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Complex permittivity of blood cells and *E. coli* suspensions

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ABSTRACT

The role played by micro-particles, such as leukocytes, erythrocytes and other lighter particles called micro light particles (MLPs), on the electric and dielectric properties of human blood has been studied for a vast frequency range (10 Hz–10 GHz). It has been found that leukocytes dominate these properties in the low frequency range (about 265 Hz), while erythrocytes control it at higher frequencies (around 1.2 MHz). MLPs dominate near 10 GHz. A theoretical model based on the relaxation of suspended micro-particles in plasma is presented which shows that each micro-particle has its own intrinsic frequency, f_P. The electric conduction is at a maximum when the frequency of the applied field matches f_P. In general, the theoretical approach gives consistent results compared to previously publish experimental results on human blood and *E. coli*, which have an intrinsic frequency of 232 Hz. The results suggest the utility of permittivity measurements for non-invasive studies of blood disorders and for microchip devices with corresponding extensions of the standard relaxation times model. In addition, these data shed some light on the mechanism by which bacteria can transfer energy.

1. Introduction

Since 1899, there has been much interest in the study of the electric and dielectric properties of human blood [1–3]. This is one of the rare subjects that has maintained its scientific importance. This is not surprising because there are still many unexplored properties of human blood. Knowledge of these properties may lead to a better understanding of the diagnosis of various symptoms, therapeutic processes and/or the underlying basic biological processes. For example, one of the first demonstrations of the existence of the cell membrane is based on dielectric studies of cell suspensions [4]. Decreased blood flow also accounts for changes in its resistivity [5]. In general, any changes in blood physiology should produce changes in the electrical properties of blood [6]. This principal has been used to identify and monitor the presence of various illnesses or conditions such as body fluid shift, blood flow, cardiac and muscular dystrophy [7].

Electrical properties can also depend on blood components other than the red blood cells (RBCs) and white blood cells (WBCs), which are also called erythrocytes and leukocytes, respectively. In fact, the different chemical compounds and bio-materials in vivo or in vitro may also drastically affect these properties. For example, plasma contains hundreds of substances like protein, glucose, hormones, and antibodies. These substances, called micro light particles (MLPs), are considerably lighter than leukocytes or erythrocytes. The contribution of these light particles to the electrical properties should be considered in certain cases. For example, the presence of some additional and permanent chemicals in the blood alters these properties [8]. Glucose, for example, in patients with diabetes mellitus, drastically affects the electric and dielectric properties of the blood [8]. Gagnon et al. [9] have shown that the lower crossover frequencies of bovine red cells are sensitive to changes in the cell membrane dielectric constant. They also have shown that two measurable crossover frequencies (COF) near 500 kHz exist for dielectrophoresis within a small range of each other. In a recent study [10], we have shown that the previously mentioned COF of reference [9] is a δ-function for several relaxation times and has a Gaussian distribution throughout the blood [11].

To complete the above mentioned study [10], the present work aims to show the contribution to the electric and dielectric properties of some of the primary components of blood: RBCs, WBCs and MLPs.

In the present work, the term blood specifically refers to human blood in standard conditions without any disorder or additional substances. Additionally, the word sample stands for the blood sample and the suffixes R, W, P, c, d and s represent red blood cells, white blood cells, micro light particles, conduction current, displacement current and static conditions (null frequency), respectively.

2. Model

2.1. Blood structure

Blood is a very inhomogeneous material. It can be described simply as insulating micro-particles in a conducting fluid. The insulation is provided by the cell membrane. In blood, the cells are surrounded by an extracellular matrix of different ions, which can be extensive, as in

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