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Experimental study of hydrodynamics in a flat ohmic cell—impact on fouling by dairy products

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Abstract

This study highlights the link between hydrodynamics and fouling phenomena in a continuous rectangular ohmic cell. The hydrodynamic study was carried out using flow visualisation techniques and particle image velocimetry (PIV). The distribution of deposits in the ohmic cell was investigated by heating an aqueous solution of β-lactoglobulin-xanthan gum mixture. Experimental results show that the deposit distribution on the electrode surfaces is directly related to the flow structures in the ohmic cell.

Keywords: Ohmic heating; Fouling; Hydrodynamic; Dairy products

1. Introduction

The food industry and in particular the dairy industry, are faced with a severe problem due to equipment fouling during processing. Consequently, several studies have been devoted to heat exchanger fouling by dairy products (Belmar-Beiny, Gotham, Paterson, & Fryer, 1993; Changani, Belmar-Beiny, & Fryer, 1997; Delplace & Leuliet, 1995; Grijspeerdt, Hazarika, & Vucinic, 2003; Lalande, Tissier, & Corrieu, 1985). All these works show the crucial effect of hydrodynamic parameters on fouling phenomena in plate heat exchangers. In spite of the advances in the comprehension of fouling phenomena, the performances of heat exchangers still remain limited by fouling problems. Therefore, the development of alternative technologies for fouling limitation is of interest.

Ohmic heating is one of these new technologies, where the absence of a hot wall should provide a considerable advantage for foodstuff applications, by avoiding the degradation of thermo-sensitive compounds by over-heating and by reducing the fouling of the surfaces during processing. Unfortunately, most studies devoted to this technology have focused on the heat treatment of food fluids with high particle contents, (Benabderrahmane & Pain, 2000; De Alwis, Halden, & Fryer, 1989; Eliot-Godéreaux, 2001; Fryer & De Alwis, 1989; Sudhir, Sastry, & Salengke, 1998; Wadad, Khalaf, Sudhir, & Sastry, 1996) or hydrocolloid solutions (Marcotte, 1999) and did not focus on fouling. Moreover, most of these studies were carried out using tubular geometry with a parallel electric field-flow configuration $\vec{E}\|\vec{V}$ ($\vec{E}$: electric field and $\vec{V}$: velocity field). Ould El Moktar, Peerhossani, and Le Peurian (1993) and El Hajal (1997) studied the combined effect

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of hydrodynamic, thermal and electrical phenomena when heating a homogenous non-fouling fluid by a rectangular ohmic channel with a perpendicular electric field-flow configuration ($\vec{E} \perp \vec{V}$). Few scientific studies have been devoted to the heat treatment of fouling food fluids by a rectangular ohmic channel (Ayadi, Bouvier, Chopard, Berthou, & Leuliet, 2003; Ayadi, Chopard, Berthou, & Leuliet, 2004). However, during the heat treatment of fouling food flows by ohmic technology, in addition to the links between the physical phenomena already mentioned by Ould El Moktar et al. (1993) and El Hajal (1997), secondary links between deposit layers and these phenomena appear as soon as the electrodes are fouled. In continuous ohmic heating, thermal behaviour depends on the quantity of energy received by the fluid during its passage through the cell. This quantity of energy depends on the electric field applied and the residence time distribution in the cell expressed by velocity fields. The fluid circulating at a lower than average velocity remains in the electric field longer and receives more energy than the fluid circulating at a velocity higher or equal to the average. This excess energy results in local overheating zones which become more subject to fouling. The presence of a non-uniform flow in a continuous ohmic cell (presence of re-circulation and acceleration zones) is bound to affect its thermal and electric behaviour and thus the intensity and distribution of fouling in it.

The objective of this paper is therefore to identify and study experimentally the impact of hydrodynamic behaviour on the intensity and distribution of fouling deposits, if any exist, in a rectangular ohmic channel with a perpendicular electric field-flow configuration. The hydrodynamic study was carried out with a Newtonian model fluid under isothermal conditions, using a flow visualisation technique (coloured tracer) and the velocity fields were measured using particle image velocimetry (PIV). The distribution of deposits in the ohmic cell was investigated by heating an aqueous solution of a β-lactoglobulin-xanthan gum mixture.

2. Materials and methods

2.1. The experimental cell

The experimental cell, shown in Fig. 1, takes the form of a rectangular channel (240 × 75 × 15 mm thick). It is composed of a spacer that houses the inlet–outlet devices and two electrodes making up the lateral surfaces. In this work, the influence of two different inlet–outlet orifice geometries on the hydrodynamic and fouling behaviour in the ohmic cell has been investigated. The geometry termed "initial" is composed of two elliptical opening with conical channels (Fig. 1(a)). The geometry termed "modified" is composed of a single elliptical opening with conical channel (Fig. 1(b)).

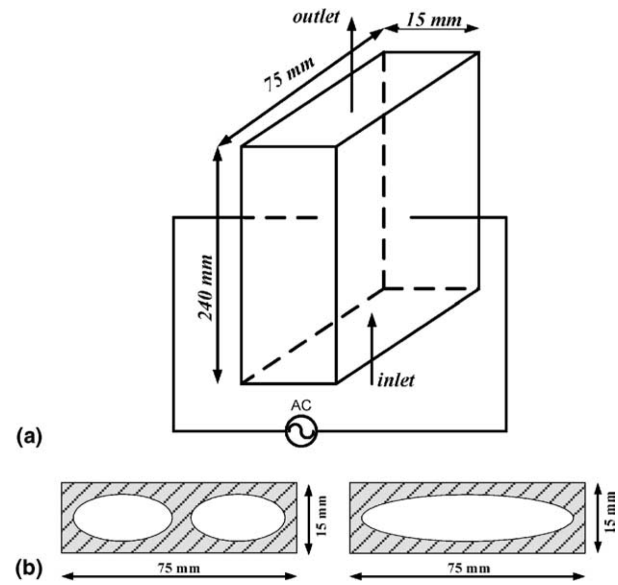

Fig. 1. Geometry of the flat ohmic cell and the studied input–output orifices: (a) initial geometry; (b) modified geometry.

2.2. Hydrodynamic study

Flow visualisation tests and velocity field measurements were performed to study the hydrodynamic behaviour in the ohmic cell. The experimental set-up used for the visualisation tests consists of a feed tank, a volumetric pump, an electromagnetic flow meter, an assembly of three transparent cells, a coloured tracer injection system, a static mixer to avoid any risk of poor mixture heterogeneity, a digital camera and a PC for video image acquisition.

Experiments were carried out, in isothermal conditions (20 ± 1 °C), with a sucrose solution at 55% (w/w) whose concentration was selected to obtain a Reynolds number of 65 for a flow of 300 l/h. 5 g of fluorescein powder was added to 100 ml of circulating fluid to act as a coloured tracer.

The coloured tracer was injected just before the cell inlet and its distribution was recorded in the form of video sequences through the transparent surface. This method allowed a qualitative characterisation of the flow. Image processing was performed on the video sequences acquired and included the following key steps:

(i) Sampling of the video image sequences at a frequency of 30 images per second (Video Editor 5.02).
(ii) Coloured tracer passage time, is normalised and reduced by the average residence time ($\tau = \frac{V}{Q}$), with V being the volume of the cell (m^3) and Q the circulation flow (m^3/s).
(iii) Visualisation of the coloured tracer head progression as a function of reduced time: $t^* = \frac{t}{\tau}$.