MATHEMATICAL MODELLING OF HEAT AND MASS TRANSFER IN FOOD PROCESSING

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ABSTRACT

Mathematical modelling is playing an important role in providing good understanding of heat and mass transfer in food processing. It has also been used to assess both microbial and biochemical changes in foods during processing. Both quality and safety must be assured, which would require good knowledge on how heat and moisture are transferred within the food materials. In this presentation, we shall illustrate examples showing how mathematics could be used to describe heat transfer, flow distribution, microbial inactivation and quality changes in three types of food processing applications in which experimental techniques failed to describe. These three applications are; (1) thermal sterilization of food in pouches, (2) pulsed electric field processing for pasteurisation, and (3) high pressure processing of food. We have used Computational Fluid Dynamic (CFD) software to describe the transport phenomena in these three different processing. The applications mentioned in 2 and 3 are the two well-known non-thermal processing of food, which have shown growing worldwide commercial interest and have been used to process varieties of liquid and solid food products.

INTRODUCTION

Heat and mass transfer are phenomena well studied and mathematically analysed in a large number of systems since long time ago but not in food processing until recently [1]. Food processing such as sterilisation, pasteurisation, drying freezing, thawing, freeze drying and spray drying and many important processes incur both heat and mass transfer, which needs to be well understood to optimise the operating conditions of these processes [1-4]. Most food processing such as evaporation consumes large amount of energy and hence understanding these processes will assist in reducing the energy used. Also, absence of such understanding could lead to poor food quality. For example, food are usually overheated during retorting to insure sterilization and complete inactivation of spores. Understanding how heat is penetrated in food contained in pouches will assist in providing the right amount of thermal treatment, saving energy and reducing thermal damage [5, 6].

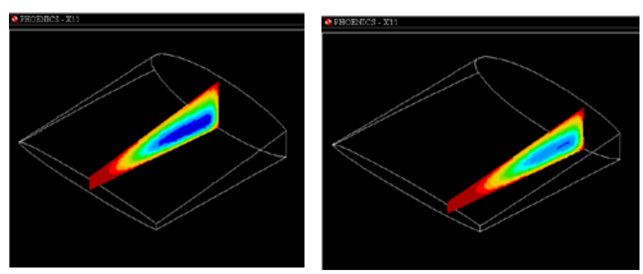
The analysis of heat and mass transfer in food processing could be done by solving the heat conduction and mass diffusion equations [2-4] whenever the process is controlled by pure conduction transport mechanism. However, whenever convective process control heat transfer such as in sterilisation of food in pouches and cans, the Naiver Socks equations needs to be solved using commercial software [5,6]. The newly developed low temperature processing of food, known as non-thermal processing, such as high pressure processing (HPP) and pulsed electric field (PEF) led to the requirements of using computational fluid dynamics (CFD) to predict temperature, microbial and nutritional changes during processing [7,8].

RESULTS

In this paper, we shall illustrate how transport phenomena plays important role in three important food processes as described below:

(1) Thermal sterilization of food in pouches

Retort sterilization of food in cans is well established, but until recently limited work has been done on sterilization of food in pouches. Measuring and predicting temperature distribution and quality attributes within a pouch during sterilization is difficult due to the complex shape of the pouch. We have used CFD to predict transient temperature, velocity profiles and concentrations of bacteria and Vitamin C in a three-dimensional pouch as heating progresses. The Navier Stocks equations, describing heat transfer and fluid flow dynamics in the pouch, controlled by free convection, were solved together with the bacteria and vitamin destruction kinetics. Figure 1 shows the temperature distribution in the pouch containing soup, while Figure 2 shows vitamin C distribution as predicted through the simulation, which could never be measured experimentally. The simulation shows the locations of insufficient heating and of maximum Vitamin C destruction.



50% pouch distance from of side wall — 80% pouch distance from the right the right of side wall

119˚C 120˚C 121˚C

Figure 1 Temperature profiles at different x-planes in a pouch filled with carrot-orange soup after 3000 s [6].

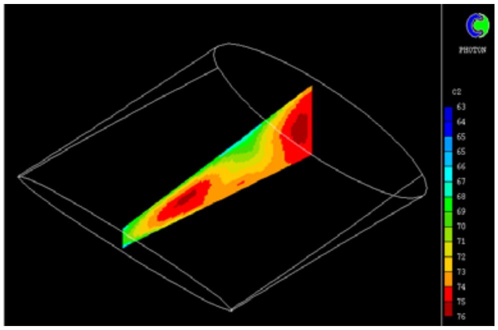


Figure 2 Relative concentration profiles of Vitamin C at 50% of x-plane of pouch filled with carrot-orange soup and heated by condensing steam after 3000 s [6].

(2) High pressure processing of food

Non-thermal food processing using high pressure (HPP) can be applied to a large number of food products using batch or continuous treatments.The adiabatic heating caused by the fluid compression can lead to a significant temperature distribution throughout the treated food and hence affect its quality. Accurate measurements of temperature distribution in the food under such high pressure of 600 MPa is rather difficult. The transport phenomena was analysed using CFD to predict temperature distribution during high pressure compression of solid-liquid food mixture (beef fat and water), within a three dimensional HPP cylinder basket and the results is shown below (Figure 3). The temperature rise in the meat slice is significantly higher than that of water, which is due to the higher compression heating of fat.

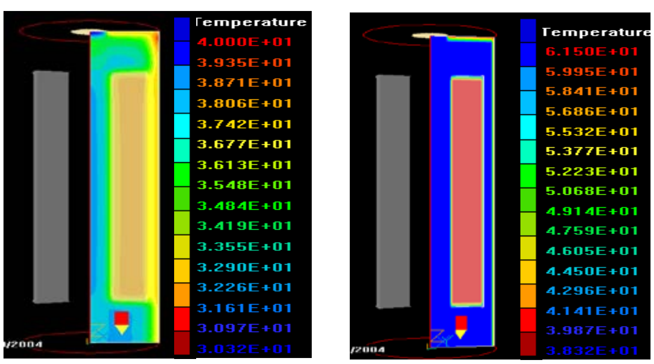


Figure 3 Temperature profile of the solid-liquid food mixture (beef fat and water) during compression. The red arrow shown in the figure is just for a point in the computation process.

(3) Pulsed electric field processing for pasteurisation

PEF involves subjecting processed liquid to high voltage electrical pulses, at maximum intensity of 60 kV/cm, for a very short duration (typically several microseconds). In recent years, there has been increasing interest in the use of Computational Fluid Dynamics (CFD) to better understand the performance of high voltage pulsed electric field (PEF) technology typically used for microbial inactivation. The efficacy of the process, measured by the extent of microbial inactivation, is influenced by a number of process variables, including electric field distribution, temperature profile, flow velocity characterization, treatment time and fluid properties. These parameters cannot be measured experimentally since the treatment is done within few micro seconds. Figure 4 shows the temperature distribution in two treatment chamber as predicted by CFD in an effort to improve the design of an existing design. The extreme rise of temperature near the wall is likely to cause water evaporation, which will induce sparking and failure of the treatment

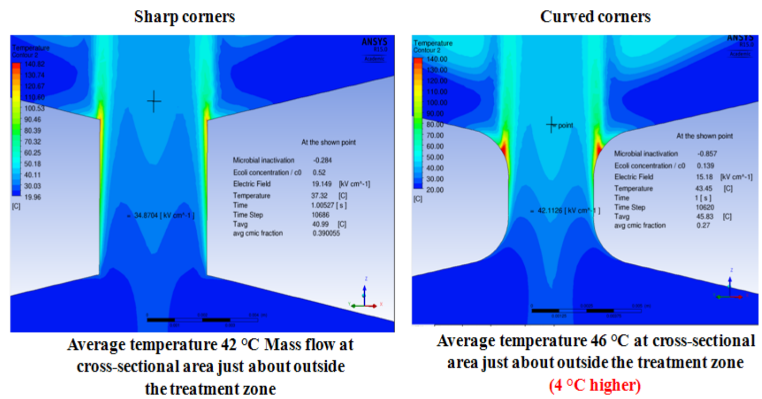


Figure 4 Temperature profile in the sharp and curved corner treatment cavity at 2.5 ml/s fluid flow.

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