Die extrusion of highly concentrated systems; from theory to 3D food printing

WILMS P. (1,2), KOHLUS R. (2), SCHUTYSER M. (1)
1 Wageningen University and Research, Department of Food Process Engineering, Wageningen, Netherlands
2 University of Hohenheim, Department of Process Engineering and Food Powders, Stuttgart, Germany

The processing of highly concentrated food systems via extrusion has always been a common processing operation. However, its importance is growing, with the increasing production of meat replacers, emergence of 3D-food printing and increasing importance of processing low moisture foods, to minimize energy intensive processes such as drying. During extrusion a material is forced to flow through a die by applying a certain pressure. The required extrusion pressure is typically estimated from the rheological properties of the material, the dimensions of the die and the required flow rate. The flow of highly concentrated systems is, however, inherently complex and care should be taken when translating apparent rheological properties obtained from rheological measurements to practical applications. Rheological properties are often directly inferred from torque-displacement data, while the actual flow of the material can show non-idealities that vary depending on the flow conditions. Examples include wall slip and shear-induced migration, which both lead to the underestimation of the determined viscosity. Given the large variety of materials being tested for extrusion applications, a deeper understanding of the flow behaviour would reduce trial-and-error approaches for optimization processes.
The aim of this contribution is to translate the knowledge obtained from fundamental research about suspension flow to practical solutions for extrusion challenges, focusing on 3D-printing of food materials. It centers around several studies performed in our research groups. To identify wall slip and shear-induced migration, work is presented that involved a high-pressure capillary rheometer, equipped with a set of smooth and custom-made rough dies. Results show the risk of relying on apparent rheological properties and help improve the mechanistic understanding of observed non-idealities. A translation is then made to 3D-printing applications. A landscape of printable recipes and processing conditions was created by using a custom-made ram extruder. Different ways to manipulate this determined landscape are then discussed based on the fundamental understanding of suspension flow. This contribution will further improve the adaptability of both researchers and industry with respect to changes in composition and/or processing conditions of highly concentrated food systems during extrusion.