Impact of Constituent Interactions on the Rheology of Lipophilic Food Suspensions

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ABSTRACT

In many cases, foods are disperse systems with a liquid continuous phase. The rheological properties of such systems strongly depends on the nature, the properties and the concentration of the constituents and determines the processing, storage and consumption properties. Aim of the present study was to evaluate the effects of surfactants (lecithin, polyglycerin-polyricinoleat (PGPR)) on the rheology of oil-based suspensions as influenced by the type, the volume fraction, and the size of the dispersed solids. The disperse phase (glass microspheres and sucrose) was characterized by particle size distribution, particle shape, BET surface, and density. The flow characteristics were measured in a stress controlled rheometer.

Generally, the flow of the suspensions is characterized by a sequence of different flow regions, representing the transition from solid-like to liquid-like behavior as the shear stress increases. The location of these regions generally depends on type and volume fraction of the disperse phase, and on the presence of surfactants.

The effects of the surfactants do also vary with particle type: While PGPR had a much more pronounced impact on the flow of glass spheres in oil, the effect of lecithin on the flow of sucrose suspended in oil was significantly higher than in the glass sphere suspensions.

INTRODUCTION

During processing but also consumption-ready, foods often appear as disperse systems with a liquid continuous phase. Depending on nature, properties and concentration of the involved systems the rheological properties of the suspensions may largely differ from those of a Newtonion fluid, and knowledge and control of flow is important for processing steps such as pumping, mixing, filling, and coating as well as for product quality. Certain foods or food components are processed as suspensions, which consist of a polar or non-polar continuous phase and of the dispersed solids. Depending on origin and pre-processing such as comminution or agglomeration, these solids may considerably vary in their granulometric properties, i.e., particle size distribution (PSD) and particle shape as well as in interfacial properties. The combination of all these properties determines the strength of polar and hydrophobic interactions between the continuous and the disperse phase and can be detected phenomenologically by rheological measurements.

For practical aspects the volume fraction, the viscosity of the continuous phase, and the addition of surfactants are common actions to modify suspension properties to meet processing, consumption, and storage requirements[1,2]. Do et al.[3] and Mongia and Ziegler[4] also found that PSD

was a crucial parameter influencing the rheological properties. For particles of the same type, Sokmen and Gunes[5] stated that a reduction in particle size induces an increase in the viscosity of the corresponding suspensions.

Because the modification of individual food components is limited the processing properties of these systems are frequently controlled by adding surfactants, which cause a higher stability or fluidity of the suspensions.

Surfactants and their effect on the flow properties of suspensions are of particular interest for the confectionary industry. The influence of surfactant (e.g., lecithin, PGPR) concentration on the flow characteristics of confectionary suspensions has already been shown by Aguilar and Ziegler[6], and by Schantz and Rohm[7]. As regards food suspensions, information was mainly gained from phenomenological investigations while, due to the number of influencing factors and their potential interactions, microstructural interactions at the molecular and interfacial level are still poorly understood. Therefore a few studies focus on singular microstructural relationships such as interfacial properties[8], and on the influence of lecithin and PGPR mixtures[7].

Considering that surfactants modify the interfacial interactions between the disperse phase and the surrounding liquid phase, the total inner surface of the suspensions is of special importance. It was the main aim of our work to evaluate how parameters which affect the inner surface of dispersions alter the rheological behavior of oil-based suspensions, and to measure the impact of surfactants in these dispersions. Whereas the interfacial properties of the solid particles were chosen to be hydrophilic, type and volume fraction of the particles, PSD and specific surface area, and the type and concentration of surfactants were varied. A better understanding of the microstructural actions of surfactants at the interface might then help to improve processing of food suspensions.

MATERIALS AND METHODS

Since most food suspensions are very complex systems, it is difficult to investigate causal effects of specific factors. Therefore, we used simple model suspensions of particles with hydrophilic surface properties and a lipophilic continuous phase.

Hollow glass microspheres (110P8, CP 2000 and CP 5000, Potters Ballotini, Germany) and micro-milled sugar (Pfeifer & Langen KG, Germany) served as the disperse phase. Glass microspheres were sized by sieving and air separating to achieve fractions with a different particle size distribution. The solids were characterized with respect to BET surface (Nova 2000, Quantachrome, Germany), their density (Nova 2000, Quantachrome, Germany), and PSD (Helios, Sympatec, Germany) (Table 1).

Table 1. BET surface, density and PSD of hollow glass microspheres (spheres) and micro-milled sugar (sugar)

		spheres	sugar
BET surface [m^2/g]		0.751	1.166
Density [g/cm^3]		1.050	1.581
PSD [µm]	d_{10}	4.330	1.108
	d_{50}	11.277	5.520
	d_{90}	21.997	15.578

The particles were dispersed in triethylhexanoin (Stearinerie Dubois, France) (density: 0.95 g/cm^3; viscosity: 42 mPa.s at 22 °C) or purified soybean oil ($\rho = 0.92$ g/cm^3; $\eta = 64$ mPa.s). A lecithin product (Solec F10, The Solae Company, Germany) and commercial PGPR 4150 (Paalsgard, Denmark) were used as surfactants.

The suspensions were prepared by dispersing the particles in the continuous phase with a laboratory stirrer (IKA-Werke, Germany) with 1000 min^{-1} for 60 min. When necessary, surfactants were added to the suspensions after 30 min stirring.

The rheological experiments were performed using a MCR 300 rheometer (Anton Paar GmbH, Germany) in the contolled shear stress mode. After transferring into the CC 27 concentric cylinder system and thermostatting to 22 °C, the samples were pre-sheared at 100 s^{-1} for 60 s. The flow characteristics were then determined at a shear stress range from 10^{-2} to 10^2 Pa at 22 °C. The Newtonian behavior of the continuous phase was confirmed using the DG 27 double gap system.

RESULTS AND DISCUSSION

Generally, the flow curves of the concentrated suspensions of glass or sucrose in oil can be separated into three domains, with each of them corresponding to a particular shear stress range:
1. solid-like behavior
2. solid-liquid transition state
3. liquid state

The extent of each of these domains generally depends on the type, PSD and volume fraction of disperse phase as well as on type and concentration of the surfactants.

Figure 1 depicts the effect of particle concentration on the rheological response of glass suspensions without surfactants.

With decreasing volume fraction, the solid-like behavior and the yield stress became less important, and the flow characteristics turned towards pure viscous flow.

Generally, the viscosity functions of the suspensions are characterised by initial shear-thinning and a subsequent plateau region at higher shear stresses. The apparent viscosity as well as the shear rate where the transition from the non-Newtonian to the Newtonian region takes place generally depends on type and volume fraction of the disperse phase, and on the presence of surfactants.

When glass spheres were dispersed in soybean oil, the addition of lecithin resulted in a small reduction in viscosity whereas PGPR caused a much more pronounced viscosity drop in the shear-thinning region (Figure 2). However, when using sucrose, the effect of lecithin on the flow properties of suspensions was significantly higher than the effect of PGPR (Figure 3).

These results show that there is an important impact of the specific properties of the surface of suspended solids on the effects which these surfactants cause in the suspensions.
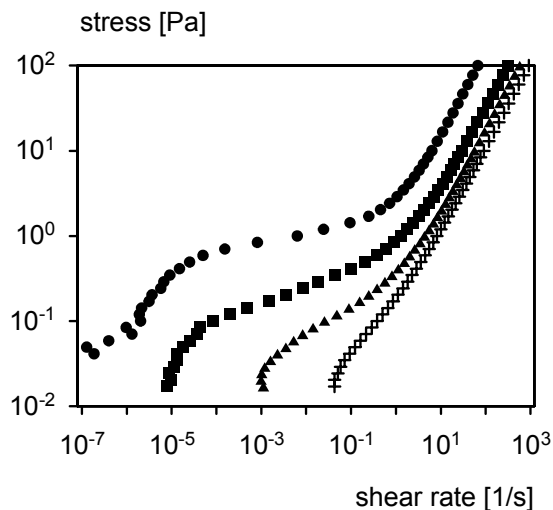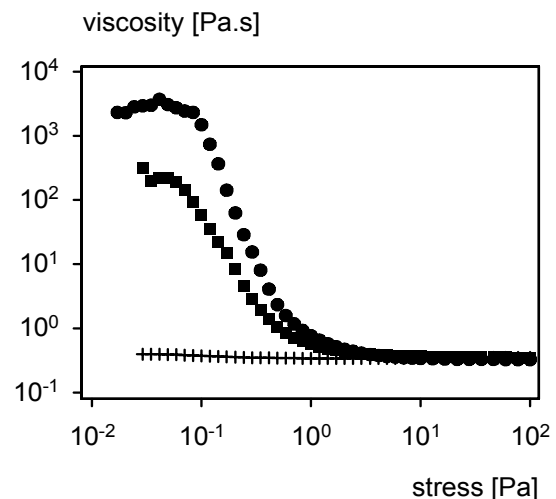

Fig 1. Flow curves of hollow glass microspheres in soybean oil. Volume fractions: $\Phi = 0.2$ (+), 0.3 (▲), 0.4 (■) and 0.55 (●). No surfactant was used.

Fig 2. Viscosity curves of hollow glass microspheres ($\Phi = 0,4$) in soybean oil. Suspensions prepared without surfactants (●), 0.5% PGPR (+) and 0.5% lecithin (■).

This leads to the assumption that the surfactants behave in a different way at the interface between disperse and continuous phase because of the different surface properties of the solids.

The specific determination of the main factors of this impact contributes to an improvement of the understanding of microstructural interactions which occur at the interface, and helps to understand their consequences on processing properties of food suspensions.
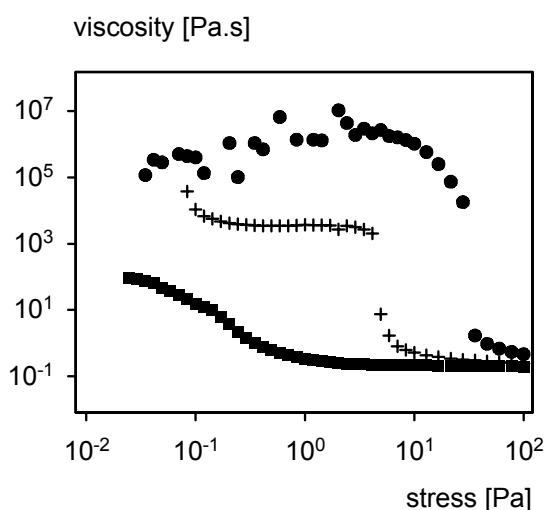

Figure 3. Viscosity of sucrose ($\Phi = 0{,}2$) in soybean oil. Suspensions were prepared without surfactants (●), 0.5% PGPR (+) and 0.5% lecithin (■).

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