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Unification of viscose models for powder suspension system①

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[Abstract] The viscose models for powder suspension system was reviewed and analysed. It is found that by introducing modification function $f(\varphi)$ in the differential form of classical Einstein's viscosity law, all of viscose models can be unified if $f(\varphi)$ takes suitable form. Some rational forms of the function $f(\varphi)$ were discussed according to functional approximation method, and a new rheological model contained two undetermined parameters was consequently developed, more suitable for high particle concentration dispersing system. The experimental results show that this new model is of better consistence.

[Key words] suspension system; rheology; Einstein's viscose law
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1 INTRODUCTION

In the field of material science and engineering, suspension disperse system formed by powder dispersed in a liquid medium is of various very important applica-

cosity, which was primarily due to the energy losses resulted from the relative racking of particles to the low viscosity medium. By averaging the energy loss of each particle-pair in the medium, they gave the viscosity formula[4]:

example, Mooney equation[11]:

$$\eta_r = \exp\left[2.5\frac{\varphi}{1-\varphi/\varphi_m}\right] \tag{18}$$

Which is analogous to Eqn. (17). In Eqn. (17), the first-order term was only taken into account, and lots of high-order terms were not considered, therefore, it was not accurate enough. In order to get a better result, all high order terms should be considered. If let $\frac{f^{(n)}(0)}{n!} = K^n$ (K is a constant, less than one), an infinite series similar to Eqn. (15) could be used for approximation, namely

$$f(\varphi) = \sum_{n=0}^{\infty} K^n \varphi^n \tag{19}$$

Input (19) into Eqn. (13) and make integration:

$$\eta_r = [1 - K\varphi]^{-2.5/K} \tag{20}$$

This equation is perfectly identical to Eqn. (6) discussed in part 2. Here, it is acquired in an analysis method. Since the effect of high-order term was considered in Eqn. (19), it should have better accuracy. Since the addition of the powder could not be unlimited, one particle could not unlimitedly approach to another. This means that when φ approaches φ_m, the η_r should be infinite. Therefore, K is a factor, which is related to the maximum addition of powder(φ_m). However, in addition to the packing effect, there are many other important factors which are of great contributions to the viscosity of the suspension system, like the particle shape, interaction between particle and medium and so on. Therefore, it is better to introduce another undetermined parameter k, which is associated with the above effects. Thus, the $f(\varphi)$ could take a more general form as below:

$$f(\varphi) = k\sum_{n=0}^{\infty} K^n \varphi^n \tag{21}$$

Where k is a constant. Inputting Eqn. (21) into Eqn. (13) and making integration, we have

$$\eta_r = [1 - K\varphi]^{-2.5k/K} \tag{22}$$

Since this model contains two parameters, which can be determined by experiments, and its accuracy should be improved a lot, especially for the suspension system with very high powder content.

4 EXPERIMENTAL VERIFICATION

The powders used in the experiments were W, Ni, and Fe with the mass ratio of 97∶2∶1. All powders were of less than 5 μm particle size and with near sphere shape. Polystyrene (PS), polypropylene (PP) and vegetal oil (VO) were used as the dispersing medium with mass ratio of 1∶1∶1. Dibutyl-phalate (DBP) was used as an additive. The powder additions were in range of 40%~55% (volume fraction). An intensive mixer and a screw extrusion machine were used to prepare the suspension system. The mixing was performed under temperature range of 145~150 ℃ for 2 h. An Instron 3211 capillary rheometer with temperature control of ±1 ℃ was used to measure the viscosity of the system. The dimension of the capillary was 1.27 mm in diameter, and 76.2 mm in length. 10 min were allowed to reach thermal equilibrium after charging the barrel. The shear rate and temperature for the viscosity measurement were 120 s^{-1} and 185 ℃ respectively. According to the experimental results, the undetermined parameters in the Eqns. (2), (3), (5), (6) and (22) had been determined. The relationship between the relative viscosity values obtained from both experiments and calculation according to the models and the powder additions was showed in Fig. 3. It could be seen that the prediction values from Eqns. (1), (3), (4) were off the experimental dots seriously, but very close for Eqns. (2), (5), (6), and (22). Particularly, the results obtained from Eqn. (22) were much closer than the other equations. The difference between the predicated values and experimental dates was less than 10%, until up to the 50% (volume fraction) powder addition.

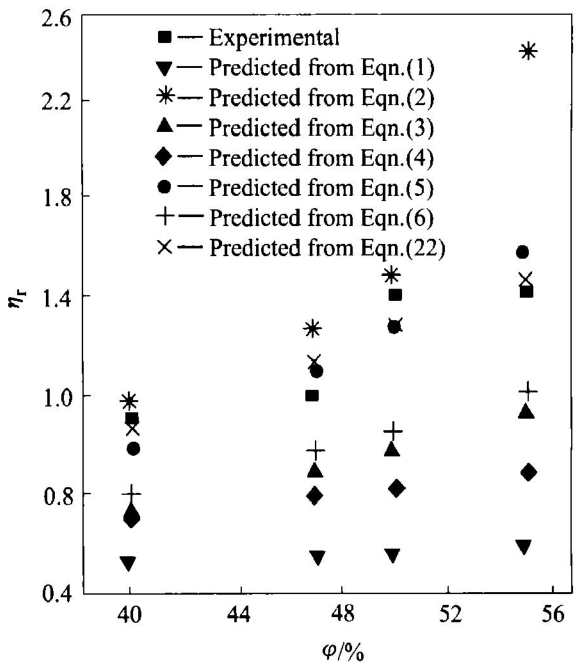

Fig. 3 Relative viscosity vs powder addition for 97W-2Ni-1Fe powders to be dispersed in PS-PP-VO-DBP medium

5 CONCLUSIONS

1) All viscose models to describe the viscose behavior of suspension system formed by dispersing solid

powder in a liquid medium could be unified by Eqn. (13), which was derived from Einstein's rheological law.

2) Different models are suitable for different viscose suspension systems.

3) When the powder content is very low, the viscose behavior of the suspension system could be described by classical Einstein's viscosity law, namely Eqn. (1).

4) For the case where the powder content is in the middle range, the viscose behavior of the system could be described by Eqns. (3), (4) and (6).

5) For the suspension systems with extremely high particle volume fraction, like the feedstock used in powder injection molding, their viscose behaviors could be described by Eqns. (2), (5) and (22).

6) Particularly, the new model, Eqn. (22), could do a much better job.

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