# ACOUSTIC AND THERMAL PROPERTIES IN AGAROSE-BASED PHANTOM WITH DIFFERENT GRAPHITE POWDER CONCENTRATION

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**Abstract:** Phantoms are test bodies that mimic the physical properties of biological tissues. The advantage of using phantoms is to obtain a standardized model with well-defined properties for the study of complex biological structures as the human organs and tissues. The main objective of this work is to evaluate the influence of different graphite powder concentrations in thermo-acoustic properties (velocity of the longitudinal wave propagation, acoustic attenuation, specific heat and thermal conductivity) in an agar-based phantom. Phantoms with acoustic attenuation speed of sound and specific heat compatible with literature and human biological tissues were obtained. Variations in graphite powder concentrations affect the phantoms' acoustic attenuation and thermal properties. The study promotes advances in the production agar-based soft tissue phantoms with better understanding of its thermo-acoustic properties for different graphite powder concentration.
**Keywords:** physical properties, phantom, ultrasound.

## Introduction

Ultrasonic phantoms are standardized model with well-defined acoustic properties, dimensions and simplified features for the study of complex biological structures. They can be used to verify the performance of ultrasound (US) equipment, as well as to teach and enhance interpretation of image techniques. Agar-based phantoms are the most widely among the soft tissue mimics because of their well characterized performance, structural stability, ease fabrication and flexibility that allows the incorporation of additional ingredients to the phantoms recipe to achieve a range of acoustic properties similar to biological tissues [1-2]. Systematized studies of the hole of each phantom's composite materials on acoustic properties are proposed in the literature to obtain phantoms of specific biological tissue [10-11].

This work aims systematizes the study of agarose-based phantoms to evaluate the hole of different graphite powder concentrations in the US propagation velocity, acoustic attenuation, specific heat and thermal conductivity.

## Materials and methods

*A. Confection of the Agarose-Based Phantoms*

Four different phantoms with progressive reduction in graphite powder concentration were built (Figure 1).The phantoms were made in accordance with the agar-based soft tissue mimic developed by Sato (2005) [3], and modified by Basto (2012) [4](Table 1).

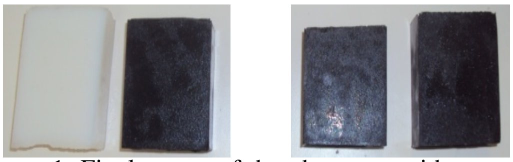

Figure 1: Final aspect of the phantoms with progressive reduction in graphite powder concentration.

Table 1: Agar-based Phantoms Recipes for Different Graphite Powder Concentrations.

| Graphite powder concentration (%) | Agar-based *Phantom* Recipes |
|---|---|
| **6** | Bastos´ original |
| **4** | Bastos´ with minus 2% of graphite powder |
| **2** | Bastos´ with minus 4% of graphite powder |
| **0** | Bastos´ without of graphite powder |

The phantoms were made in rectangular shape and dimensions of 2.3x2.3x6.0 cm to characterize the acoustic properties, and in circular shape of 2.54 cm diameter to characterize the density and thermal properties.

*B. Density and Acoustic Properties Experimental Procedures*

The density measurement followed the Archimedes Principle employing a Hubbard type pycnometer of 25 ml (Roni Alzi, Rio de Janeiro, Brazil) positioned on a balance (AY220; Shimadzu, Kyoto, Japan) with resolution of 0.0001 g [5]. This procedures was repeated 10 times.

The through-transmission technique was employed to measure the ultrasonic properties of the phantoms (propagation velocity and acoustic attenuation). This method uses a pair of transducers with the same central frequency. One transducer is used for transmission (Tx) and other for the reception of the ultrasound signal (Rx). Three pairs of US transducers with central frequencies 1 MHz (V303; Olympus-Panametrics, Waltham, MA, EUA); 2.25 MHz (V306; Olympus-Panametrics, Waltham, MA, EUA) and 5 MHz (V326; Olympus-Panametrics, Waltham, MA, EUA) were used. Each pair of transducers was aligned and immersed in a tank with deionized water; the phantom was positioned between the pair of transducers, and put to rest for 30 minutes for the entire system to come into thermal equilibrium. The temperature was monitored during the experiment with a digital thermometer (MTH 1362W; Minipa, São Paulo, Brazil). A function generator, model 3021 AFG (Tektronix, Beaverton, OR, USA) was used to excite Tx with a 5-cicles sinusoid burst of 10 $V_{pp}$ (peak-to-peak amplitude), repetition period of 10 ms. Rx received the US signal from Tx, this signal was acquired and displayed on an oscilloscope model DSO 5012A (Agilent Technologies, Santa Clara, CA, USA) and stored on a computer by a program developed in LabVIEW™ (National Instruments, Austin, Texas, USA) (Figure 2).

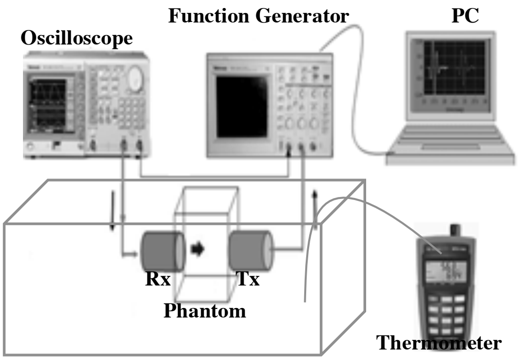


Figure 2: Experimental procedures set-up for characterization of acoustic properties of the phantoms.

The experimental procedure to characterize the acoustic properties follows two simple steps. At first, the signal with the phantom between the transducers (Sp) was collected and the temperature recorded. Then, the phantom was removed and the reference signal (Sr) was acquired. These procedures were repeated 20 times to evaluate US velocity measure repeatability condition. The signals were processed with routines implemented in MATLAB® (MathWorks®, Natick, MA, EUA).

The longitudinal US propagation velocity (c) was obtained by (1).

$$c = \frac{x \cdot c_r}{x - t \cdot c_r}, \quad (1)$$

Where "x" is the phantom thickness in m, *t* is the time-delay between phantom (Sp) and reference (Sr) signals, and $c_r$ is the US propagation velocity in water.

The acoustic attenuation (α) in dB/cm was obtained by dividing the RMS (Root Mean Square) values from reference signal (Sr) and phantom signal (Sp) as in (2):

$$\propto = 20 \frac{\log\left(\frac{A}{A_0}\right)}{x}, \quad (2)$$

Where *x* is the phantom thickness in cm, $A_o$ is the RMS peak amplitude of the reference signal (Sr), and A is the RMS peak amplitude of the phantom signal (Sp).

Statistical analyses of the acoustic parameters were performed with Shapiro-Wilk test for normality, Kruskal-Wallis non-parametric test and Newman-Keuls t-Student post-hoc tests. The results for all statistical tests were considered significant if p-value <0.05.

### C. *Thermal Properties Experimental Procedures*

The differential scanning calorimetry (DSC) was used to measure the specific heat of the phantoms. The method compares the thermal power from a material sample and an inert reference standard material. The equipment has temperature controlled compartments, for the sample measurements. The sample and a reference material are heated or cooled in a controlled and constant temperature rate. DSC technique follows the power compensation, maintaining constant the temperature difference between sample and reference. The occurrence of any chemical or physical event involving heat exchange will be compensated for the temperature difference remains constant, generating a sign that will be registered in DSC equipment. At the end of the procedure a curve is provided representing the difference between the amount of energy delivered to the sample and reference material expressed in terms of heat flow (mW) versus temperature (°C) and time (minutes). This signal can be further analyzed to obtain the specific heat for the sample material [6-7].A DSC equipment (Phoenix 204 F1; Netzsch, Selb Germany) was used to obtain the specific heat in the temperature range of 22-97°C. In order to characterize the thermal properties of the phantoms at 25°C, the specific heat measure procedure was repeated 5 times at this temperature.

The thermal conductivity can be determined by the linear probe method, developed by Blackwell (1954). The probe consists of a steel needle (70 mm length and 1.2 mm diameter); a thermocouple junction type K located about 15 mm from the probe tip; and a resistor capable of heating and measure the sample temperature. In present study a linear probe (TP08; Hukseflux Thermal Sensors, Delft, Netherlands) was employed. The trial was conducted 5 times at 25 °C. The probe allows measurement of the thermal conductivity of pasty, gelatinous and viscous fluids materials from 0.1 to 6.0 W□m$^{-1}$□K$^{-1}$ at temperatures from -55 to 180 °C [8-9].

## Results

A summary for the values from density and acoustic properties of the phantoms in the four different graphite's concentrations are resumed in Table 2.

Table 2: Density and Acoustic Properties of the Phantoms at ≈ 26 °C with Different Graphite Powder Concentrations.

| Graphite powder concentration (%) | Density and Acoustic Properties | | |
|---|---|---|---|
| | *Density* (*g*□*cm*$^{-3}$) | *c* (*m*□*s*$^{-1}$) | *α* (*dB*□*cm*$^{-1}$) *1MHz* |
| **6** | 1.154 ±0.001 | 1593.864 ±3.124 | 0.626 ±0.013 |
| **4** | 1.136 ±0.001 | 1596.454 ±1.647 | 0.472 ±0.010 |
| **2** | 1.118 ±0.001 | 1585.135 ±2.320 | 0.321 ±0.005 |
| **0** | 1.084 ±0.001 | 1590.038 ±2.232 | 0.174 ±0.005 |

The values of the US propagation velocity in the phantoms, as well as attenuation with the frequency can be observed respectively in Figures 3-4.

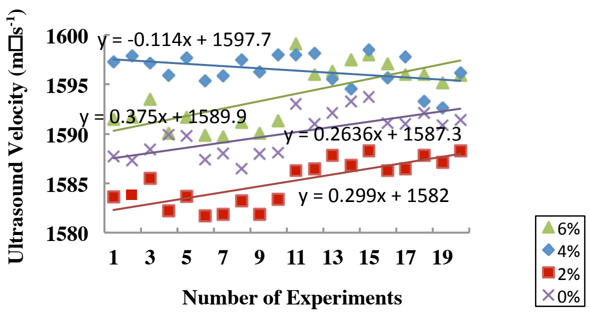


Figure 3: Ultrasound propagation velocity (m□s$^{-1}$) with repeatability in time for the phantoms progressive reduction in graphite powder concentration at ≈ 26 °C.

Specific Heat (J□Kg$^{-1}$□K$^{-1}$)

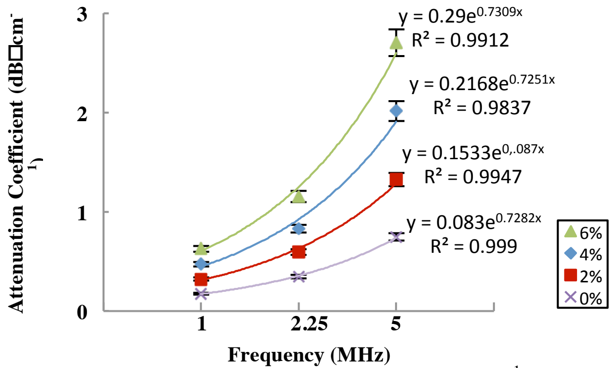


Figure 4: Ultrasound attenuation (dB□cm$^{-1}$) with frequency (MHz) of the phantoms progressive reduction in graphite powder concentration ≈ 26 °C.

Furthermore, as the value of acoustic attenuation for the phantom without graphite powder was very low, and not compatible with biological tissues, this material was not considered in the phantoms thermal properties evaluation.

A summary for the values from thermal properties of the phantoms at 25°C for graphite concentrations 2-6% are resumed in Table 3. The values of specific heat of the phantoms as a function of temperature for graphite concentrations 2-6% can be observed in Figure 5.

Table 3: Thermal Properties of the Phantoms at 25°C for Different Graphite Powder Concentrations.

| Graphite powder concentration (%) | Thermal Properties | |
|---|---|---|
| | *Specific Heat (J□kg$^{-1}$□K$^{-1}$)* | *Conductivity (W□m$^{-1}$□K$^{-1}$)* |
| **6** | 3300.340 ±0.001 | 0.760 ±0.070 |
| **4** | 3474.423 ±0.001 | 0.654 ±0.060 |
| **2** | 4841.510 ±0.001 | 0.469 ±0.033 |

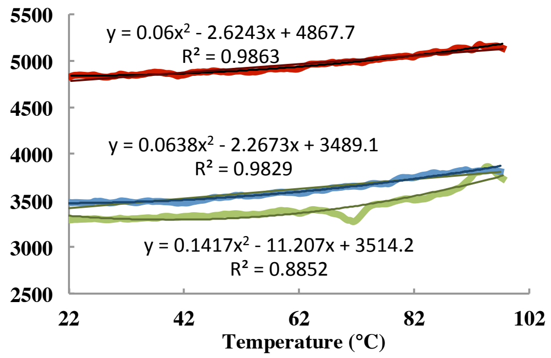


Figure 5: Specific heat (J□Kg$^{-1}$□K$^{-1}$) of the phantoms with temperature (°C) with progressive reductions in graphite powder concentration (-2, -4 and -6 %).

## Discussion

Agarose-based phantoms are the most well described soft tissue mimic materials described in the literature. These materials have a good performance and structural stability. In addition, agarose-based phantoms are easy to fabricate and flexible to incorporate additional ingredients to achieve acoustic properties similar to biological tissues [2].

In the present study four agar-based phantoms were made with different graphite powder concentrations from a recipe of tissue mimic material according to Sato (2005) [3], and Basto (2012) [4]. The variations of graphite powder concentrations were performed to evaluate the physical properties of phantoms, to obtain materials that best mimic human soft tissues.

The values for speed of sound in the phantom are compatible with the literature, and similar with the ones for human soft tissues [2, 3, 10-13].

The speed of sound for the phantoms had an apparent difference when the variations of graphite powder concentrations were performed (Table 2 and Figure 3). Then, statistic analisys were performed, and statistical significant difference were observed for the speed of sound values for the four different graphite powder concentrations. When compared in pairs, except for the phantoms of 6 and 4 % graphite powder concentrations, statistical significant difference were also observed for the values of speed of sound.

The literature affirms that variation in backscatter particles concentration (such as graphite, SiC or $Al_2O_3$ powders) does not affect the phantom speed of sound; and suggests that speed of sound modulation of these materials should be performed varying the concentrations of glycerol or adding propranolol to the phantoms recipe [2, 10]. Furthermore, the statistical significant difference observed for the different graphite powder concentrations can be justified by phantoms heterogeneities, such as the presence of air bubbles.

A wide range of attenuation coefficients were obtained when the variations of graphite powder concentrations were performed (Table 2 and Figure 4). It was observed that attenuation coefficients decrease with progressive reductions in graphite powder concentrations. This fact was also observed in the literature, which indicates an increase in attenuation coefficients when ingredients such as SiC, $Al_2O_3$, and graphite powders were progressively increased in the phantoms recipes [2, 10]. The values of attenuation with frequency for the phantoms made are compatible with those for human soft tissues at 1MHz [1, 2].

The influence of frequency on attenuation coefficient values for the different graphite powder concentration can be seen in Figure 4. The proposed model of frequency dependence for attenuation coefficients was considered good, with correlation coefficient (R) higher than 0.9 in the fit proposed. Then, attenuation in the phantoms can be expressed as non-linear increases in attenuation coefficient with frequency. The frequency dependence model for attenuation in the phantoms is compatible with the literature [10-12], and similar to those, for human soft tissues [13].

The specific heat values as a function of temperature for different graphite concentrations can be observed in Figure 5. The values of specific heat for the phantoms with 4 and 6% of graphite powder concentration are compatible with human soft tissues at 25°C [2]. The phantoms recipes need some adjust to mimic thermal conductivity values of human biological tissue as well.

## Conclusion

Phantoms with acoustic properties (attenuation and speed of sound) and specific heat compatible with the literature, and similar to human biological tissues were obtained. The values of heat condutivity still need some adjust. These phantoms could be used to verify the performance of US equipment and enhance interpretation of image techniques. The present work systematizes the study of agarose-based phantoms by raising the curves of variation of acoustic and thermal properties for different graphite powder concentrations, evaluating the US propagation velocity repeatability; the frequency dependence in acoustic attenuation; and the specific heat as function of temperature in these materials. The study promotes advances in the production soft tissue phantoms with better understanding of the modulation its thermo-acoustic properties.

**Acknowledgments**

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