Thermal and Acoustic Properties of Agar Phantom Fabricated from Agar Powder

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Abstract

We present in this paper, step by step procedure in obtaining Agar Phantom from Agar Powder and degassed water using specified bioinstruments, therewith subsequently demonstrate by the Step - Wise Transient Method (STM), how the manufactured (TMM) was utilized in identifying the thermal, and acoustic properties of the fabricated material. TMMs are materials which mimic human body tissues, and as human body tissues are not readily easy to come by, Agar Agar has been used for fabrication of this suitable alternative to simulate the properties of human body tissues in certain medium.

Keywords: Phantom, Transducer, Agar, Ultrasound, Step - wise Transient Plane Source (STPS) Method.

1. Introduction

Phantoms or imaging phantoms are highly specialized objects used in medical imaging for quality control, equipment calibration, dosimetry and education. The name is used interchangeably for each object despite their differences.

1.1 Definition

Two types of phantoms exist: Anthropomorphic and calibration.

1.1.1 Anthropomorphic Phantoms

Anthropomorphic Phantoms are made of materials with similar tissue characteristics to normal biological tissues/organisms. Due to their availability and likeliness to real patients, anthropomorphic phantoms can be used for a variety of tasks. Rather than image multiple patients or patient tissues, anthropomorphic phantoms can be used for trial and error to assess the optimal use of radiation such as in new protocols or image reconstruction techniques. In the same vein anthropomorphic Phantoms can be utilized for teaching students, and/or Staff different imaging techniques or exposure factors. Recent Biomedical Engineering advancements are improving the development of anthropomorphic phantoms to better mimic patient tissue.

1.1.2 Calibration Phantoms

A calibration phantom is often a cylinder, or plate with densities of already known values. They are utilized in quality control to ensure images are reconstructing the imaged phantom to the correct density values. Deviation from these values can indicate a need for imaging equipment service.

In the perspective of this work, a phantom is a representation of something abstract, ideal, or incorporeal. The following process lead to fabrication of Anthropomorphic Phantoms from Agar powder. This Phantom can be made from Agar Powder or Agar Agar Powder (In this case, non - edible) Some Agar are edible. This was noted for precautions to avoid harm due to injestion. We present the results of experiment for the manufacture and testing of the thermal and acoustic properties of this material. In this study, the Step - wise Transient Plane Source (STPS) Method was used in establishing the thermal property, while the Single Transducer method was used for the acoustic properties measurement of the fabricated Phantom.

2. Materials and Method

Fig. 1: Agar Chem. Structure (Pubmed)

Fig. 2: Weighing Pan

Fig. 3: Beaker

Fig.4: Microwave Ove

Fig. 5: Table Spoon

(a) 2g of Agar Agar ($C_{14}H_{24}O_9$) powder was measured with table spoon from a plastic container of the non - edible type using the Electronic Weighing Pan (EWP).

Agar agar is a tan powder (NTP, 1992). Agar is a complex sulfated polymer of galactose units, extracted from Gelidium cartilagineum, Gracilaria confervoides. It is related to red algae. It can be used as a gel in the preparation of solid culture media for microorganisms, as a bulk laxative, in making emulsions, and as a supporting medium for immunodiffusion and immunoelectrophoresis.

(b) The 2g Agar powder was poured into the cylindrical cup (Beaker) with 100ml degassed water. During degassing, dissolved gases are removed from the water. Oxygen and carbon dioxide are absorbed by water in certain quantities, so they need to be removed to eliminate gas bubbles which might have negative impact on the results of using the Phantom produced for Ultrasound purposes. The technical removal of troublesome, gaseous contents is generally referred to as "degassing" [6]. The mixture was then boiled at about 100°C.

(c) The mixed Agar was stirred and microwaved 3 minutes in a Microwave oven.

(d) In each period of microwaving, the preparation was checked by viewing through the lid of the Microwave to ascertain when it is vaporizing, so as to stop it to a avoid spillage inside the equipment which is not advisable for such electrical machine.

(e) To avoid Agar suspension in the solution, we removed suspension by underlined stirring to clear gas bubbles.

(f) The solution was for a number of times microwaved and stirred to further remove gas bubbles.

(g) The preparation was checked to ascertain when the volume of the solution had diminished in the container (beaker) as this could affect the quality of phantom produced.

(h) Degassed water level was topped up to ensure maintenance of 100ml, while ensuring there were no gas bubbles in the solution.

(i) Then, we put the preparation beaker containing Agar solution with no gas bubbles on a magnetic stirrer and set the stirring knob to above stirring speed of 2 until the temperature is a little above 95°C.

(j) Still checked and removed any more gas bubbles, and pour formation into a meter mold.

(k) The container of the wet preparation was labelled and dated and put in the refrigerator for the agar Phantom to set overnight.

N/B: Hot Plate Method can be used in Agar Phantom fabrication, but Microwave approach was adopted to speed up the process.

3. Measurement of Thermal Property of Agar Phantom

(a) *Thermal Experiment Set-up*

The detailed set up for the thermal property measurement using the fabricated agar phantom is shown in the diagram below (Fig. 6):
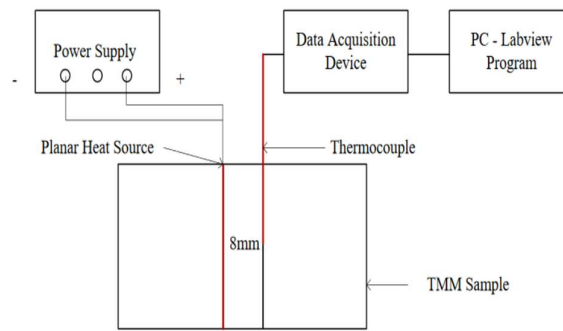
Fig 6: Pictogram illustrating experimental set up for Thermal Property Measurement

Following the experimental set up above:

1. The thermocouple' sensor was aligned into the phantom at an angle of 90º to the surface. The Phantom rests and at a height of 1cm from the top surface of the Phantom. The LabView application was allowed to run for no more than 600 seconds.
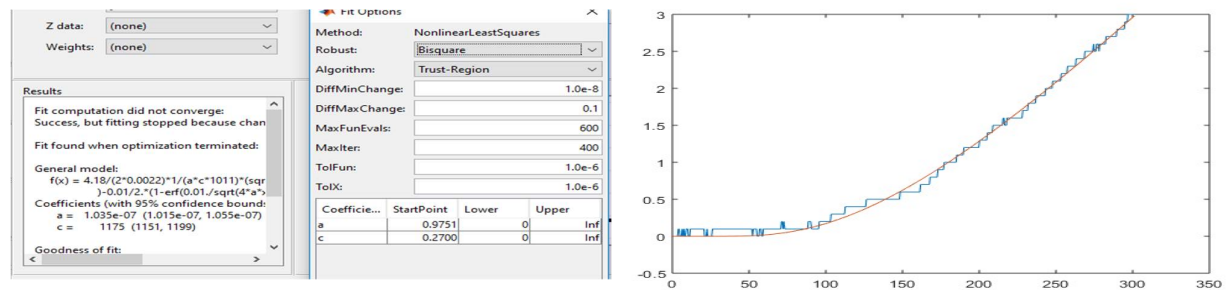

Fig. 7: *D = 1cm* (Curve Fitting for Phantom resting 1cm

2. Alignment of the thermocouple's sensor into the phantom at an angle of 90º to the surface of the phantom and resting at a height of 2cm from the top. A Labview application of no more than 600 seconds was maintained. Precisely maintained for 300 seconds in the first Labview application, and for 470 seconds in the second. The results obtained by the execution of the LabView was extracted and saved to an external excel file containing the timings and the amplitudes at each of the time intervals. Next was to show the work done on the two format files of the results of no more than 600 seconds of data acquisition from both experiment set up.
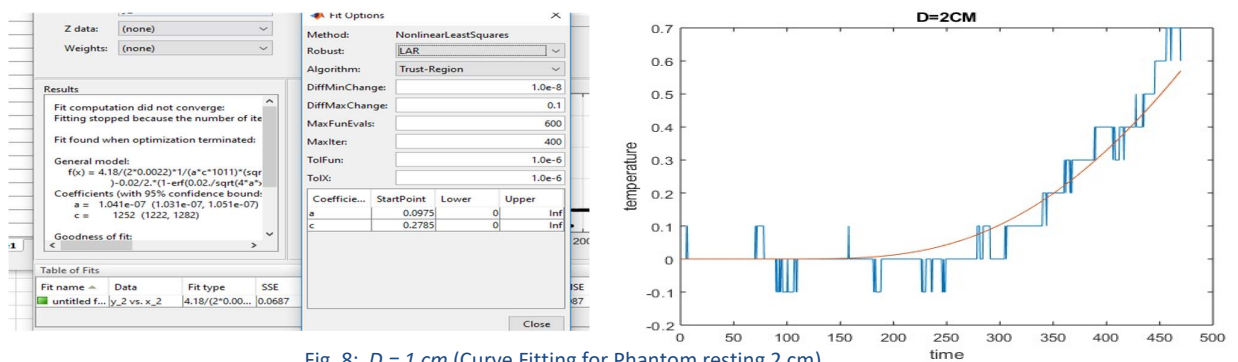

Fig. 8: *D = 1 cm* (Curve Fitting for Phantom resting 2 cm)

(b) *Measurement of Thermal Property of Agar based Phantom*
The Step - wise transient Plane Source (TPS) Method was used for the measurement of the thermal properties of the tissue mimicking phantom. The step - wise transient method is a method used for the measurement of the thermal diffusivity and thermal conductivity of a material, in this case the material is the phantom [3]. To determine thermal properties of materials, it is sufficient to measure the temperature as a function of time by only one thermocouple [1]. See figure 9 for a diagram showing set up of the experiment.
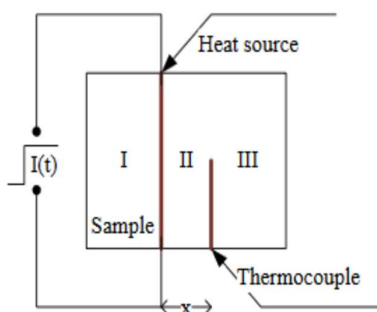

Fig 9: Set up showing step-wise transient method

Following are the results obtained from the raw data exported into Excel worksheet before simulation in MathLab, using curve fitting to obtain the results of the thermophysical parameters $\alpha = a$, and c: So we obtain k, using $k = \alpha.c.\rho$

4. Detailed set up of Acoustic Property Measurement
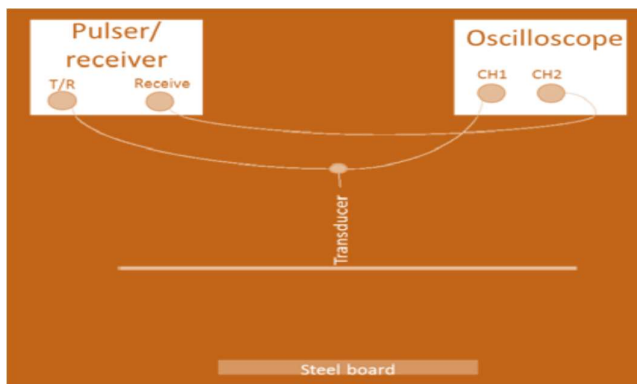
b₁. Single Transducer Method (Without Phantom)

Fig. 10: Pictogram of the setup of the Single Transducer Method (without phantom)

In the single transducer method, the transducer serves the dual place as the ultrasound generator and the ultrasound receiver. In this case measurements were obtained as follows: Distance from the steel board to the transducer at 8.5cm in 114.5μs. The density of water is 1000kg/m³. It is natural to follow the density of Phantom is 1000kg/m³ as well. The aim of this set up is to enable us quickly obtain the ultrasound' velocity in the water, given by:

$$Vw = \frac{2D}{dt}$$

Where dt (in seconds) corresponds to the time needed for the reception by the transducer of the first echo, where D is the distance between the steel board and the transducer, measured in meters (m). From the experimental results

obtained we have 114.5μs as the time dt which corresponds to the time needed for the reception by the transducer of the first echo and

D = 8.5cm when measured with a meter rule.

$$\text{This yields } Vw = \frac{2 \times 8.5}{dt} = \frac{17cm}{114.5\mu s} = \frac{17000000}{11450} = 1484.72 \text{m/s,}$$

This looks nice as it corresponds to the standard Velocity of Ultrasound in water which is at 1480m/s [4]

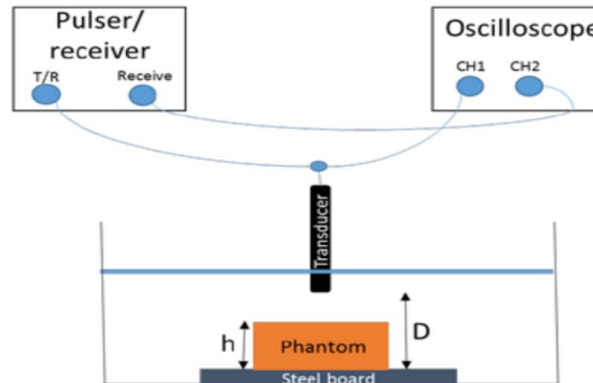b_2 **Single Transducer Method** (With Phantom) - The setup is as shown in Fig. 11 below:

Fig. 11: *showing the setup of the Single Transducer Method* (With Phantom)

In the steps of b_2, the Phantom was added between the two transducers with a thickness of h, shown by Figure 11. We obtained h = 4.5cm. First and second echoes were obtained at 52.2μs and 114.4μs, representing the times for the signals reflected by the top of the phantom and the time for the corresponding signal reflected by the border between the steel board and the bottom of the phantom. Required is the velocity of Ultrasound speed into a Phantom, designated V_p. The equation:

$$\frac{2(D-h)}{V_w} + \frac{2h}{V_p} = dt'$$

was used, where the parameters are as defined below:

$D(m)$ is distance between the transducer and the steel Board, m, meters

h (m), is phantom thickness, m, meter

V_w $(m$/s), velocity of Ultrasound in the water

V_P $(m$/s), velocity of ultrasound in the Phantom

dt' (s), time between the original signal delivered by the transducer and the second echo.

$$\text{Simply put, } Vp = \frac{2h}{dt'} = \frac{2 \,^{\wedge}4.5c}{114.40 - 52.20} = \frac{9cm}{62.2\mu s} = \frac{0.09}{0.0000622}$$

Vp represents the Acoustic Velocity of the ultrasound while in the phantom.

$$V_p = 1446.94m\text{/s}$$

Finally, we compute the Acoustic Attenuation Coefficient using the rearranged formula:

$$\alpha = \frac{20}{h}\log\left(\frac{4z_p z_w}{z_{p+} z_w} \ X \ \frac{A'}{A''}\right)$$

$Z = \rho * V$, the acoustic impedance (in pas./m^3) with ρ in k/m^3 and V in m/s. A' and A'' are the first and second echo amplitude (V), while h is the thickness of the Phantom. Further, we obtain the following properties:

Zw = 1000 x V_w = 148720 $pas./m^3$; Z_p = 1000 x V_p = 1000 x 1446.94 = 1446940 $pas./m^3$

A' = 18.5 and A'' = 3.25 and h is already known to be 4.5cm = 0.045m

Substituting the parameters, and calculating for α with the formula above, we actually obtained the value

α = 2884.42dB/m = 28.84dBcm^{-1} (bone has a range of high attenuation category $\geq$ 8.7dBcm^{-1} at f = 1MHZ [2]).

5.   Conclusion

This work has illustrated how Tissue Mimicking Phantom (TMMP) can be fabricated from Agar powder. The experimental process for determining the Thermal and Acoustic properties of the material manufactured has been demonstrated. Since the 1960s, tissue - mimicking materials (TMMs) have been utilized for the preparation and characterization of ultrasound imaging Wall-less flow phantoms are as well utilized to examine the performance of ultrasound device for practicing sonography. The achievement of equivalent TMM is necessary to process for a quality monitor of Doppler ultrasound diagnostic instrument. It is essential that chemical items utilized in fabricating TMMs are prepared in a planned method to be nearly equal to the acoustical properties of real tissue with attenuation and speed of sound respectively. This objective has been achieved in this work [4].

6. Acknowledgment

References
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