Predicting the Transformation of a Liquid Food Product Within a Tubular Heat Exchanger

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Abstract

Thermal processing with heat exchangers is a widely-used method for improving the safety and extending the shelf life of many liquid food products (milk, juices, etc). It is also employed for inducing transformation of selected food constituents, like starch, as a way to promote food characteristics which are appreciated by consumers, like texture.
Fluid flow, heat transfer and transformation phenomena are coupled throughout heat exchangers used for thermal processing of liquid food products. On one hand, the product transformation depends on local temperature and shear rate. On the other hand, the thermal and rheological properties of the liquid product can themselves be modified as a consequence of the transformation phenomena. Physics-based modeling became an important tool in food science and industry, firstly by reducing the amount of experimentation in designing product, process and equipment, and secondly by providing a level of insight that is often not possible experimentally.

We compare here three approaches for studying the transformation of a liquid food product during its pathway throughout a tubular heat exchanger.
The first approach assumes that the fluid parcels move according to a plug-flow velocity field; hence they are exposed to a temperature which depends only on the distance from the heat exchanger inlet. In this one-dimensional (1D) approach, the velocity field does not depend on the product viscosity, and therefore no coupling takes place between fluid flow and product transformation.

The second approach solves the coupled problem involving fluid flow, heat transfer and product transformation after representing the heat exchanger by a sequence of axi-symmetrical two-dimensional (2D) computational domains; in such a representation, the tubular sections are separated by curved tubes (bends) which in turn are assumed to act as thermally-insulated perfectly-mixed reactors.

The third approach solves the coupled problem while considering the three-dimensional (3D) geometrical characteristics of the heat exchanger. In fact, the thermal mixing due to the secondary flow in bends is more or less effective depending on the flow rate and the liquid fluid rheological behavior. This approach is more realistic but requires higher memory and computing time.

In this study the three approaches are illustrated by studying the evolution of an aqueous

suspension of starch granules which progressively swell under thermal processing. The transformation kinetics and the rheological behavior of this simple liquid product are available from previous experimental work conducted at laboratory scale using small stirred tank reactors. The second and third approaches are implemented with the help of COMSOL Multiphysics. All the approaches consider the geometrical characteristics of an existing tubular heat exchanger, as well as the operating conditions which have been considered in running it.

Model predictions are compared with results from experiment work, in terms of a selected indicator of the product transformation state: the mean volume diameter of starch granules. Experimental results were obtained after sampling the liquid product under thermal processing and later characterization using laboratory techniques. Our results show that differences between observations and model predictions decrease as the 1D, 2D, and 3D approaches are successively applied.