A microscopic look at the fouling mechanisms in dairy protein mixes by rheometry and microfluidics

LANOTTE L. (1), KHELIFAOUI S. (1), GROSTETE M. (1), TANGUY G. (1), BOISSEL F. (1), LE FLOCH-FOUC. (1), JEANTET R. (1), LEE J. (1)
1 INRAE, Institut Agro, STLO, 35042 Rennes, France

Thermal fouling is an unsolved and costly question for the dairy industry and consists in the accumulation of the solid fraction of a processed liquid stream on a stainless-steel surface due to the combined action of flow and thermal/concentration gradients. Understanding and preventing the phenomena related to thermal fouling is of paramount help to optimize the operation unit efficiency and to improve the quality of the products. Until now, most of the studies available in the literature focused on the fouling dynamics in heat exchangers and led to contradictory results based on the off-line analysis of the solid deposits. Conversely, the fouling mechanisms have been rarely explored in the evaporators despite their increasingly essential and sensitive use in dairy industry (*e.g.* , infant formula production).
The hypothesis explored in this work is that the initiation of the fouling process is not exclusively due to protein thermal denaturation in the liquid stream once a critical temperature is achieved (T>65°C), but also to the impact of the shear rate near the equipment walls. Mixes of whey proteins and calcium with different overall concentrations were processed by rheometry, undergoing the range of temperatures (45-80°C) and shear rates ($100s^{-1}$) typical of falling film evaporators in a wide temporal range (0-4h). The effect of the combined thermal and shearing action on protein denaturation/aggregation was evaluated:

- In the bulk, by extracting the kinetics of denaturation in the solutions using high-performance liquid chromatography (HPLC) and estimating the average aggregate size using dynamic light scattering (DLS);
- At the solid-liquid interface, by observing the formation and the development of the deposits (density, size, shape) at different local shear conditions using an optical microscopy.

The results provided an insight into the dependency of fouling mechanisms on key factors such as time, shear and concentration. Starting from this rheometry-based approach, the challenging next step was to provide a direct observation of the fouling dynamics in dairy mixes by microfluidics. Preliminary tests were conducted in microchannels with variable geometries reproducing the environmental and flow characteristics typical of the evaporators with the aim of characterizing the different steps of the deposit accumulation.