Rational Chemical Design of Broadband Tissue-Simulating Liquids

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Abstract: Standard method for Specific Absorption Rate (SAR) measurement of wireless devices is highly time consuming. Changing between a number of biological tissue simulating fluids to cover a large frequency range is one of the tedious aspects in radiofrequency dosimetric assessment. Materials capable of broadband matching with standard target dielectric parameters are hence of great utility. This paper illustrates how the application of basic physical chemistry principles can be used to define a straightforward methodology for deriving new broadband and stable tissue-simulating liquids.

Introduction

During a communication with a handheld or body-worn wireless device, biological tissues of the user are exposed to electromagnetic field energy. At frequencies used by mobile phones or other commercial devices, the radiofrequency power absorbed by the tissues is usually quantified in terms of Specific Absorption Rate (SAR). Limits of SAR averaged over the whole-body or locally over 1g or 10 gram of tissue (peak spatial-average) are established in international exposure guidelines / standards [1], [2]. In order to ensure the protection of public health and safety, national regulators have widely adopted such limits and recognized the use of measurement standards for assessing the peak spatial-average SAR [3]-[5]. Measuring a wireless device according to the adequate standard allows demonstrating the compliance with established limits.

Measurement standards specify the use of head and body mannequins or phantoms consisting of plastic shells filled with homogeneous tissue-simulating liquids. Test configurations, phantom shapes and dielectric properties of the liquids have been designed to ensure a conservative estimate (higher value) of measured SAR compared to the SAR in a person, for a large majority of exposure conditions.

In order to achieve target dielectric characteristics defined in [3]-[5] various recipes for homogeneous liquids have been proposed. Well-known solutions are for example based on water, salt and glycol (see e.g. Annex C of [5]). Such simple mixtures are easily fabricated but have the drawback to approach target values within 5% in narrow frequency ranges, typically from 4 to 10% for a given formulation. As a consequence, the fluid has to be changed several times when a device is tested in different frequency bands, leading to tedious and time-consuming measurement sessions. So as to solve this problem, several research groups have tried to develop tissue-simulating liquids usable over a wider range of frequencies [6], [7] and tolerances of the standards on dielectric values have been relaxed from 5 to 10% [5].

The present communication shows how it is possible to develop a rational strategy based on physical chemistry principles to derive a new broadband tissue recipe. Using this methodology, a non-toxic fluid has been obtained, which offers a good stability over time and temperature. This tissue stimulant can be used for SAR compliance testing as defined in [5] over a frequency decade (0.6 - 6 GHz).

1. Methodology

We assumed that a deeper understanding of the interactions of different chemical components together with specific properties of colloidal systems would provide fruitful guidelines for the efficient design of a new broadband tissue-equivalent liquid. The target relative permittivity (ε') of standard tissue models is about 40. Water has a typical relative permittivity between 70 and 80 for the frequency range of interest, and oils about 3. [6] hence applied the straightforward idea that a mixture of water and oil could match the right permittivity. However, oil is not miscible with water leading to phase separation.

In order to form a homogeneous system with a mixture of two non-miscible liquids, an emulsion has to be created. An emulsion is a microscopically heterogeneous system in which the less abundant component is typically dispersed as droplets (dispersed phase) in the so-called continuous phase (the major component). Due to immiscibility of the two components, this dispersion is thermodynamically instable. To slow down

destabilization, additional components with amphiphilic structures, called surfactants, are generally introduced into the formulation. Those molecules adsorb at the interface between oil droplets and water phase and isolate each oil droplet from others by electrostatic or steric repulsion, thereby avoiding destabilization phenomena such as coalescence. The stake of the formulation is to find the right surfactant or combination of surfactants in the suitable proportion, in order to provide the best stability for the system.

A first step in the methodology which has been developed is to determine the appropriate type of emulsion based on the volume fraction of the dispersed phase. Further adjustment of the conductivity has to be carried out by a combination of salt-mediated ionic strength control and molecule-induced dipolar relaxation effects. Ionic conduction is brought by the addition of inorganic salts, selected via a careful screening of their chemical nature and concentration. Adequate dipolar relaxation phenomena are induced by the addition of a molecular component through hydrogen-bondings with water. This permits to fit the tissue simulant conductivity in the requirements range, by controlling dielectric losses.

2. Materials & Methods

- *Emulsion preparation and stability*

According to the above-described methodology, an emulsion matching the different criteria has been formulated using non-toxic components. The emulsion was prepared by weighting each component and mixing under mechanical stirring. Mixing rate and temperature have been optimized for a better stability. Stability was estimated visually as the time before phase separation occurs. In this work, an emulsion was considered stable if no separation occurred visually after six months.

- *Dielectric properties measurements*

Dielectric properties were measured using an open-ended coaxial dielectric probe (DPK) from Agilent Technologies (85070E Dielectric Probe Kit, High Temperature probe) as described in [8]. This widely-used technique has the advantage to be easy-to-use, available to everyone and applicable up to 6 GHz. Measurements were carried out with a temperature of the sample under test varying from 20°C to 40°C.

3. Results

As shown in Fig.1, the previously-described approach allowed the design of a broadband solution matching with standard requirements for tissue dielectric properties, stable for at least twelve months in a hermetic mannequin under laboratory temperature conditions.

It is noteworthy that the derived simulant formulation can be used in a wide range of temperatures from at least 20°C to 40°C, as dielectric properties are still in the tolerance zone (Fig. 2).

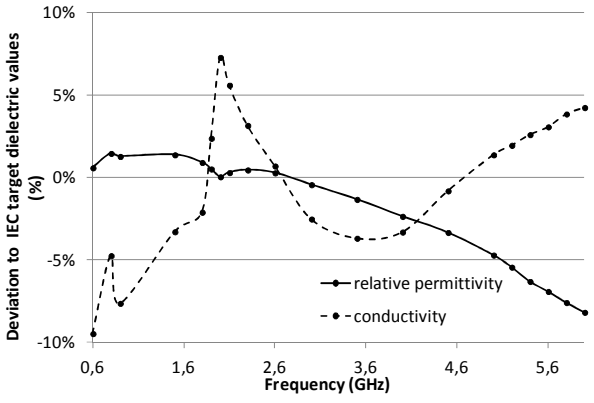

Fig.1 : Dielectric properties of the broadband tissue-simulant at 25°C relatively to IEC target dielectric values.

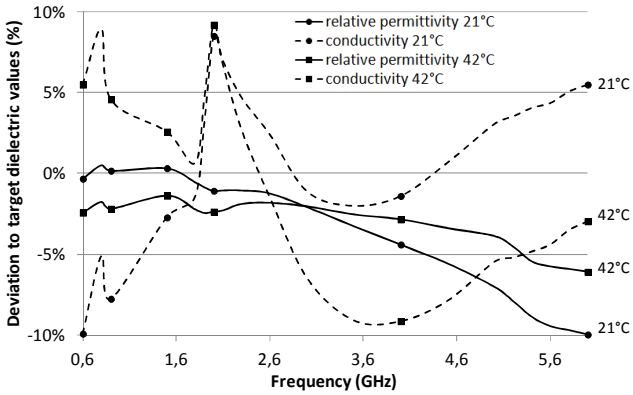

Fig. 2 : Dielectric properties of the broadband tissue-simulant, at 21°C and 42°C, relatively to IEC target dielectric values.

4. Conclusions and perspectives

A methodology and its application to design a novel broadband tissue-simulating liquid suitable for dosimetric assessment were presented. From simple physical chemistry concepts, emulsions appear to be a well-adapted solution to the addressed problem. Yet determination of chemical composition and emulsion preparation conditions to reach the target dielectric values of tissue-simulating models require some understanding of the underlying processes that govern dielectric losses and colloidal stability.

Thanks to a rational strategy based on physics and chemistry of matter in the colloidal state, we were able to combine the properties of different molecules in a synergetic manner and create a homogeneous and stable system meeting IEC and IEEE standard tissue requirements.

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