PHANTOM MATERIALS USED TO MODEL DETECTION OF CONCEALED WEAPONS AND EFFECTS ON IMPLANT DEVICES IN METAL DETECTORS*

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ABSTRACT

We discuss the characterization of phantom materials that simulate the electromagnetic characteristics of various human tissues from 100 Hz to 10 MHz, and over a temperature range of 15 ^{o}C to 40 ^{o}C. The materials studied were: 1) a solution of potassium chloride in water, 2) a solution of propylene carbonate, ethylene carbonate, and salts, 3) a semi-solid material consisting of silicone and carbon black, 4) a semi-solid mixture of glycine, carrageenan, potassium chloride, and water. We found that to obtain time stability, the carbon black mixture must be temperature annealed. The silicone material has the advantage of being more rugged than the glycine mixture. The glycine material was jello-like in consistency and required refrigeration.

INTRODUCTION

The goal of this work is to develop a phantom material (PM) that simulates the relevant electromagnetic properties of the human body over the frequency range of 100 Hz to 10 MHz and a temperature range of 15 ^{o}C to 40 ^{o}C [1]. The development of these phantom materials is important for modeling the detection of weapons by metal detectors and understanding the interaction between medical implant devices and metal detector fields.

Metal-detector magnetic fields interact with metallic objects by inducing eddy currents ($\mathbf{J} = \nabla \times \mathbf{H}$) in objects that modify the net magnetic field. Metal detector magnetic fields incident on the human body also generate eddy currents in the tissues, but to a much smaller degree than in metals. The incident magnetic fields attenuate as they pass into tissues. Characterization of phantom materials for study of metal detector response requires determination of the conductivity.

Since the human body is electrically heterogeneous, PMs can be made that simulate the electrical response of a particular area of the human body. Most of the previously developed phantoms attempted to mimic both the conductivity and the permittivity of the human body. In this study we concentrate on the conductivity. Various candidate phantom materials have been studied by previous researchers [2–11].

The novel feature in our study was the comparison of four candidate materials. These were potassium chloride solutions (KCl); a liquid composed of ethylene carbonate, propylene carbonate, and tetraethyleammonium tetrafluoroborate (TEATFB) [3]; carbon black mixed into silicone (CBS), and a semisolid made form glycine, carrageenan, KCl, and water. All of these composites can be mixed to match the average conductivity of the various human tissues. There are advantages and disadvantages of each when used as PMs.

CONDUCTIVITY MEASUREMENTS

The conductivity measurements of PMs were made using an open-circuited coaxial holder and a dc conductivity meter [12]. We developed a full-mode model for the open-circuit termination and used it for conductivity determination. This model rigorously models the fringing capacitance at the open-circuit termination. The measurement data are the corrected reflection coefficients, Γ, from a network analyzer or LCR meter. In order to obtain an empirical estimate of our measurement uncertainties we measured liquid KCl reference standards.

CONDUCTIVITY OF CANDIDATE LIQUIDS

In this section we summarize the measurements on liquid PMs. In Figure 1, the conductivity of KCl in deionized water is plotted versus concentration for minor variations in temperature. The dependence of conductivity on KCl concentration is nearly linear. The required conductivities can be obtained by using the appropriate concentration of KCl.

We also measured another liquid mixture which was studied by Broadhurst [3]. This liquid contains ethylene carbonate, propylene carbonate, and tetraethyleammonium tetrafluoroborate (salts). We found that for this liquid we could vary the conductivity over the range of human body tissue properties.

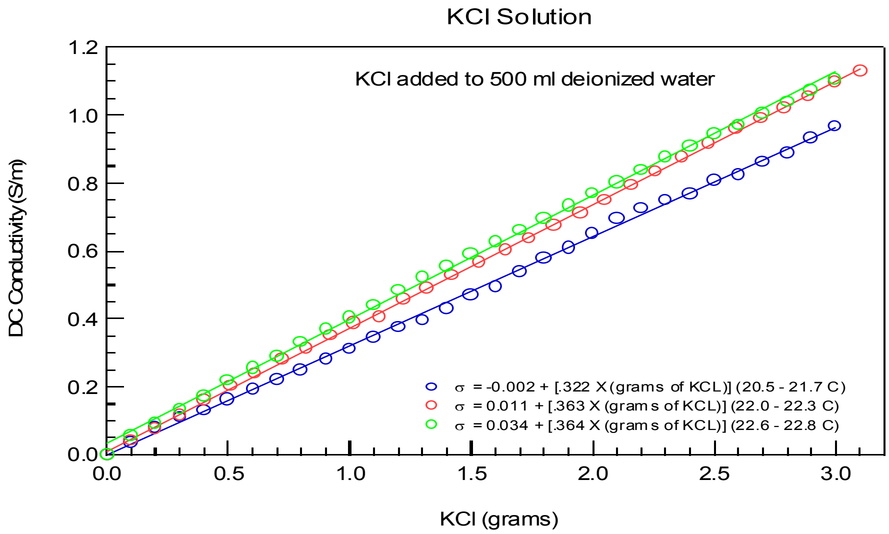

Figure 1: Three different conductivity measurements of potassium chloride solution conductivity in 500 ml deionized water, at slightly different temperatures. Type B expanded relative uncertainty: U=0.05 S/m (k=1).

CONDUCTIVITY OF SEMI-SOLIDS: CARBON-BLACK-SILICONE AND GLYCINE MATERIALS

We also studied carbon-black silicone composite mixtures (CBS). These materials are semisolids and very flexible. The material reported here was for **All Black Pearls**, from Cabot Inc.* While the conductivity of KCl varies nearly linearly with concentration, CBS is not a linear function of concentration below the percolation threshold. At the percolation threshold it increases abruptly. This conductivity increase is due to a percolation phenomenon, where the conducting paths in the carbon black begin to become interconnected throughout the sample. The measurements of the composite as a function of carbon black and silicone weight fractions are shown in Figure 2. These results indicate that we could simulate human-body conductivity with carbon black. These measurements were above the percolation threshold. The carbon black composites are more frequency dispersive than the KCl liquid mixtures and need to be temperature annealed to obtain time stability. Conductivity versus concentration of Black Pearls is given in Figure 2.

We also studied glycine mixed with KCl and water. Glycine sets into a semi-solid, jello-like state and needs refrigeration for long-term storage. In Figure 3 we show the dependence of conductivity on KCl concentration in glycine. We see a nearly linear dependence of conductivity on concentration.

DISCUSSION

Conductivities close to that of all human body tissues can be reproduced by either carbon-black composites, glycine composites, or various salty solutions. The CBS conductivity exhibits a percolation threshold point where the conductivity increases abruptly. To obtain time stability in the silicone-carbon-black mixture the sample must be temperature annealed. The silicone material has the advantage of being more rugged than the glycine mixture which needs refrigeration. The CBS material has the disadvantage of requiring temperature annealing to obtain time stability of the conductivity. It also needs to be mixed in a very reproducible manner to obtain reproducible conductivity measurements. Note that liquids are not as a convenient as solids for metal detector materials.

*Specific materials that are commonly used are mentioned for informational purposes only. This does not imply or constitute any endorsement by the National Institute of Standards and Technology.

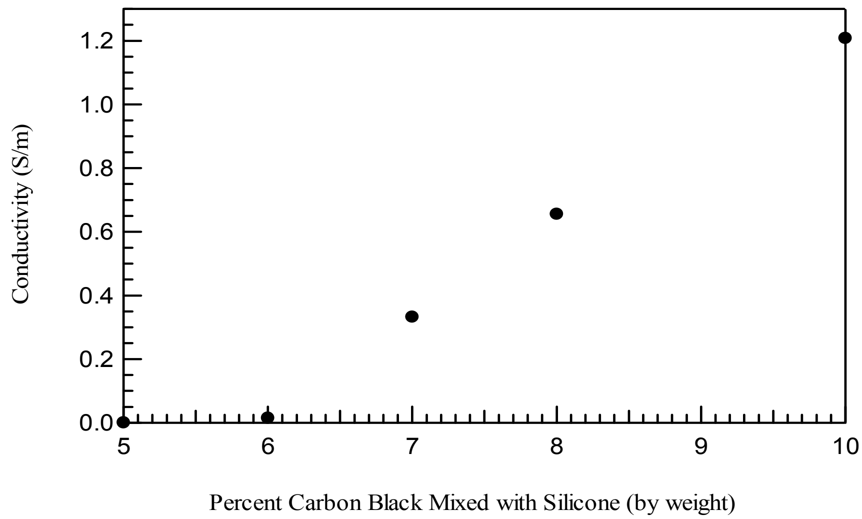

Figure 2: Conductivity vs concentration for carbon-black-silicone (CBS). The conductivity uncertainty for a $\sigma = 0.001$ has a Type B expanded relative uncertainty of $U = ku_c = 0.001$ (k=2). For a $\sigma = 0.1$, the Type B expanded relative uncertainty for CBS is $U = ku_c = 0.02$ (k=2), and for a $\sigma = 0.56$ the Type B expanded relative uncertainty is $U = ku_c = 0.02$ (k=2).

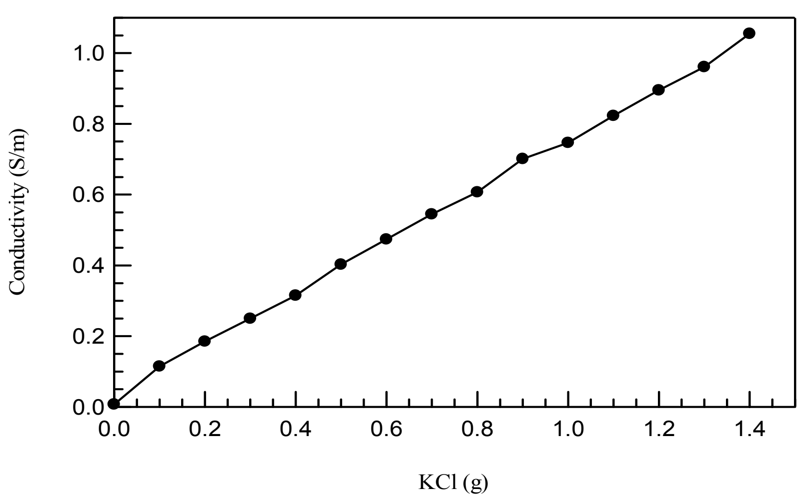

Figure 3: Conductivity of glycine as a function of KCl in water. The glycine concentration was 6% by weight. Uncertainty for $\sigma = 0.56$, the Type B expanded relative uncertainty is $U = ku_c = 0.02$ (k=2). Linear fits of the conductivity are given in the lower right part of the plot.

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