Coupling between flow, heat transfer and rheological properties of starch suspensions in a tubular heat exchanger

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Starch is a polysaccharide found in large quantities in plants, in which it is stored in dense micrometric granules. It is widely used in food formulations as a colloidal stabilizer, thickener and water-retention ingredient. Starch granules absorb water and swell above a temperature of around 60-70°C (gelatinization). We propose a study of the gelatinization of starch suspensions combining kinetic modeling of individual starch granules, pilot-plant scale experimentation and numerical modeling. At the individual starch granule scale, the swelling as a function of temperature and time is predicted by a kinetic model based on real-time microscopic observations previously developed in the laboratory. However, when this transformation is conducted in industrial steady-state equipment, the local quantities (residence time and temperature) can significantly diverge from the average operating conditions due to the fluid flow profile and heat transfers. Moreover, the changes in the rheology during the starch gelatinization will modify the heat- and momentum-transfer coefficients. To better understand the resulting coupled phenomena, we have used a pilot-scale heat exchanger. A control system allows to select the temperature at the center of the pipe at different points along the duct and a volumetric pump to select the flow rate and thus the mean residence time. According to the previously established kinetic model, different operating conditions (flow-temperature) were chosen to theoretically lead to the same swelling degree. The gelatinized suspensions obtained were characterized showing that fast treatments at higher temperatures lead to more viscous products corresponding to more strongly swollen starch granules. This can be explained by a coupled effect related to heat and momentum transfer: heat flow results in a temperature gradient from the walls, in the vicinity of which the fluid elements move more slowly, to the center of the tube, in which the fluid elements are subject to less heat treatment. As consequence, these gradients result in very different residence time/heat treatment depending on the position (distance from the wall) of the fluid element considered. Numerical modeling of the coupled phenomena (fluid flow, heat transfer, gelatinization and rheology) is performed and the resulting model predictions are compared with the experimental results.