Measurement of the velocities of dielectric particles in ER fluids with laser speckle

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Abstract: Usually, it is regarded that the movement of dielectric particles in ER fluids is related to the generation of electro rheological effect. In this paper, the principle of measuring infinitesimal displacement by laser speckle is proposed to measure the velocities of particles in ER fluids. It is verified that speckles can be formed by illuminating laser beam on the starch ER fluids. The speckle patterns was recorded with high speed CCD camera, and the speckle patterns sequences with short time intervals was obtained by intercepting laser speckle video. Displacements parallel to electric field and perpendicular to electric field were obtained by processing the two consecutive speckle patterns. The experimental results showed the velocities of particles exhibit the trend towards an oscillatory decreased with time, and a critical electric field and a critical sample concentration exist, when lower than this critical electric field (concentration), the mean particle velocity tends to increase; when high than that, decrease instead. Moreover, the horizontal velocity of particle is almost zero, there is only small oscillatory movement of particles in the vertical direction of electric field when the particle chain of ER fluid forms a relatively stable structure.

Keywords: ER fluids, velocity measurement, laser speckle, dielectric particles

1 Introduction

ER fluid is a kind of suspension by mixing the micron-sized particles of high dielectric constant with the insulating oil of low dielectric constant. When the applied electric field is changed from zero to high, ER fluid is usually considered to transform from Newton fluid under zero electric field to Bingham fluid which means the fluid can exhibit similar solid behavior and have certain yield stress under certain applied electric field\textsuperscript{[1-3]}. In order to explain and quantitatively describe this singular behavior of ER fluid under applied electric field, many kinds of models were built to try to explain the ER effect. According to the current research results, it is generally believed that the ER effect is the result of the polarization of dielectric particles under the influence of an applied electric field\textsuperscript{[4]}.

It can be found from experiments that when the applied electric field is relatively low, the particles have certain movements but no ER effect is formed; as long as the applied electric field is increased to a critical range, the ER effect can be observed. Through the microscopic observation, it was found that the particles in ER fluid were arranged in nonuniform chain or column structure with the increase of the applied
electric field, and the moving speed of the particles also changed along with the formation of the micro structure. Tamura and Doi\cite{5} equated polarized particles with dipoles, simulated the Poiseuilleflow of ER fluid by molecular dynamics method. Gao\cite{6,7}, etc. considered the edge effect, simulated the Poiseuilleflow of ER fluid by using molecular dynamics of dipoles and found the movement velocity of particles not only had blocking area but also exhibited ‘breath pattern’ transition state in the contact zone. Liu Yulan, etc. studied the mechanism of the chain structure formation of particles in ER fluid, could realize the prediction of the formation rate and response time of the particle chain\cite{8}. Yananda\cite{9-11} studied coagulation of silica particles in oil by an a.c. electric field and the observation of the coagulation process under various mechanical conditions was made using a video-microscope with a CCD camera. Recently, Qian measured the velocities of nanoparticles in nanofluids by laser speckle velocimetry\cite{12}.

The characteristic and mechanism study on ER fluid involves: distribution, coagulation and structure of particles; shear stress of ER fluid; interaction among particles caused by applied electric field and synthesis of ER fluid. Only when the mechanism of ER fluid is investigated clearly, can the macroscopic properties of ER fluid be completely understood, so as to obtain the optimum synthesis plan of ER fluid and then develop more practical ones. So, whether from the point of practice or theory, the mechanism study of ER fluid is always of great importance.

When a laser beam passes through a transparent scatter, speckle will be formed. Much information of the light beam and the object passed through by it is carried by the speckle, it can be analyzed by using related calculation software, and it is known that starch ER fluid of low concentration is just regarded as transparent scatter. In the paper, different laser speckle were observed by laser speckle experimental facility in terms of different concentration of starch ER fluid under different applied electric field, and the movement velocities of starch particles were measured according to the dynamic situation of laser speckle. The relation between the formation of micro structure and the velocity of particles was also discussed.

2 Experiment

2.1 Sample preparation

Taking starch particles as dispersed phase, dimethyl silicone oil as carrier fluid, four different concentrations of samples were made, the mass percentage were 0.5%, 1%, 1.5%, 2%, 2.5%, 3%.

2.2 Experimental facility

Fig.1 is the schematic diagram of experimental facility. It includes: laser, double Polaroid, total reflection mirror, high voltage power supply and CCD camera. The laser’s length is 25cm, its ideal wavelength is 632.8nm; the double Polaroid is used to adjust the intensity of light; the total reflection mirror is used to change the propagation path of light; CCD camera is to pickup image.

The sample container is made up of glass and copper electrode. Its length, width and height are 10.76mm, 2.5mm (inner distance) and 24.00mm. It should be noted
that the length here means the distance between two electrodes.

![Fig.1 the schematic diagram of experimental facility](image1)

2.3 Experimental procedure

In this experiment, the distance from total reflection mirror to lens, from lens to sample, and from sample to CCD are fixed. Different electric fields were applied to each sample, a 30-second laserspeckle video was cut out for each electric field strength. Fig.2 is the laserspeckle pattern of ER fluid when the sample has 1%

![Fig.2 laserspeckle pattern of 1% starch ER fluid under 400v/mm electric field concentration under 400v/mm electric field](image2)

Taking screenshots from the laserspeckle video by KMplayer software, a certain number of images were captured per second (in theory, the more images are got per second, the more accurate is the calculation for the velocity of starch particles, but the more calculated amount is needed). Make cross-correlation calculations for every two neighboring images, to obtain statistical displacements of particles per unit time interval in the direction of electric field and also in the vertical direction of it, so as to calculate the velocity. Thus velocity component in the direction of electric field (horizontal velocity for short) and that in the vertical direction of it (vertical velocity for short) could be obtained.
3 Experimental results and discussions

3.1 Particle velocity changes with time

Fig. 3 for a given particle concentration (1%), particle velocity changes with time.

Fig. 3 gives the particle velocity variations in terms of time when the ER fluid with 1% particle concentration is applied in the electric field of 400v/m and 700v/m respectively. From the figures, it is known that horizontal and vertical velocity both show the trend towards an oscillatory decrease with time, moreover, the horizontal and vertical velocity in fig. 3b are obviously larger than that in fig. 3a, which illustrates that the horizontal and vertical velocity would increase with the increase of applied electric field.

Fig. 4 for a given particle concentration (2%), particle velocity changes with time.

a. electric field of 400v/mm  b. electric field of 700v/mm

a. electric field of 500v/mm  b. electric field of 800v/mm
Fig. 4 shows the relation between velocity and time when the particle concentration of ER fluid is 2%. Fig.a and fig.b indicate two different applied electric fields of 500v/m and 800v/m respectively. It could be known from above figures that the horizontal and vertical velocity under two different electric fields both trend towards an oscillatory decrease, furthermore, the horizontal and vertical peak basically remain unchanged with the increase of electric field.

![Graph showing velocity over time for a and b electric field](image)

a. electric field of 300v/mm  
b. electric field of 600v/mm

Fig. 5 for a given particle concentration (3%), particle velocity changes with time.

Fig. 5 gives the relation between velocity and time when the particle concentration of ER fluid is 3%. In fig.a, the applied electric field is 300v/m, it is obvious to see the particle velocity become smaller and the horizontal velocity is smaller than the vertical one. Fig.b shows, with the further increase of electric field and particle concentration, the horizontal velocity of particle is almost zero, there is only small oscillatory movement of particles in the vertical direction of electric field.

3.2 Particle velocity changes with sample concentration
Fig. 6 shows variation curves of mean particle velocity (that is, a mean value of velocity within 30 seconds) in terms of sample concentration under two different electric fields (400v/mm and 800v/mm). Fig. a and fig.b both illustrate that a critical concentration exists when mean particle velocity changes with sample concentration, when lower than this concentration, mean velocity would increase with concentration, but when higher than that, it exhibits a trend of decrease. Comparing these two figures, it is also shown that in the condition of higher electric field, the critical concentration becomes smaller (that is, the peak of curve moves to left), which means when the sample concentration is low, provided the applied electric field is high enough, the particle velocity could also reach its peak.

3.3 Particle velocity changes with electric field

Fig. 7 for a given particle concentration, particle velocity changes with electric field.
Fig. 7 gives relation curves between mean particle velocity (that is, a mean value of velocity within 30 seconds) and applied electric field with two different sample concentrations (1% and 2%). Fig. a and fig. b both illustrate that a critical electric field exists when mean particle velocity changes with electric field, when lower than this electric field, mean velocity would increase with electric field, but when higher than that, it exhibits a trend of decrease. Comparing these two figures, it is also shown that in the condition of higher sample concentration, the critical concentration becomes smaller (that is, the peak of curve moves to left), which means lower electric field could be applied to a sample with high concentration, because the particle velocity would also reach its peak.

To sum up, the ER fluid can form a relatively stable structure only when the sample reaches a certain concentration and the applied electric field is high enough, at this time, the particle velocity of ER fluid is close to zero, as shown in fig. 8.

![Fig. 8 Laserspeckle pattern of 3% ER fluid under 700v/mm electric field](image)

4 Conclusion

In the paper, laser speckle measuring system was utilized to measure the velocity of micro particles in ER fluid, the influence of the applied electric field, sample concentration on the particle velocity was analyzed, and the relation between particle arrangement, coagulation and particle velocity was discussed when ER fluid is acted on by an electric field, the main conclusions are as follows:

1) Under certain electric field, the horizontal and vertical velocity both exhibit the trend towards an oscillatory decrease with time.

2) It is shown from the experiment that particle velocity is closely related to sample concentration and electric field, and a critical electric field and a critical sample concentration exist, when lower than this critical electric field (concentration), the mean particle velocity tends to increase; when high than that, decrease instead.

3) When the concentration reach a certain value, the particle chain of ER fluid
forms a relatively stable structure, so, under the applied electric field, the horizontal velocity of particle is almost zero, there is only small oscillatory movement of particles in the vertical direction of electric field.

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