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Electrorheology of HMDA Coupled Chitosan Succinate Suspension as an Anhydrous ER Fluid

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Abstract: The electrorheology of the HMDA coupled chitosan succinate suspension in silicone oil was investigated. HMDA coupled chitosan succinate suspension showed a typical ER response upon application of an electric field. The shear stress for the HMDA coupled chitosan succinate suspension exhibited an electric field power of 2.0. The experimental results for the HMDA coupled chitosan succinate suspension was found to be an anhydrous ER fluid.

Keywords: *electrorheological fluid, ER effect, HMDA coupled chitosan succinate, shear stress*

1. Introduction

Electrorheological (ER) fluids are smart materials which have the ability to control the electric field mechanical devices such as shock absorbers, dampers, clutchs and engine mounts under the effect of electric field [1,2]. Their flow behavior is characterized by a rapid and reversible increase in apparent viscosity due to the formation of particle chains upon application of an electric field [3-5]. Since the ER effect was discovered by Winslow in 1947, many researchers have investigated ER phenomenon for a variety of ER fluids and demonstrated the polarization models based on the point-dipole approximation, with focus on the mismatch between the real components of the dielectric permittivities of the particles and base fluid [6,7].

ER fluids are nonaqueous suspensions composed of electrically polarizable particles dispersed in a dielectric fluid and the disperse phase plays an important role in the ER phenomenon. Cellulose [8], starch [4,9], silica[10], and zeolite [11] 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[12] and polyurethane [13]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.

To solve this problem, chitosan derivatives as the new organic disperse phases of the ER fluid have been synthesized[14,15]. Of these, in this study, the electrorheology pertaining to the ER behavior of HMDA coupled chitosan succinate suspension in silicone oil was investigated. The synthesized HMDA coupled chitosan succinate suspension provides the ER response upon application of an electric field. This study describes the ER behavior of HMDA coupled chitosan succinate suspension and the possibility as an anhydrous ER fluid.

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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. The HMDA coupled chitosan succinate as the organic disperse phase was synthesized by amide reaction between chitosan succinate and hexamethylene diamine under the catalysis of TPP(Triphenyl phosphine) and DEAD(Diethyl azodicarboxylate). Prior to mixing in silicone oil, HMDA coupled chitosan succinate particles were dried for 5 h at 150°C and silicone oil for 3h at 130°C to remove moisture in vacuum oven. HMDA coupled chitosan succinate suspensions were then prepared at volume fractions of 0.1 to 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(σ) of the silicone oil and the HMDA coupled chitosan succinate suspension 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 1MΩ resistor in series with the metal cell containing the oil using a voltmeter with a sensitivity of 0.01mV. This method gave a current measuring sensitivity of 0.01nA. The dc conductivity was taken to be $\sigma = J / E_0$.

The rheological properties of the suspension were investigated in a dc field using the Physica Couette-type rheometer with a 1mm 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 0.1 to 0.3, respectively.

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 conductivity of HMDA coupled chitosan succinate suspension for a volume fraction of 0.3 vs electric field is given in Figure 1. As seen in Figure 1, the conductivity of HMDA coupled chitosan succinate suspension increases with the electric field and moreover , the conductivity of the suspension is about 8 orders of magnitude higher than that of the the silicone oil.

3.2. Rheological properties

The effect of HMDA coupled chitosan succinate suspension on the rheological properties was invesitigated. The shear rate on the shear stress for HMDA coupled chitosan succinate suspension is illustrated in Figure 2. HMDA coupled chitosan succinate suspension behaves as a Newtonian fluid without the electric field, but upon application of the electric field, it exhibits a shear yield stress τ_E. This suspension approximates a Bingham flow behavior, which is described by the equation

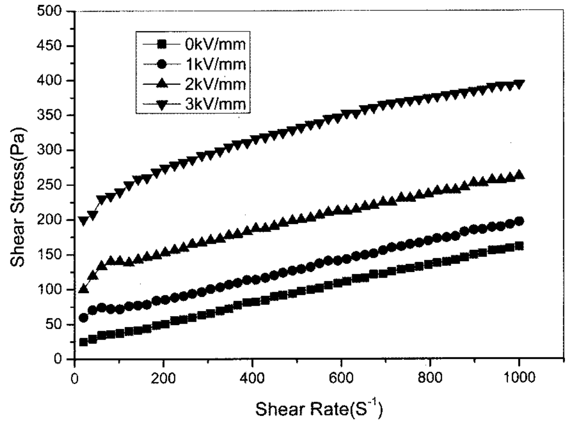

Fig. 2. Effect of the shear rate on the shear stress

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

Figure 3 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 3 indicate that the shear stress is proportional to 2.0 power of the electric field, that is $\tau \propto E^2$.

To describe the status of ER behavior of the HMDA coupled chitosan succinate 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.[16] 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, β the relative polarizability($\cong$ 1) and R/a the ratio of the

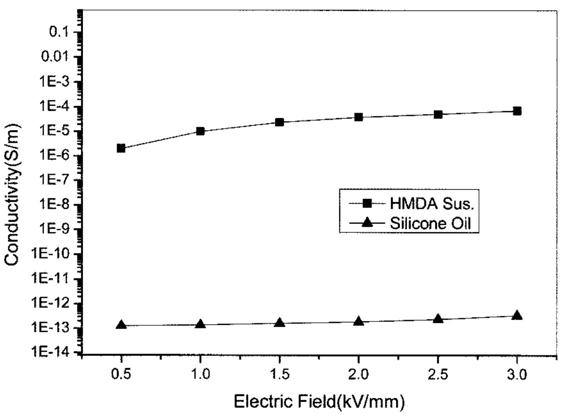

Fig. 1. Effect of the electric field on the conductivity

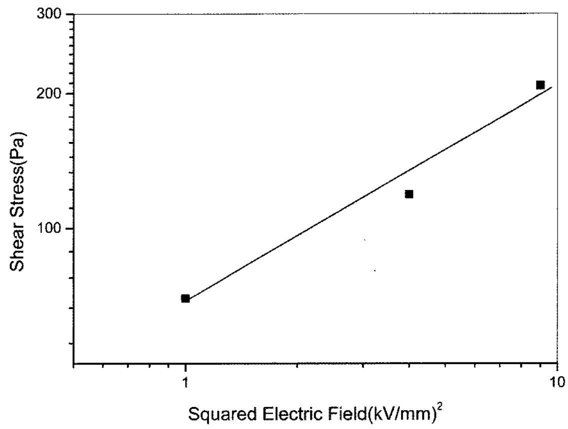

Fig. 3. Effect of the squared electric field on the shear stress

separation of the particle center to their radius (≥ 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 obtained $A_s = 1$ for all of the test conditions at the shear rate of $10s^{-1}$., 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 multiple aligned between electrodes[10,16].

4. Conclusion

This study was conducted to investigate electrorheological behavior of the HMDA coupled chitosan succinate suspension and the following conclusions were found:

(1) The HMDA coupled chitosan succinate suspension showed the ER response upon the application of the field and it behaved similar to a Bingham flow.

(2) The shear stress of the HMDA coupled chitosan succinate suspension exhibited an electric field power of 2.0.

(3) The value of the structure factor, A_s was 1 and it may be resulted due to the formation of multiple chains upon application of the electric field.

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