1.03 g/ml, therefor, the mixture's liquid density must match with this this density to preserve a neutrally buoyant of scattered particles material in the mixture liquid. Similarly, polystyrene microsphere has a density of 1.050 g/ml, thus, the mixture liquid should have a density matches with the polystyrene density to keep neutrally buoyant. In addition, the densities of mixture liquid and BMF after preparation must match with the fixed values which are defined in IEC standard. In this experimental study, our purpose is to produce BMFs with both the physical and acoustical features known in the IEC standard requirements, and the dynamic viscosity from 4 and more since the BMF is Newtonian and not depends on the shear rate.

Table I: The BMF properties (acoustical and physical) which defined in the IEC standard.

Viscosity ($\times 10^{-3}$ Pas)	4.0 ± 0.4
Acoustic speed (m/s)	1570 ± 30
Attenuation [(dB/cm/MHz)]	$<0.1 \times 10^{-4} \times f$
Density ($\times 10^{3}$ kg/m^{3})	1.050 ± 0.040

MATERIAL AND METHODS

The fluid mixture and BMF is prepared in the following method:

- Using plastic beaker with size two times the amount of wanted fluids for preparation of BMF to avoid overflow of the components during stirring. The plastic beaker cleaned carefully and properly with plenty of distilled water and then wiped with tissue or clean wipers.
- Put a magnetic stirrer rod into the clean plastic beaker. The diameter of a plastic beaker is 7cm larger than the magnetic stirrer rod (2cm) to allow complete mixing over stirring.
- Weigh all of the fluid components which is required for the sample such as, propylene glycol, distilled water, and glycerol in a fume hood and pour them into the plastic beaker.
- Put the beaker on the stirrer plate then turn it on and allow the components stirring inside the beaker for 20 minutes for each sample, and set the room temperature to be 37±0.7˚C where the stirrer plate rotate per minute was 700 rpm.

- After the 20 minutes of stirring are completed, turn off the stirrer plate then using a vacuum pump device to degas the fluid mixture for 30 minutes. After this, measure both the acoustical (speed of sound and attenuation) and physical (density and viscosity) properties of fluids of each sample.
- Choose the best mixture fluid sample which has suitable speed of sound, viscosity and density which match to the defined IEC standard. The density of sample liquid must be match to the nominal density of scattered particles material to allow keep neutrally buoyant of scattered particles material inside this liquid.
- Measure the required amount of scattered particles material in the fume hood and then put it into the plastic beaker. During this step, the scattered particles (powder material) should sit on the surface top of the mixture fluid and do not attempt to stirring it inside the plastic beaker via any other equipment to prevent losing powder.
- Clean down any contaminants powder which spilled down by utilizing wet wiper then rid of wipers suitably.
- Again, Put the beaker on the stirrer plate then turn on it and allow the components stirring inside the beaker for 1 hour until the powders material to become wetted then allow it to suspension in the fluid mixture. After this, when finished, turn off fume hood.
- Using a vacuum pump device to remove the gas (degas) the BMF for around 1 hour. When the air bubbles appear during degassing by a vacuum pump, liberate the vacuum pump slowly until the air bubbles settle down. When the blood mimicking fluid has been degassed via a vacuum pump, it is ready to utilize and apply.

Preparation of BMF

In this experimental research, our goal was to prepare and present a new BMF with appropriate density, viscosity, attenuation and speed of sound which defined as constant values in the IEC standard. The BMF was prepared by several steps described in the appendix. Because of the BMF viscosity does not depend on the shear rate, the arbitrary viscosity could be taken into account [2]. To gain a new BMF, we proposed to prepare a suitable mixture fluid consists of that distilled water, propylene glycol, and glycerol. Then, dispersed polystyrene microsphere particles with mixture fluid to be adopted in the BMF. In this research study, we have altered the concentration of propylene glycol and the glycerol many times to achieve appropriate acoustical and physical properties that is defined in the IEC standards. Fundamentally, when the concentration of propylene glycol and glycerol will increase, the average density of mixture liquid will increase due to the density of both the propylene glycol (1.036 g/ml) and glycerol (1.25 g/ml) are larger than the water density (0.998 g/ml). Subsequently, the average velocity of sound will increase immediately because of proportional relationship with the density. The velocity of sound of propylene glycol, glycerol, and water was measured in this research study, 1513, 1900, and 1508 m/s, respectively.

At the beginning, in the first test experiment of ternary mixture fluid, we increased both the propylene glycol and glycerol concentration with adding a large ratio. The experiment concentrations were changed several times (Table II (b)-II (c)) to get additional appropriate density and velocity of sound which should be around International Electrotechnical Commission (IEC) standard requirements. However, in the second experiment, the ratios of propylene glycol and glycerol were equal. Furthermore, to know which caused much effect on the mixture fluid, the propylene glycol or glycerol, we have made two additional experiments. First one, we increased propylene glycol ratios and fixed the glycerol ratio (Table II (c)). The second one, we fixed the ratios of propylene glycol and increased the glycerol ratio (Table II (d)). Finally, many researches added surfactant to make sure that the scattering particle materials were sufficiently dispersed. In our research, we added a different amount of a new type of non-ionic surfactant which is called (Synperonic® F 108 510.00), to find out if it influences on the acoustical and physical properties of the mixture fluid (Table III).

Table II (a): The acoustical and physical features of water, propylene glycol, and glycerol at increasing both the propylene glycol and the glycerol concentration with high ratios.

Number of sample	Water wt%	propylene glycol wt%	Glycerol wt%	density g/ml	speed of sound m/s	viscosity mPas
1	100	0	0	0.998	1508	0.89
2	90	8	2	1.01	1461	3.1
3	80	15	5	1.02	1495	4.1
4	75	17	8	1.03	1550	5.4
5	70	20	10	1.04	1564	6.8
6	60	25	15	1.05	1580	10.1
7	50	30	20	1.062	1640	16

Table II (b): The acoustical and physical features of water, propylene glycol, and glycerol at the same concentration of the propylene glycol and the glycerol.

Number of sample	Water wt%	propylene glycol wt%	Glycerol wt%	density g/ml	speed of sound m/s	viscosity mPas
1	100	0	0	0.998	1508	0.89
2	90	5	5	1.01	1525	3.7
3	80	10	10	1.02	1540	4.6
4	75	12.5	12.5	1.03	1578	5
5	70	15	15	1.04	1595	7.4
6	60	20	20	1.06	1612	10.1
7	50	25	25	1.08	1644	13.2

Table II (c): The acoustical and physical features of water, propylene glycol, and glycerol when the concentration of the propylene glycol increased and fixed the glycerol concentration.

Number of sample	Water wt%	propylene glycol wt%	Glycerol wt%	Density g/ml	speed of sound m/s	viscosity mPas
1	100	0	0	0.998	1508	0.89
2	95	3	2	1.003	1480	0.5
3	90	8	2	1.005	1490	1.1
4	85	13	2	1.008	1505	1.4
5	80	18	2	1.01	1517	2.0
6	75	23	2	1.013	1535	2.4
7	70	28	2	1.015	1568	3.0

Table II (d): The acoustical and physical features of water, propylene glycol, and glycerol when the concentration of the glycerol increased and fixed the propylene glycol concentration

Number of sample	Water wt%	propylene glycol wt%	Glycerol wt%	density g/ml	speed of sound m/s	viscosity mPas
1	100	0	0	0.998	1508	0.89
2	95	2	3	1.01	1497	2.0
3	90	2	8	1.02	1520	2.6
4	85	2	13	1.03	1552	3.1
5	80	2	18	1.04	1600	4.3
6	75	2	23	1.05	1620	6.5
7	70	2	28	1.06	1648	9.0

Table III: The same information in table 2.d with adding different ratios of surfactant Synperonic® F 108.

Number of sample	Water wt%	propylene glycol wt%	Glycerol wt%	surfactant	density g/ml	speed of sound m/s	viscosity mPas
1	100	0	0	0	0.998	1508	0.89
2	95	2	3	1	1.01	1497	3.5
3	90	2	8	1.3	1.02	1520	5.7
4	85	2	13	1.5	1.03	1552	13.7
5	80	2	18	2.0	1.04	1600	20.5
6	75	2	23	2.5	1.05	1620	28.0
7	70	2	28	3.0	1.06	1648	35.0

Urick Formula for Preparation BMF

Usually, choosing the scattering particle materials depends on the speed of sound and density of the mixture fluid. But, when using many solid, rigid and spherical particles materials suspended in the mixture fluid, it is suggests to use formula for simplest it. Thus, Urick has derived and deduced a theoretical formula expressing the longitudinal signal wave density and speed in suspensions [11].

The density do of a blood mimicking fluid (BMF) is given by this formula:

$$Do = D_1 S_{01} + D_2 S_{02} \quad (1)$$

Where D_1 and D_2 are the densities of the fluid and the particle materials, and S_{01} and S_{02} are the size ratios of the fluid and the particle materials, respectively.

The velocity of sound Vo of a BMF is given by this formula:

$$Vo = 1/ [Do\ (L1\ S_{01} + L_2\ S_{02})]\ \text{^}\ ½ \quad (2)$$

$$\text{Where } L1 = 1/D_1 V_1^2,\ L2 = 1/D_2 V_2^2 \quad (3)$$

Where V_1 and V_2 are the velocities of the sound of the fluid and the particle materials, respectively. Here, by following this formula, which it is self-evident.

$$S_{01} + S_{02} = 1 \quad (4)$$

The density of the mixture fluid must be equal and identical to the density of the particle materials to prevent the particles deposit down or floating and allow it neutrally buoyant in a BMF.

Formulas (1) and (2) can be written again as

$$Do = D_1 = D_2 \quad (5)$$

$$Vo = 1/ [(S01/ V_1^2) + (S_{02}/ V_2^2)] \wedge ½ \quad (6)$$

Basically, the velocity of sound in the solid particle materials V_2 is higher than that in the fluid V_1. As a result of this, the velocity of sound of the fluid V_1 must be less than the velocity of sound of the BMF Vo.

$$V_1 < Vo \quad (7)$$

Note: Speed of sound of nylon is 1800 m/s and the polystyrene is 2240 m/s.

Measure the Velocity (Speed) of Sound by A-scan (GAMPT) technique

The typical formula for determining the speed of ultrasound using pulse echo (PE) method was displayed in Eq. (8). Thus, the speed of ultrasound can be measured by using PE method, by measuring the time of flight (TOF) between the highest two following peaks of transmitted and received wave and then use the depth or distance of the sample. In addition, the speed of ultrasound can be measured by measuring the time of flight (TOF) between two identical peak signal pulses. Furthermore, the average measurements between the highest two following peaks and two identical peak signal pulses of transmitted and received wave were taken in account. However, the protective layer of the transducer can effect on ToF, because the measured value of ToF does not just point to the travelled time of ultrasound signal wave in the specimen, but it also represents the travelled time in the protective layer of transducer [12], see Fig.2. For good precision of ultrasonic speed measurement, protective layer thickness should be measured first, then measuring speed of sound with taken the protective layer thickness in account by following the Eq. (9).

$$SS = \frac{2xl}{t} \quad (8)$$

$$SS = \frac{2\,(d + dpl)}{t} \quad (9)$$

Where SS is the speed of sound, l is the sample thickness or sample distance, dpl is the thickness of transducer protective layer and equal to 1.03 mm, and t is the time of flight.

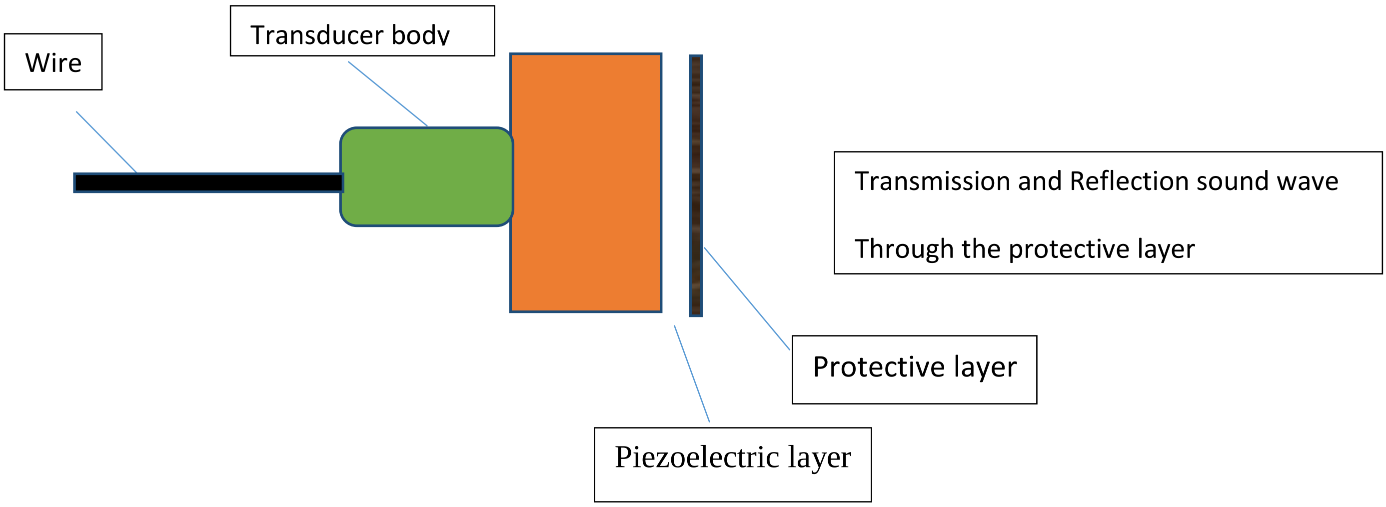

Figure 2: Structure of ultrasonic probe with protective layer.

Measure the Attenuation by A-scan (GAMPT) Technique

For attenuation measurements, the frequency-based attenuation of the individual signal was measured by proceeding a Fast Fourier Transform (FFT) on the radio frequency (RF) signal from the reflector. Attenuation unit in dB, it was calculated by the natural log (In) difference between the signal waves by using Eq. 4. After knowing the speed of sound of the sample, inserting the value in pulse-echo techniques (A-scan system) to calculate the attenuation coefficient of the sample (distilled water) by the following equation:

$$\alpha = \frac{1}{x1-x2} \text{In} \frac{A2}{A1} \quad (10)$$

Where_ α is the attenuation coefficient of sample, $x1$ *and* $x2$ is the difference in distance or depth of sample in mm, A1 is the power signal amplitude at frequency f and x, y position of (reference signal) with no presence sample (amplitude of transmitted signal wave), A2 is the power signal amplitude at frequency f and x, y position through the sample (amplitude of received signal wave).

Measure the Density and Viscosity of BMF

In this experimental research, we measured the density of the mixture fluid for each sample by an electronic instrument called Density Meter (DMA35). This instrument used for measure the density in g/cm^3or in g/ml unit, the merit of this instrument that you able to measure the mixture fluid temperature. Using this instrument is better than using pycnometer because this instrument produce more accurate density measurement than pycnometer, see Fig.3. In addition, the density measurement uncertainty it was ±0.01 g/ml. However, on the other hand, the samples viscosity of the mixture fluid were measured by Electronic Rotational Viscometer (ERV), which is an electronic instrument used for measuring the dynamic viscosity (mPas) directly instead of measuring the kinematic viscosity then convert it to dynamic viscosity (mPas).

Figure 3: Electronic Density Meter (DMA35) for samples density measurements.

Furthermore, when the flow phantom (wall- less flow phantom) using with this BMF, must adjust with temperature simulate to the real human body temperature (37℃) to check the validation of the new BMF which consists of water, propylene glycol, glycerol, and polystyrene. Those items were 99% pure, provided via Sigma Aldrich Company, and, the distilled water used from medical physics laboratory utilizing a quartz distiller.

RESULTS AND DISCUSSION

In the first experiment, with increasing both the concentration of propylene glycol and the glycerol, the density of mixture liquid solution increased and then the speed of sound (SoS) increased immediately due to the directly proportional relationship to each other. During this mixing, we found result with matching between the density and speed of sound in some samples (Table II (a)). In other words, sample number 4 is a suitable mixture liquid for mixing with a specific type of nylon as a scattered particles because the density of mixture fluid at sample 4 is 1.03 g/ml and the nominal density of nylon is 1.03 g/ml like 2001EXDNAT, also, the speed of sound 1550 m/s is proper according to IEC standard values. In addition, sample number 6 is suitable also for mixing with polystyrene particles which have density of 1.05 g/ml, and the speed of sound 1580 m/s is proper according to IEC standard values. However, even the viscosity of both samples was more than 4.1 mPas, but it accepted due to the fact the BMF is a Newtonian which that means not depend on shear rate, thus the viscosity here arbitrary.

Moreover, when the ratios of propylene glycol and glycerol were equal, the density and the speed of sound (SoS) of mixture liquid solution increased directly, because as we mentioned before, due to the density of propylene glycol and glycerol being more than the density of water, thus any increase of their ratios will cause an increase in both the density and speed of sound even with increasing a small ratios (Table II (b)). Samples number 3 and 4 in Table II (b) are suitable mixture liquid for mixing with a specific type of nylon as a scattered particles because the density of mixture fluid at sample 3 is 1.02 g/ml and at sample 4 is 1.03 g/ml and the nominal density of some types of nylon is 1.02 g/ml such as nylon 12 and other types is 1.03 g/ml such as 2001UDNAT, also the speed of sound in both samples were proper according to International Electrotechnical Commission IEC standard values.

Furthermore, the results of the previous experiments (Table II (c) and II (d)) were indicated that the density of mixture was increased much slightly and was not suitable with IEC requirements. However, in the second test of the previous experiments (Table II (d)), when the ratios of propylene glycol were fixed, and the glycerol ratio were increased, the density and speed of sound of the mixture fluid were increased properly, and it was agree with IEC standard values, but the viscosity was less than 4.1 mPas, so it was not suitable for preparation BMF. It is worth to mention that these results indicate that the mixture density and velocity of sound depend on the density of items compared to water density, because the blood density is very close to the water density. The density and velocity of sound highly increased with increasing the glycerol concentration, while slightly increase in density and velocity of sound with increasing the propylene glycol concentration (see Figs. 1(a) and 1(b). The Figs. shows that the highest value of the speed of sound with increasing concentration of propylene glycol is 1568 m/s and 1.015 g/ml as a highest density value at this point. While, at the same concentration of glycerol, the highest value of the speed of sound and density were 1648 m/s and 1.06 g/ml, respectively. That means, when the density of the material or the item which used as a mixture fluid in BMF preparation is large compared with the other material of mixture regard to water density, so the acoustical and physical properties will be high.

At the final step of this research study, the result of adding surfactant to the mixture fluid was that the acoustical and physical properties of mixture fluid remained constant without any changing. Thus, the surfactant has no effect on speed of sound and density of mixture fluid and its main function is to ensure that the scattering particle materials were sufficiently dispersed. Nevertheless, the viscosity was affected and was increased by using the non-ionic surfactant (see Fig.4.). However, the attenuation of all suitable mixture fluid and BMFs were < 0.1 dB/cm·MHz. Thus, the attenuation of ternary mixture fluid and BMFs were corresponded to the IEC requirements. Moreover, the speed of sound measurement uncertainty it was ±1.0 m/s. While the density measurement uncertainty it was ±0.01 g/ml.

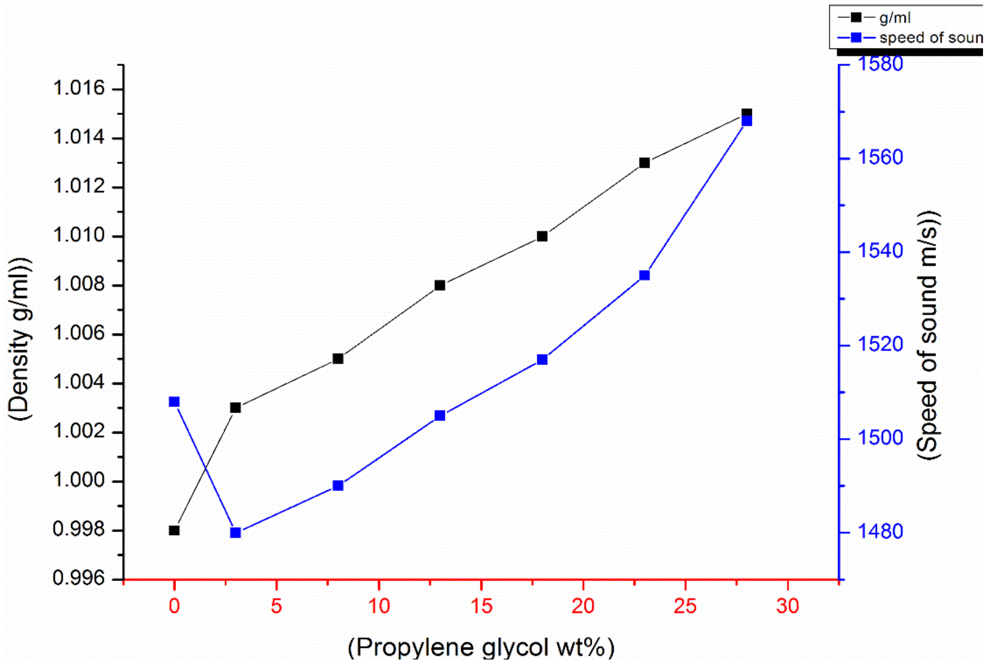

Figure 1(a): The relationship between increasing the glycerol and propylene glycol concentration with speed of sound and density.

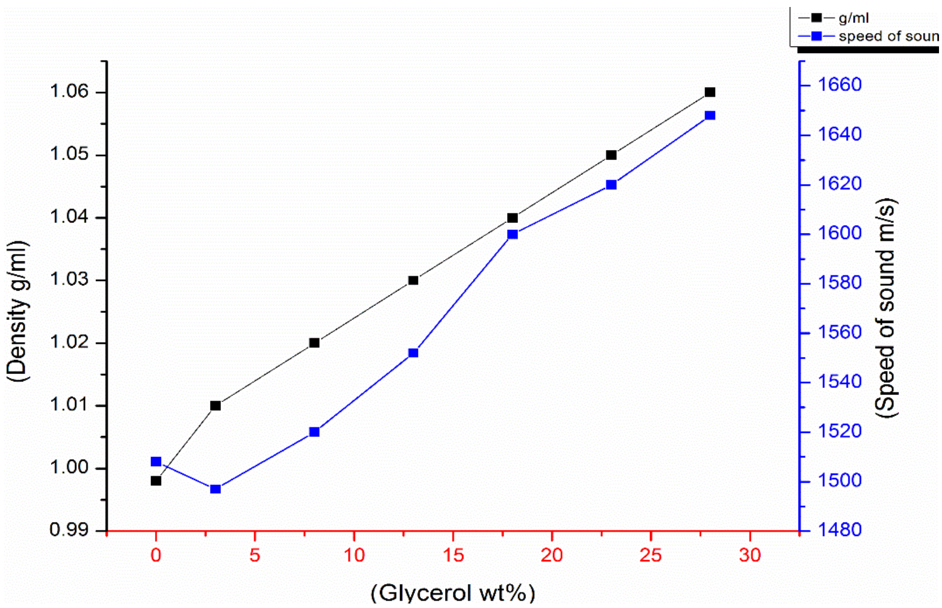

Figure 1(b): The relationship between increasing the glycerol and propylene glycol concentration with speed of sound and density.

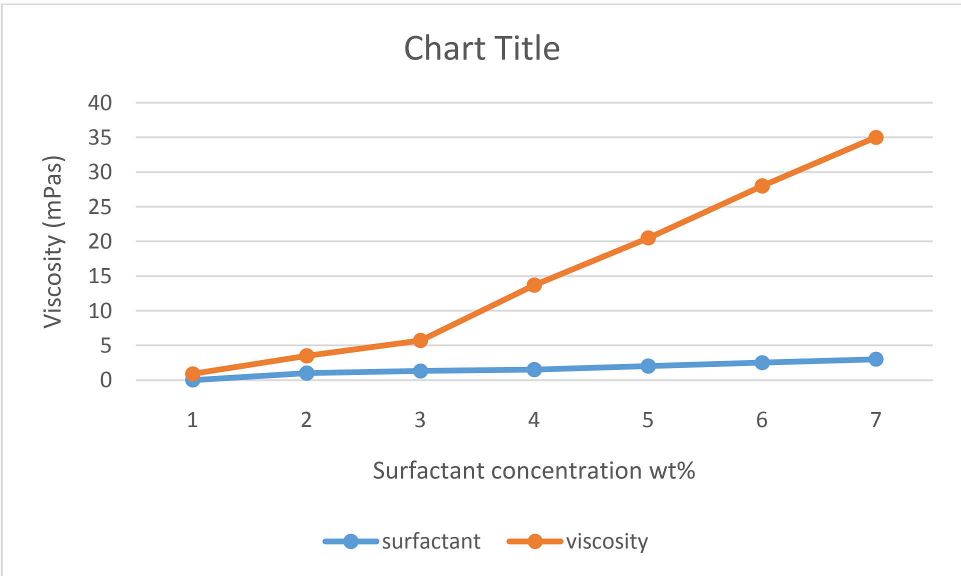

Figure 4: Affect the non-ionic surfactant concentration on the viscosity (mPas).

CONCLUSION

Three various sorts of ternary solvent solution were used for preparing the blood mimicking fluid (BMF). In this research study, two types of BMF were prepared to be used in flow phantom. The first one prepared by mixing the fluid items (distilled water 75.0 wt %, propylene glycol 17.0 wt %, and glycerol 8.0 wt %) with nylon 1.82 wt %. The second one prepared by mixing the fluid items (distilled water 60.0 wt %, propylene glycol 25.0 wt %, and glycerol 15.0 wt %) with polystyrene 1.0 wt %. The speed of sound and density of the first type of BMF were 1550 m/s and 1.03 g/ml, respectively. On the other hand, the speed of sound and density of the second type of BMF were 1580 m/s and 1.05 g/ml, respectively. The experiment values agree well with the IEC requirements. In other words, the acoustical and physical features of the two types of a BMFs were defined and known in IEC standard requirements. However, because there is no linear relationship between the components of items and the density in the mixture fluid, so the speed of sounds and the densities were varied with changing the concentration of items. Typically, when the ratios of glycerol are more than the ratios of propylene glycol, the density of mixture fluid will increase highly and the velocity of sound increase too, due to the velocity of sound direct proportion to the density. In contrast, when the ratios of propylene glycol are more than the ratios of glycerol, the density of mixture fluid will increase but slightly because the density of propylene glycol is less than the density of glycerol compared to the density of water. Moreover, the advantages of this new BMF that is cheaper than the commercial available BMF products, because the propylene glycol is much cheaper and available than dextran that used usually. In addition, new BMF needs less time for preparation compared to the commercial BMF.

Two types of a new blood-mimicking fluid with speed of sound and density corresponded to IEC requirements. Those two types of BMFs have been desired for using in a precise wall- less flow phantom.

ACKNOWLEDGMENTS

This research study was supported by Prof. Dr. Mohammad Zubir Mat Jafri, under the grant number 304/PFIZIK/6315023. We thank our colleagues from [Universiti Sains Malaysia, Medical physics and Radiation Science department] who provided insight and expertise that greatly assisted the research, although they may not agree with all of the interpretations of this paper.

REFERENCES

1. Smith, H.-J., Quantitative Doppler Flowmetry I. Construction and Testing of a Duplex Scanning System. Acta Radiologica Diagnosis (Sweden), 1984. **25**(4): p. 305-312.
2. Yoshida, T., K. Sato, and T. Kondo, Blood-mimicking fluid using glycols aqueous solution and their physical properties. Japanese Journal of Applied Physics, 2014. **53**(7S): p. 07KF01.
3. Browne, J., et al., Assessment of the acoustic properties of common tissue-mimicking test phantoms. Ultrasound in medicine & biology, 2003. **29**(7): p. 1053-1060.
4. Law, Y., et al., On the design and evaluation of a steady flow model for Doppler ultrasound studies. Ultrasound in medicine & biology, 1989. **15**(5): p. 505-516.
5. Hoskins, P.R., Simulation and validation of arterial ultrasound imaging and blood flow. Ultrasound in medicine & biology, 2008. **34**(5): p. 693-717.
6. Ramnarine, K.V., et al., Validation of a new blood-mimicking fluid for use in Doppler flow test objects. Ultrasound in medicine & biology, 1998. **24**(3): p. 451-459.
7. Tanaka, K., et al., Blood-Mimicking Fluid for Testing Ultrasonic Diagnostic Instrument. Japanese Journal of Applied Physics, 2012. **51**(7S): p. 07GF18.
8. Oates, C., Towards an ideal blood analogue for Doppler ultrasound phantoms. Physics in medicine and biology, 1991. **36**(11): p. 1433.
9. Samavat, H. and J. Evans, An ideal blood mimicking fluid for doppler ultrasound phantoms. Journal of Medical Physics, 2006. **31**(4): p. 275.
10. Hoskins, P., T. Loupas, and W. McDicken, A comparison of the Doppler spectra from human blood and artificial blood used in a flow phantom. Ultrasound in medicine & biology, 1990. **16**(2): p. 141-147.
11. Urick, R., A sound velocity method for determining the compressibility of finely divided substances. Journal of Applied Physics, 1947. **18**(11): p. 983-987.

12. Halim, M.A., N. Buniyamin, and Z. Mohamad. Improving intramuscular fat measurement by considering the thickness of protective layer in ultrasonic transducer in Electrical, Electronics and System Engineering (ICEESE), 2014 International Conference on 2014 IEEE.