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Origin of the synthetic circuits and the Brownian motion in stretchable crystal violet doped and biocompatible composite hydrogels

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ABSTRACT

Crystal violet dye doped hydrogels as real materials with varying doses have been prepared for smart synthetic circuits in flexible electronic devices by using the polymerization technique. The electric modulus-based Cole-Cole diagrams and their adopted to Smith-Chart, frequency evolution of the dielectric properties, and correlation effects in a viscoelastic (Maxwell) system were analyzed by using the impedance spectroscopy at room temperature. The synthetic electric circuits, the Brownian motion, the viscoelastic/relaxation behavior, the fluctuation feature of the concentrations and the total polarization effects are observed for the crystal violet doped biocompatible hydrogels. The observed circuit and Brownian motion in Maxwell system originated from the interaction between dye ions and hydrogels, coulomb interaction between crystal violet dye molecules and oxygen groups, and the ion-migration in the composite hydrogels channels.

1. Introduction

Cationic dye doped hydrogels characterized by a frequency-dependent complex electric modulus, the concept of electric modulus-based Cole-Cole diagrams and their adopted to the Smith-Chart and dielectric properties have become attractive in recent years [1–4]. These types of so-called stretchable hydrogels are defined as three-dimensional networks of polymer chains that swellable in water due to ability to hold huge amounts of water in their hydrophilic structure, but not soluble [1–8]. Especially, these types of hydrogels can be classified as ionic, non-ionic, zwitterionic and amphoteric electrolyte according to existence or absence of electric charge in their chains [9–14]. The dye doped biocompatible hydrogels known as smart gels have the ability to exhibit Langevin equivalent of Brownian motion in viscoelastic fluids, the surface/bulk Maxwellian stress relaxation behavior and the validity of the Stokes-Einstein relationship in biological fluids. The viscoelastic behavior of doped hydrogels displays significant properties for the equilibrium dynamics of Brownian motion such as a spherical particle immersed in a complex Maxwell fluid [15–20]. The most used areas of doped smart hydrogels are photonic sensors [21], supercapacitor [22–25], ultrahigh power density capacitors [26], microbial fuel cell, microelectronic applications [27–31], electrochemical capacitors [32], cell microenvironment [33], tissue regeneration applications [34,35], synthetic circuits, monitoring of human health and therapeutic treatment [36]. Besides these, the dielectric properties and their technological applications of the different dose crystal violet (CrV) doped hydrogels have not been studied in great detail with low and high frequency up to the present. In additional, the Cole-Cole diagram and their adopted to Smith-Chart have not been studied equivalent organic electrical circuits for CrV doped hydrogels.

In the scope of this work, we have investigated the electric modulus-based Cole-Cole diagram and their adopted to Smith-Chart and the frequency dependence of dielectric properties for different dose crystal violet (CrV) doped composite hydrogels by using the impedance spectroscopy (IS) at room temperature (RT). Furthermore, the frequency evolution of the complex dielectric constant, impedance, electric modulus, ionic conductivity and phase angles are analyzed in detail by considering the polarization effects, the hydrodynamic interactions, concentration quantities and correlation effects in a viscoelastic (Maxwell) system for different dose CrV doped stretchable composite hydrogels in too. In this sense, origin of the synthetic circuits and the Brownian motion, viscoelastic behavior, relaxation behavior, fluctuation feature and the total polarization effects for CrV doped smart composite hydrogels have been investigated in the present work [15–20]. The experimental results (the electric modulus-based Cole-Cole diagram and their adopted to Smith-Chart and the frequency dependence of dielectric properties) showed that different dose CrV doped hydrogels can be suitable for many technological applications such as electronic

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packing applications, synthetic circuits, microelectronic applications and laser materials.

2. Experimental

2.1. Sample preparation and CrV doping study

The composite hydrogels with the ability to absorb large amounts of water, poly 2-acrylamido-2-methylpropane sulfonic acid-co-itaconic acid (poly (AMPS-co-IA)) were prepared by co–polymerization of AMPS and IA in aqueous solution using N, N′–methylenebisacrylamide, (MBAAm) as cross linker and potassium peroxodisulfate, (KPS) as initiator (see for detail refs. [1–4]). We supplemented 0.1 g hydrogels to model solutions in a 100 mL Erlenmeyer that included pH = 5.0 adjusted 30 cm^3 CrV solutions with different dose (25, 50, 75 and 100 mg/L). Subsequently, the mixture was shaken with a shaker for 24 h at 25 °C. Different dose CrV doped hydrogels were taken from the Erlenmeyer then were washed with deionizer water and were dried in oven at 55 °C. CrV25, CrV50, CrV75 and CrV100 codes were used instead of 25 mg/L, 50 mg/L, 75 mg/L and 100 mg/L doses in this work, respectively.

Schematic representation of the pure hydrogels, chemical structure of crystal violet, schematic representation of the crystal violet doped hydrogels, light microscopy (50×) images of undoped hydrogels, photographs showing the reversible response process for different dose CrV-doped composite hydrogels and light microscopy (50×) images of 100 mg/L CrV-doped composite hydrogels are shown in Fig. 1(a)–(f), respectively.

The cationic dye amount in doped composite hydrogels has been calculated from Eq. (1) [1,2].

$$Q = \frac{V(C_1 - C_2)}{W} \quad (1)$$

Here, Q, W, V, C_1 and C_2 are amount of the doped dye, amount of the hydrogels, total solution volume, beginning dye concentration and ending dye concentration with respectively.

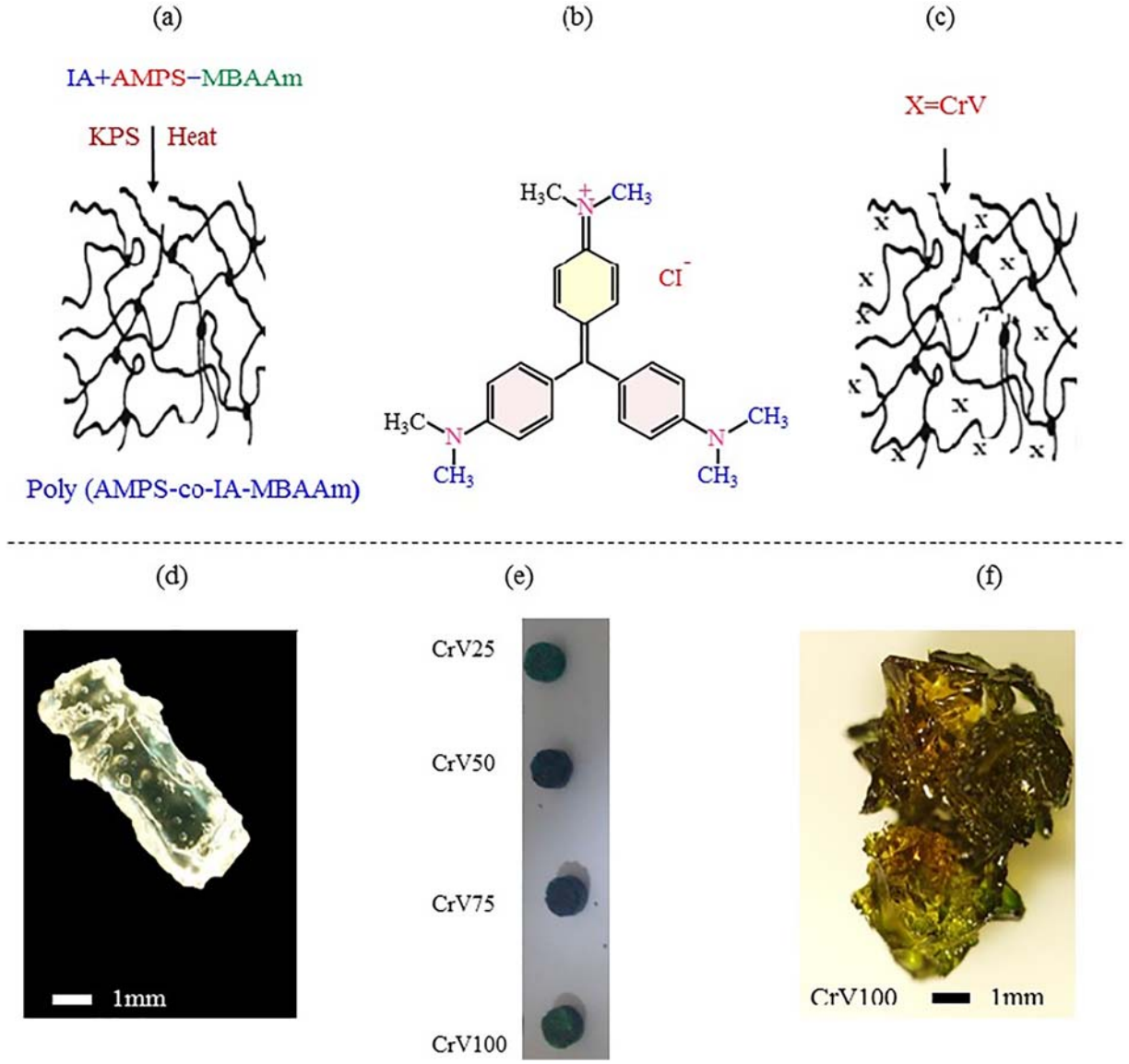

Fig. 1. (a) Schematic representation of the pure hydrogels, (b) chemical structure of crystal violet (gentian violet, methyl violet 10B, hexamethyl pararosaniline chloride) dye, (c) schematic representation of the crystal violet doped composite hydrogels, (d) light microscopy (50×) images of un-doped hydrogels, (e) photographs showing the reversible response process for different dose CrV-doped composite hydrogels and (f) light microscopy (50×) images of 100 mg/L CrV-doped composite hydrogels.