Controlled shear stressed rheological investigations of ferrofluids

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Motivation

In the recent years rheological experiments performed on ferrofluids demonstrated strong changes of their viscosity with an applied magnetic field, the so called magnetoviscous effect [1]. This effect can be described with chain and structure formation due to interparticle interaction in the presence of a magnetic field. Further, these structures break up under the influence of shear resulting in a reduction of the field dependent viscosity increase, the so called shear thinning.

In order to explain the magnetoviscous effect a theoretical model [2, 3] has been developed, which describes the ferrofluid as a bidispers system. Admittedly the theoretical approach of the magnetoviscous effect can be applied only for the lower newtonian regime of the flow curves that cannot be achieved in ferrofluids with a shear rate controlled rheometer [4]. Additionally, with such a shear rate rheometer, the question whether a yield stress exists could not be answered directly [4]. Extrapolating the measured flow curves to shear rate zero, an upper border for the yield stress of 0.1 Pa could be estimated for the fluid APG513A and a magnetic field strength of 30 kA/m.

Experimental setup

In order to investigate the lower newtonian regime of the flow curves and to proof the existence of a yield stress, a special shear stress controlled rheometer has been designed.

The magnetic field, which is necessary for the invesigations, is produced by a cylindrical coil. A maximum field up to 80 kA/m with a homogeneity of 0.05 % in the region of the shear cell can be applied. The measuring cell is a cone-plate arrangement combined with a Couette region. With this combination the disturbing dewetting of the cone, which can arise by the appearance of fluid spikes due to the normal field instability, can be avoided.

Figure 1: shear stress rheometer

The cone is fixed via an air bearing with an optical encoder. With this device, which works contactless, the rotation frequency of the cone is measured with high precision. The encoder allows the detection of a minimum rotation frequency of 10^{-7} Hz. To apply shear stresses below the mentioned value of 0.1 Pa [4] a conventional electric motor is used in combination with a fluid coupling.

The upper plate of the coupling (fig. 2) is fixed to the electric motor. The torque is transmitted by the liquid to the second plate, which is fixed to the cone of the cone-plate cell. With this system a minimum torque of 10^{-9} Nm can be realized, which corresponds to a shear stress of 10^{-4} Pa.

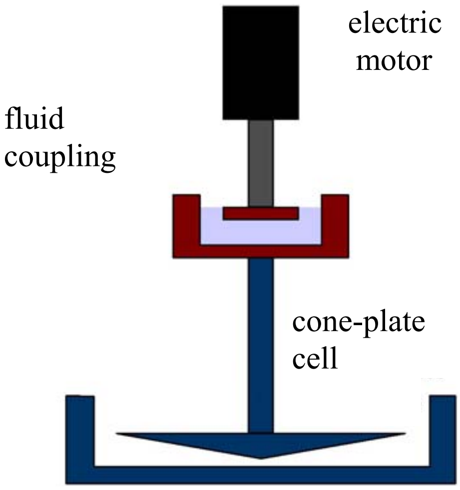

Figure 2: schematic sketch of the driving unit (electric motor combined with the fluid coupling)

Preliminary results

In the first experiments, using a conventional driving unit, two kinds of ferrofluids, one with low and one with high content of large particles were investigated. The fluids tend not to show a Bingham behaviour, but rather a Prandtl-Eyring behaviour.

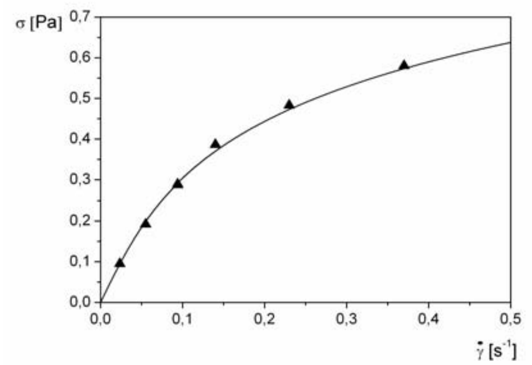

Figure 3: flow curve for the fluid with high content of large particles and a magnetic field of 15 kA/m with a fit of Prandtl-Eyring behavior (black line)

Figure 3 shows the experimental results of the ferrofluid with high content of large particles and using as fit parameters a characteristic viscosity of $\eta_* = 4.16$ Pas and a characteristic stress of $\tau_* = 0.215$ Pa. With these values the dependence of the ferrofluid´s viscosity related to the stress can be calculated (fig.4). For a stress less than 0.04 Pa the fluid does not show any change of viscosity. That means that stresses about 0.04 Pa have to be applied to come down to the lower newtonian regime of the flow curves.

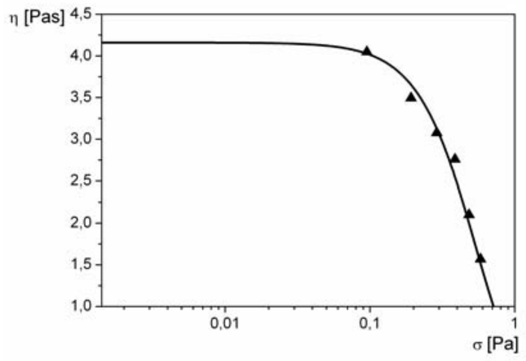

Figure 4: the dependence of viscosity related to the stress calculated with the characteristic values from the fit shown in fig.3.

By optimization of the driving unit - electric motor combined with fluid coupling – the stress applied to the ferrofluid could be reduced from 0.095 Pa down to 0.04 Pa.
As mentioned, for the fluid APG513A and a magnetic field strength of 30 kA/m a yield stress of 0.1 Pa [4] is estimated. With the new driving unit stresses below this value can be applied directly. Thus the question whether a yield stress exists can also be answered directly as a function of the strength of the applied magnetic field.

References

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