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# Rheological Behavior of Glucosamine and Glucosamine Hydrochloride Suspensions under DC Electric Field

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**Abstract: The electrorheological behavior of the glucosamine and glucosamine hydrochloride suspensions was investigated. The the glucosamine suspension behaved as a Newtonian fluid due to low conductivity even though it has polar group. The glucosamine hydrochloride suspension behaved as a Nonnewtonian fluid under the application of the electric field .The shear stress of the glucosamine hydrochloride suspension is proportional to 1.86 power of the electric field. The value of the structure factor, $A_s$ was 1 and it may be resulted due to the formation of single chain upon application of the electric field.**

**Keywords:** Electrorheological fluid, nonnewtonian fluid, glucosamine, glucosamine hydrochloride salt

## 1. Introduction

Electrorheological (ER) fluids are the suspensions composed of electrically polarizable particles dispersed in a dielectric fluid and the disperse phase plays an important role in the ER phenomenon. Cellulose [1], starch [2,3], silica [4], and zeolite [5] have been widely utilized as the disperse phases in the formulation of the hydrous ER fluids, which have several problems about durability, corrosion, limited temperature and dispersion stability in actual use.

Recently, the anhydrous ER fluids which do not contain water in the disperse phase have been introduced, which compose of polyaniline [6,7] and polyurethane [8] as the organic disperse phases. However, they also have some problems, such as dispersion stability and adhesion to the cell inspite of their high ER performance. As the new anhydrous ER fluids, chitosan has been studied because of its various advantages. It shows good dispersion in silicone oil [9] and environmental friendly. Especially, it has polar groups such as amine ($-NH_2$) and hydroxyl ($-OH$) radicals [10]. The polar groups may affect the ER behavior by playing the role of the electronic donor under the imposed electric field. And various functional groups can be coupled to these groups. Therefore, chitosan is good material to study the effect of the functional group. Due to these merits, there have been many researches related with chitosan in the field of electrorheoloy [11,12].

In this study, we has investigated ER behavior of the suspension based on glucosamine having similar chemical structure such as amine ($-NH_2$) and hydroxyl ($-OH$) radicals with chitosan as the dispersed phases under DC electric field. And also glucosamine chloride salt by chemical reaction between glucosamine and hydrochloride.

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## 2.Experimental

### 2.1. Materials

The base fluid was silicone oil provided by Dow Corning with a specific gravity of 0.97, a kinematic viscosity of 50 cSt at 40°C, and a dielectric constant of 2.61 at 25°C. Glucosamine and glucosamine hydrochloride salt as the organic dispersed phases was supplied by Sigma Aldrich co.. Prior to mixing in silicone oil, glucosamine and glucosamine hydrochloride salt particles were dried for 5 h at 150°C and silicone oil for 3 h at 130°C to remove moisture in vacuum oven. Glucosamine and glucosamine hydrochloride salt suspensions were then prepared at volume fractions of 0.3. After vigorous mixing in ball mill, the suspensions were stored in a dessicator to maintain the dry state.

### 2.2. Electrical and rheological tests

The dc current density (J) and the conductivity ($\sigma$) of the silicone oil, glucosamine and glucosamine hydrochloride salt suspensions were determined at room temperature by measuring the current passing through the fluid upon application of the electric field $E_0$ and dividing the current by the area of the electrodes in contact with the fluid. The current was determined from the voltages drop across a 1 M$\Omega$ resistor in series with the metal cell containing the oil using a voltmeter with a sensitivity of 0.01 mV. This method gave a current measuring sensitivity of 0.01 nA. The dc conductivity was taken to be $\sigma = J/E_0$.

The rheological properties of the suspensions were investigated in a dc field using the Physica Couette-type rheometer with a 1 mm gap between the bob and cup. The resistance to shear produced by the suspensions was measured as a torque on the drive shaft and then converted to shear stress and viscosity. The shear stress for the suspensions was measured under shear rates of 1 to 1000 $s^{-1}$, electric fields of 0 to 3 kV/mm and volume fractions of 0.3, respectively.

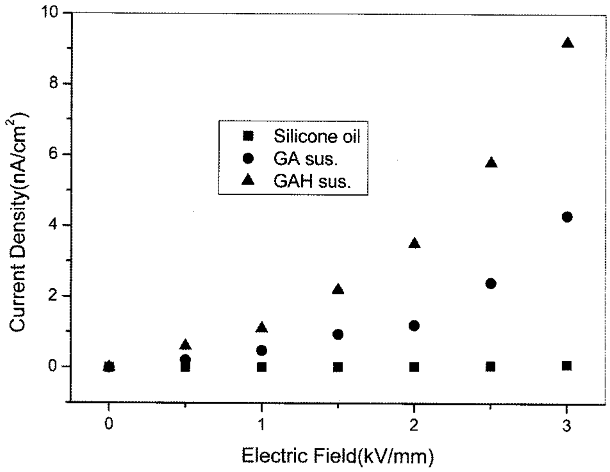


**Fig. 1. Effect of the electric field on the current density for suspensions.**

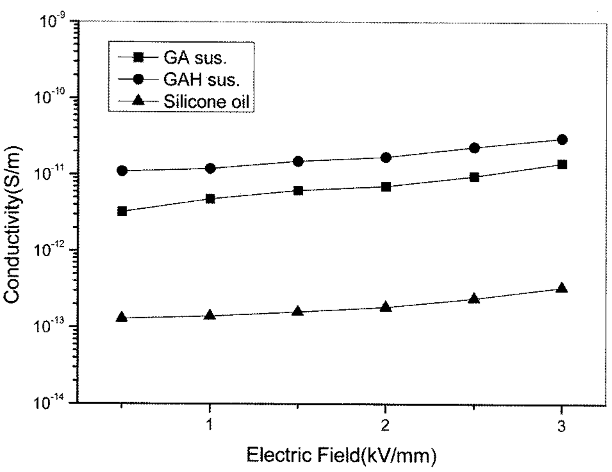


**Fig. 2. Effect of the electric field on the conductivity for the suspensions.**

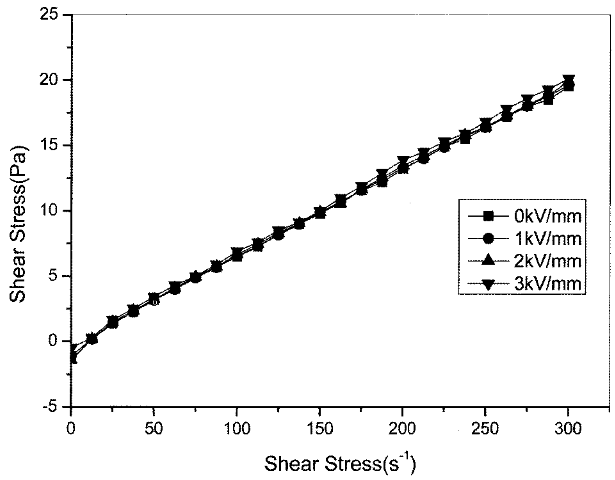


**Fig. 3. Shear stress vs shear rate for silicone oil.**

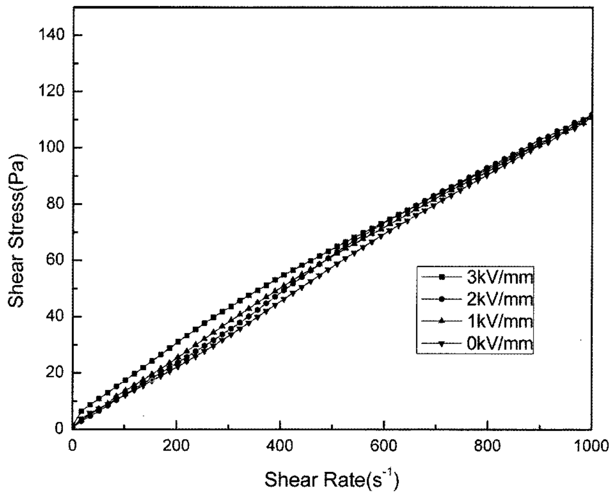


**Fig. 4. Shear stress vs shear rate for glucosamine suspension.**

## 3. Results and Discussion

### 3.1. Eelctrical properties

ER fluids consist of dielectric particles surrendered by an insulating fluid, and in a device they essentially function as leaky capacitors. The transfer of charge between particles results in an electric current through the fluid. The current density associated with a particular ER fluid is useful for estimating the power consumption of devices using the fluid. The electrical properties of ER fluids are therefore important for predicting the power requirements for the design of an ER device and also identifying the ER effect mechanism. The electrical properties of glucosamine and glucosamine hydrochloride suspensions for a volume fraction of 0.3 vs electric field are given in Figures 1 and 2. As seen in Figure 1, the current density of glucosamine and glucosamine hydrochloride suspensions increases with the electric field and conductivity of the suspensions is about 1 and 2 orders of magnitude higher than that of the silicone oil in Figure 2. But, it has low conductivity when compared with chitosan suspension [9].

### 3.2. Rheological properties

To investigate the effect of glucosamine and glucosamine hydrochloride suspensions on the rheological properties, studies were carried out by varying shear rates, electric fields, and volume fractions of particles. Figure 3 shows a plot of the shear stress vs shear rate for silicone oil. There is no effect on the shear stress of the silicone oil with the electric field. The shear stress, ô, is proportional to the shear rate, ã in accord with a Newtonian fluid. The effect of the shear rate on the shear stress for glucosamine and glucosamine hydrochloride suspensions are illustrated in Figures 4 and 5. In Figure 4, it behaves as a Newtonian fluid such as silicone oil due to its low conductivity. As seen in Figure 5, glucosamine hydrochloride suspension behaves as a Newtonian fluid without the electric field, but upon application of the electric field, it exhibits a shear yield stress $\tau_E$. This suspension approximates a Bingham flow behavior, which is described by the equation

$$\tau = \tau_E(E_0, \gamma) + \eta\gamma \qquad (1)$$

Figure 6 gives a plot of log t vs log $E_0$ for the suspension under a shear rate of 10 $s^{-1}$ and a volume fraction of 0.3. The results in Figure 6 indicate that the shear stress is proportional to 1.86

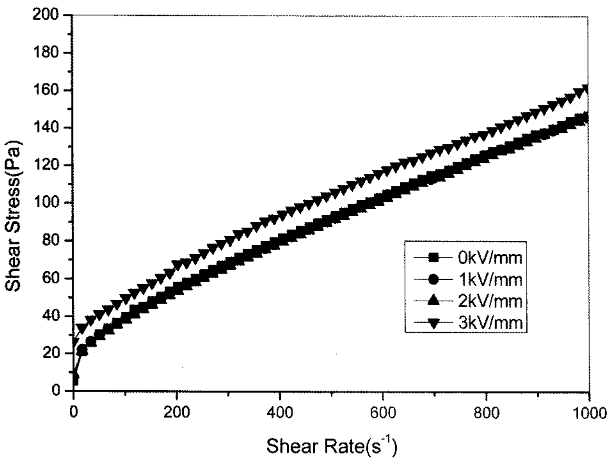


**Fig. 5. Shear stress vs shear rate for glucosamine hydrochloride suspension.**

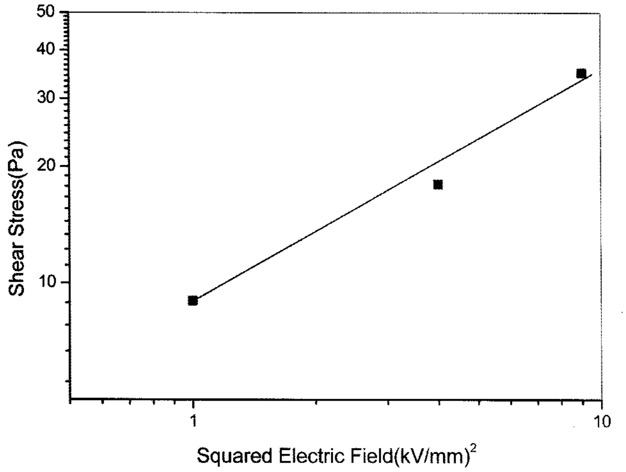


**Fig. 6. Shear stress vs squared electric field for glucosamine hydrochloride suspension.**

power of the electric field, that is $\tau \propto E^{1.86}$.

To describe the status of ER behavior of the glucosamine hydrochloride suspension, the examination process for obtaining the results will be conducted with the assumption that the base fluid and particles behave as ideal dielectric materials, and the particles are aligned in chains or columns between electrodes. With these assumptions, the theoretical analysis of Conrad et al. [13] gives for the polarization component of the yield shear stress

$$\tau_E = 44.1 A_s \phi \varepsilon_0 K_f (\beta E)^2 | \{\exp[(14.84 - 6.165\,(R/a))\beta^2]\} \times 1/(R/a)^4 (1 - 4/(R/a)^2)^{1/2} |_{max} \quad (2)$$

where $A_s$ is taken to be a structure factor pertaining to the alignment of the particles. It is equal to one for perfectly aligned single-row chains and may a value of the orders of ~10 for multiple chains or columns. $K_f$ is the dielectric constant, $\beta$ the relative polarizability ($\cong$1) and R/a the ratio of the separation of the particle center to their radius ($\geq$2.05 ). The structure factor, $A_s$ is obtained from the ratio value of measured- to-calculated shear stress using Eq. (2), that is, $A_s = \tau_{meas}/\tau_{calc}$. We obtain $A_s = 1$ for all of the test conditions at the shear rate of $10\ s^{-1}$., the elelctric fields of 1 to 3 kV/mm and the volume fraction of 0.3, and it maybe be resulted the above mentioned conclusion due to the experimental output in relation with the formation of single chain aligned between electrodes [5,13].

## 4. Conclusions

This study was conducted to investigate electrorheological behavior of the glucosamine and glucosamine hydrochloride suspensions and the following conclusions were found:

(1) The the glucosamine suspension behaved as a Newtonian fluid due to low conductivity even though it has polar group.

(2) The glucosamine hydrochloride suspension behaved as a Nonnewtonian fluid under the application of the electric field.

(3) The shear stress of the glucosamine hydrochloride suspension is proportional to 1.86 power of the electric field, that is $\tau \propto E^{1.86}$.

(4) The value of the structure factor, $A_s$ was 1 and it may be resulted due to the formation of single chain upon application of the electric field.

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