# Extrusion of food pastes – the influence of the liquid phase on the flow behaviour of highly concentrated systems

*Patrick Wilms, Reinhard Kohlus, University of Hohenheim,*
*Institute of Food Science and Biotechnology, Stuttgart, Germany*

Food pastes are concentrated suspensions that consist of solid particles, dispersed in a liquid matrix, examples include chocolate (fat-based) and fondant (water-based). Their production often includes a dosing step that involves high speed extrusion through dies of varying geometry. During this extrusion, the high volume fraction of solid fillers not only leads to high operating pressures, but it also greatly increases the risk of jamming, thereby blocking production lines and increasing machine downtime. To prevent these processing complications and provide possibilities for improvement of both machine and product, a deeper understanding of the flow behavior of pastes is desired. Apart from rheological parameters like viscosity and flow index, this includes knowledge regarding the prevalence of apparent wall slip. Apparent wall slip is thought to originate from the depletion of particles close to the wall, which results in a liquid rich layer showing a significantly lower viscosity than the bulk material. Direct determination of bulk viscosity from pressure readings could thus lead to grossly underestimated values. Furthermore, the existence of the solid-depleted layer increases the importance of the rheological properties of the liquid phase. The liquid not only indirectly influences the bulk flow properties, but also directly influences wall slip.

In this contribution, the focus is on the true non-Newtonian behavior of paste in relation to the non-Newtonian behavior of the liquid phase. For the measurements, paste material with a solid volume fraction of 0.60 is used. Limestone ($D_{4,3}$ ~ 15 µm) is chosen as a model solid, since it does not dissolve in, or react with, both water and oil.  To understand the influence of liquid phase, four different structured liquids are used; one Newtonian water-based (polyethyleneglycol), two non-Newtonian water-based (sodium alginate, hydroxypropyl methylcellulose) and one non-Newtonian oil-based (sunflower wax in rapeseed oil). Their rheological behavior is measured in a rotational rheometer (Kinexus Ultra, Malvern Instruments, UK). All viscosity curves can be described by the Ostwald-de Waele relationship at the shear rates of interest.

Extrusion experiments are performed using a high pressure capillary rheometer (Rosand RH2000, Malvern Instruments, UK) at shear rates of 10 – 640 $s^{-1}$. By measuring the pressure drop over a specific set of dies (Ø 1.0, 1.5, 2.0 mm), both the entry- as well as the wall slip effects can be determined.

The resulting true viscosities of all pastes as a function of shear rate are described by the Ostwald-de Waele relationship and varied considerably from apparent viscosities, calculated without accounting for slip. We were furthermore able to separate the individual effects of solid- and liquid phase by using the rheological behavior of the Newtonian paste. The wall slip velocity scaled with the flow index of the pure liquid phase, whereas the flow index of the bulk is intermediate to that of the solid- and liquid phase. These insights suggest possibilities in altering the flow properties of the liquid phase such that the extrusion pressures of pastes can be reduced, whilst ensuring a stable end product.