Conjugate fluid flow and kinetics modeling for heat exchanger fouling simulation

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Abstract

Thermal treatment of fluid foods represents a major unit operation in the food industry, to ensure the product’s safety and quality features. But during the thermal treatments of such sensible fluids in common plate heat exchangers, food constituents such as proteins can be thermally damaged and precipitated to form fouling that greatly affect the treatment efficiency and alter the product’s desired features.

Computational Fluid Dynamics simulations can then be successfully exploited, bringing forth temperature and velocity information that yield for deposit distributions when coupled to biochemical notations for thermal denaturation of fluid constituents.

The present work exploits such modeling for a single-channel heat exchanger during pasteurization of milk. The model enforces a conjugate system of differential equations to a heat exchanger’s corrugated plate to combine flow, heat transfer and local transport of β-lactoglobulin. A preliminary computation has been performed that could be applied to geometry optimization (different corrugation shape and orientation) and for a variety of biochemically evolutive products.

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1. Introduction

The increasing attention on safety and quality of medium and long time shelf-life has stimulated the application of various and optimized thermal treatments, in order to get flavor and nutritional values closer to those of untreated foods. For this very reason, thermal treatment of fluid foods is one of the most important unit operation in the dairy (milk) or fruit juices industry, to ensure microbial safety and extend storage. Energy delivery is a paramount parameter (through temperature) in controlling the alterations among the fluid constituents during its biochemical evolution, and must be coupled with time exposure, to quantify the energy intake. Therefore the temperature–time coupling is the most important feature to be optimized in this technology, but recently the attention has been drawn upon the management of the treatment device as well, as reviewed by Jun and Puri [6].

The device generally entitled to realize an indirect heating of fluid food is the Plate Heat Exchanger (PHE) (Fig. 1), which features a number of favorable aspects: flexibility to allow different fluid treatment, safety, high thermofluid efficiency, high turbulence to enhance heat transfer and low weight/surface ratio [11]. Nevertheless, during its working cycles, a PHE is subject to a complex phenomenon which causes undesired material accumulation (or fouling) along its working surfaces. Fouling formation and control is a common problem in process industries, causing an increase of capital costs, energy and maintenance time, and a loss of production, together with a meaningful environmental impact: fouling causes increased pressure drop, reduction of working efficiency through the reduction of the heat transfer, and increased downtime due to the frequent cleaning stage, with environmentally offensive chemicals, to ensure stable processing [12].

The biochemical fouling mechanism has been long studied specially for milk processing, and its reflected flow-dependent features have favored some complex analyses. As shown by de Jong et al. [12], Georgiadis et al. [3], Georgiadis and Macchietto [4] and Grijspeerdt et al. [5], the denaturation of the β-lactoglobulin (BLG) protein is responsible for fouling for thermal treatment close to 90 °C, while several additional parameters influencing such as milk composition, pH, plate geometry and entrained air.

The optimization of technological process and their operating conditions are nowadays looked upon with the aid of numerical modeling of transfer phenomena. Integration of governing Partial Differential Equations (PDEs) allows for a fundamental and quantitative way to understand complex phenomena which is complementary to the traditional approaches of theory and experiment. This approach is becoming increasingly widespread in basic research and advanced technological applications, cross cutting many scientific fields including biotechnology and food engineering. Again for the dairy industry, Georgiadis and Macchietto [4]...