# FLUID IMMOBILIZATION – A STRUCTURE-RELATED KEY MECHANISM FOR THE VISCOUS FLOW BEHAVIOR OF CONCENTRATED SUSPENSION SYSTEMS

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## ABSTRACT

The role of fluid immobilization (FIM) is not only of great importance for solid food systems with respect to their stability, but is also a crucial factor for the rheological behaviour of suspension systems [1]. Besides the fluid binding mechanisms known for porous solids an additional hydro-dynamically induced fluid immobilization (HIFI) is of importance for suspensions in flow. The contribution of the HIFI-mechanism is taken into account by a particle or aggregate shape factor, which for non-spherical or non-cube-like shapes depends additionally on the orientation in the flow field. In many food suspension systems sphere- or cube-like particles with hydrophilic or hydrophobic surface properties build aggregates in the watery and/or fat continuous phases. Such particle aggregates are characterised by different surface and volume FIM-properties. The fluid fraction which is immobilized at the surface $\phi_{sif}$ depends on surface characteristics like fluid adhesion, interfacial tension and roughness. The volume related immobilized fluid fraction $\phi_{vif}$ depends on porosity, pore size distribution or packing density.

## ZUSAMMENFASSUNG

Die Rolle der Flüssigkeitsimmobilisierung (FIM) ist nicht nur für die Stabilität von Lebensmittelsystemen von grosser Wichtigkeit, sondern ist auch der entscheidende Faktor für das rheologische Verhalten von Suspensionen [1]. Neben den flüssigkeitsbindenden Mechanismen poröser Festkörper ist eine zusätzliche hydrodynamisch induzierte Flüssigkeitsimmobilisierung (HIFI) für fliessende Suspensionen wichtig. Der Beitrag des HIFI-Mechanismus wird mittels eines Partikel- oder Aggregatformfaktors berücksichtigt, welcher für nichtsphärische oder nichtkubische Formen zusätzlich von der Orientierung im Strömungsfeld abhängt. In vielen Lebensmittelsuspensionen bauen kugel- oder würfelförmige Partikel mit hydrophilen oder hydrophoben Oberflächeneigenschaften Aggregate in der wässrigen oder öligen Kontinuumphase auf. Solche Partikelaggregate werden durch verschiedenen Oberflächen- und Volumen-FIM-Eigenschaften charakterisiert. Der an der Oberfläche immobilisierte Flüssiganteil $\phi_{sif}$ hängt von Oberflächeneigenschaften, wie z. B. Flüssigkeitsadhesion, Grenzflächenspannung und Rauhigkeit, ab. Der volumenartige, immobilisierte Flüssigkeitsanteil $\phi_{vif}$ hängt von der Porosität, der Porengrössenverteilung oder der Packungsdichte ab.

## RÉSUMÉ

Le rôle de l'immobilisation de fluide (FIM) sur les propriétés de stabilité des systèmes alimentaires à l'état solide est non seulement important, mais aussi, est un facteur crucial sur le comportement rhéologique des suspensions [1]. En plus des mécanismes de fluides liants connus dans le cas des solides poreux, une immobilisation de fluide induite hydrodynamiquement (HIFI) additionnelle tient une place importante dans l'écoulement des suspensions. La contribution du mécanisme HIFI est prise en compte par un facteur de forme de la particule ou de l'agrégat, qui pour des formes non sphériques ou non cubiques, dépend de manière additionnelle de l'orientation dans le champ d'écoulement. Dans beaucoup de suspensions alimentaires, des particules sphériques ou cubiques, avec des surfaces hydrophyliques ou hydrophobiques, construisent des agrégats dans les phases continues acqueuses ou huileuses. De tels agrégats de particules sont caractérisés par des propriétés FIM de surface et de volume différentes. La fraction de fluide qui est immobilisée à la surface $\phi_{sif}$ dépend des caractéristiques surfaciques telles que l'adhésion de fluide, la tension interfaciale et la topologie. La fraction volumique relative de fluide immobilisé $\phi_{vif}$ dépend de la porosité, de la distribution en taille des pores ou de la densité de remplissage.

## 8 FIM-CALCULATION / EXPERIMENTS COMPARISON

For the sugar/oil suspension system investigated, an initial solid mean particle size of $x_{50,o}$ = 3 mm was measured. From such particles and silicon oil aggregates with a mean diameter of $x_{50,o}$ = 52 mm were formed using a 3-roller mill. With these aggregates a concentrated suspension was mixed ($\phi_S$ = 0.3) which was subsequently sheared in a kneeder.

In the most strongly shear treated state of these aggregates (representative shear rate $\gamma_r \approx$ 100 1/s) an aggregate mean diameter of 30 microns was detected (see Fig. 4). Knowing the primary particle mean diameter one can estimate the number of primary particles forming an aggregate, which leads to about 5000 primary particles per aggregate for the non-sheared aggregates and about 1000 primary particles for the strongly dispersed final state. It was shown that the related measured viscosity functions are in good agreement with calculated curves (FIM model, Eq. 7) from the same model data sets, just varying the aggregate size according to the measured values (Fig. 16). These results confirm that the rheological behaviour of concentrated suspension systems can be related to the immobilization of a certain fluid fraction, which is shear rate/shear stress and time dependent and reflects related changes in the disperse structure properties. The shear rate and time dependent aggregate size provides further information on the aggregation and deaggregation kinetics within investigated shear flow fields. Structure flow functions allow for defining microstructure-rheology relation-ships which do explain the shear rate/shear stress, time and solid volume fraction dependencies of measured viscosity functions for real suspension systems.

In future work experiments will be set up in order to evaluate the relevance of the introduced fluid immobilization model (FIM) for various structural characteristics of particles and aggregates like their surfaces, shapes and inner morphology. Furthermore the influence of the type of flow on the fluid immobilization characteristics are of particular interest, with special regard of elongational and mixed shear-/elongational flow fields in processing unit operations.
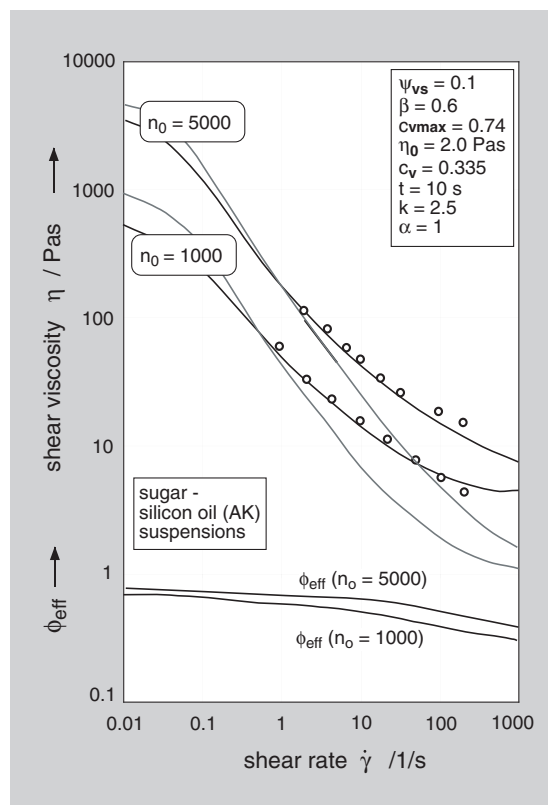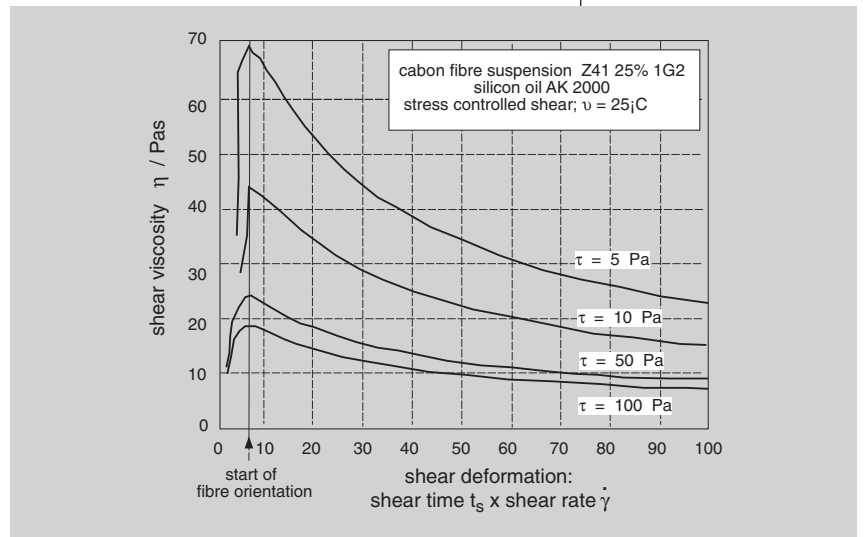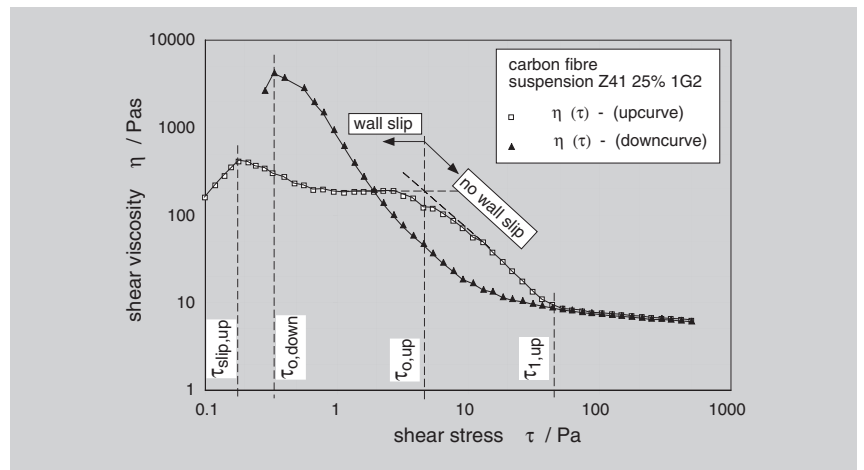






*Figure 14 (upper):*
*Shear viscosity function of concentrated fibre suspension (carbon fibres in silicon oil AK 2000; $\phi_S$ = 0.25); up/down functions (25°C, [16]).*

*Figure 15 (middle):*
*Shear viscosity versus shear deformation (shear time times shear rate) for concentrated fibre suspension (carbon fibres in silicon oil AK 2000, $\phi_S$ = 0.25) at various shear stresses [16].*

*Figure 16:*
*Comparison of measured and calculated shear viscosity functions for sugar/silicon oil (AK 1000) suspensions before and after deaggregation.*

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