THERMAL AND ELECTRICAL CHARACTERIZATION OF PAA AND HEC GEL USED IN MRI TESTING OF ACTIVE AND PASSIVE MEDICAL IMPLANTS

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Introduction

Historically, Polyacrylic acid (PAA) gel had been used as the phantom material in MRI testing of passive and active medical implants. However, PAA exhibits undesirable variability in bulk electrical and thermal properties between batches due to the presence of crystallites. Hydroxyethyl Cellulose (HEC) gel has been referenced in the most recent version of ASTM F 2182-02a as an acceptable substitute for PAA gel. HEC gel has similar electrical, thermal, and materials properties as PAA gel, but those properties can vary significantly depending on solids loading of the gel.

$J=\sigma E$ **(1)**

$P= I^2R$ **(2)**

$R\alpha 1/\sigma$ **(3)**

$P=\sigma E^2$ **(4)**

$SAR= Cp\ (dT/dt)$ **(5)**

$SAR= \sigma|E|^2 / \rho$ **(6)**

$$\frac{\sigma}{c_p}\frac{|E|^2}{\rho}dt = dT \quad (7)$$

Figure 1. Equations 1 through 7 show how variations in electrical conductivity (σ) and specific heat capacity (Cp) with constant gel density (ρ) and electric field (E) can affect the amount of hating (dT) seen in the gel in an MRI environment.

Variations in electrical conductivity and specific heat capacity can greatly affect the amount of temperature rise seen in a test phantom in an MRI environment, see equations in Figure 1. This study, therefore, investigates the impact of various material properties on the performance of these two media as proper heating phantoms as defined in the ASTM Standard.

Methods

Five batches of HEC gel were prepared with varying levels of NaCl and HEC loading. As defined by the recipe in ASTM 2182-02a, these batches included nominal solids levels and combinations of high and low allowable levels. Four batches of PAA gel were also made, including two nominals, one high solids, and one low solids The electrical conductivity, specific heat capacity, and viscosity of the gel samples were evaluated and compared. All of the PAA and HEC gel samples met the criteria set forth in ASTM F 2182-02a sections 8.2.1, 8.2.3, 8.2.4 for electrical conductivity, thermal parameters, and viscosity.

Results

The results for specific heat (C_p) and electrical conductivity (σ) for the HEC mixtures are shown in Table I. Electrical conductivity for PAA was measured for all mixtures, and is shown in Table II. C_p for the nominal PAA batches was also measured.

Conclusion

Data shows that there is significant variability in prepared batches of HEC gel using the process and ingredient tolerances defined. The electrical conductivity measured between batches of prepared HEC showed a relevant change with respect to solids content. It was found that at a given SAR value, gel temperatures could vary as much as 20% when evaluating Cp alone and could be as high as 25% when evaluating both electrical conductivity and Cp. Additionally, viscosity of the HEC is impacted by the formulation, and has an impact on mixing and handling of the gel. This amount of temperature variation creates significant measurement error when try to evaluate small changes in local temperatures.

Although the electrical conductivity and specific heat capacity of the HEC gel varies widely over the range of samples tested, it was found that the electrical and thermal properties of HEC gel are much more consistent than those of PAA gel when ingredient tolerances for solids loading are held to ±0.01g. It was found that HEC gel is an acceptable substitute for PAA gel and in many ways is a superior phantom medium.

Table I. HEC gel properties

Sample ID	Cp (J/g-K) @ 25˚C	E Conductivity (mS/cm) @ 1 kHz
High NaCl and HEC	4.133	5.22
High NaCl, Low HEC	3.978	4.91
Low NaCl, High HEC	3.851	4.69
Nominal NaCl and HEC	4.151	4.78
Low NaCl and HEC	3.938	4.4

Table II. PAA gel properties

Sample ID	Cp (J/g-K) @ 25˚C	E Conductivity (mS/cm) @ 1 kHz
High NaCl and PAA	Under evaluation	3.45
Low NaCl and PAA	Under evaluation	3.37
Nominal NaCl and PAA	4.11	3.45
Nominal NaCl and PAA	4.14	3.14

References

(2) ASTM F 2182–02a Standard Test Method for Measurement of Radio Frequency Induced Heating Near Passive Implants During Magnetic Resonance Imaging, ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA.