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An investigation on the application of ohmic heating of cold water shrimp and brine mixtures

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ABSTRACT

Cooking is an important unit-operation in the production of cooked and peeled shrimps. The present study explores the feasibility of using ohmic heating for cooking of shrimps. The focus is on investigating the effects of different process parameters on heating time and quality of ohmic cooked shrimps (*Pandalus Borelias*). The shrimps were heated to a core temperature of 72 °C in a brine solution using a small batch ohmic heater. Three experiments were performed: 1) a comparative analyses of the temperature development between different sizes of shrimps and thickness (head and tail region of the shrimp) over varying salt concentrations (10 kg m^{-3} to 20 kg m^{-3}) and electric field strengths (1150 V m^{-1} to 1725 V m^{-1}) with the heating time as the response; 2) a 2 level factorial experiment for screening the impact of processing conditions using electric field strengths of 1250 V m^{-1} and 1580 V m^{-1} and salt concentrations of 13.75 kg m^{-3} and 25.75 kg m^{-3} and 3) evaluating the effect of pretreatment (maturation) of the shrimps before ohmic processing. The maturation experiment was performed with the following maturation pre-treatments: normal tap water, a 21.25 kg m^{-3} brine solution and without maturation. The measured responses for experiments 2 and 3 were: the heating time until the set temperature of the shrimps was reached, weight loss, press juice and texture profile. It was possible to fit main effects model relating process settings and the heating time, weight loss and press juice measurements. Furthermore, the results showed that over the tested process workspace no significant changes were seen in the texture measurements of the shrimps and that the shrimp achieved a comparable quality compared to the conventional heating processes reported in the literature. The findings show a promising utilization of ohmic heating as a unit operation for the shrimp processing industries.

1. Introduction

Optimal heating of solid foods using the conventional technologies can be challenging due to the fact that heat transfer is limited by internal conduction. Heating of shrimps can be problematic due to the size variation within a batch of shrimps. The size variation within a batch induces over-processing of especially the smallest shrimps in the batch. This means that in order to process according to safety criteria and to meet product specification there is a certain risk for deteriorated product quality and yield loss.

Ohmic heating is a technology, which potentially heats the product volumetrically by passing an alternating electrical current through a conductive food material (Sastry, 2008). The volumetric heating can reduce or eliminate temperature gradients within the shrimps and thereby alleviate overcooking issues. However, this is conditional on the electric conductivity of the product - this means that - in the case of products with spatial variation in the electric conductivity due to heterogeneous composition spatial differences in the heating profiles can be induce. Ohmic heating is an old application that has been under development for a long time and in recent decades seen a rise in research and development. The application of ohmic heating has been studied for various applications and food stuffs, and the research results have been extensively reviewed (Kaur and Singh, 2015; Knirsch et al., 2010; Sastry, 2008; Varghese et al., 2012). Salengke and Sastry (2007) investigated the temperature distribution when using ohmic heating of solid–liquid mixture in both static and mixed (agitated) conditions for cases with a difference in electric conductivity between the inclusion particle and the surrounding medium. The authors observed that for the cases where the particle was more conductive than the medium the cold spot was within the medium in zones parallel to the particle (also referred to as shadow regions).

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Additionally, it was found that the process conditions (static and agitation) and particle size had an impact on the temperature development. This occurrence in solid–liquid mixtures has been observed and studied by several other authors (Davies et al., 1999; de Alwis et al., 1989; Fryer et al., 1993). Such phenomenon is highly important to understand and to be able to determine the slowest heating location (cold spot) within the system to secure food safety.

Some possible benefits of ohmic heating include reduced burning of the surface, better nutrient and vitamin retention, increased energy efficiency and environmentally friendly systems (Sensoy, 2012). The study on ohmic heating of meat and meat products is a growing field (McKenna et al., 2006; Sarang et al., 2008) although the application of ohmic heating on portions of fish and crustaceans reported in the literature is sparse. The use of ohmic heating for thawing of shrimps has been reported (Roberts et al., 1996, 1998, 2002). The results were compared against water immersion thawing and showed comparable findings in microbial safety, quality and weight loss.

Several studies have reported on the influence of traditional thermal processing of shrimps with heated or with boiling water, and the resulting impact on product quality (Erdogdu et al., 2004; Erdogdu & Balaban, 2000; Mizuta et al., 1999; Niamnuy et al., 2007, 2008; Murakami, 1994). In these studies the quality assessments were on textural properties either with instrumental measurements or sensory evaluation, water loss and safety assessment of microbial inactivation. Erdogdu & Balaban (2000) reported on the change in texture of thermally processed shrimps and correlated the findings with sensory assessment showing a general higher acceptability of minimally processed shrimp. Niamnuy et al. (2007) studied the impact of boiling shrimps in a brine solution and showed that time was the significant factor for the observed changes in texture and shrinkage.

The scope of this study is to provide knowledge on ohmic heating of shrimps, which could be either used as a pretreatment or the main cooking operation. The experiments performed address factors such as influence of shrimp size and ion (salt) concentration in the brine, which in the literature has been identified as important variables in relation to ohmic heating (Sastry, 2008). The experiments were planned in a stepwise manner. *The first step*; is to assess the effect of size variation and the effect of spatial variation within the shrimp (head and tail) with respect to the temperature profile. *The second step*; is to evaluate the effect of the ohmic heating process variables (electric field strength and salt concentration) on the process time and quality of shrimps (weight loss and texture). *Finally, the third step*; is to evaluate the effect of preprocessing (maturation step) on the process time and quality of shrimps (weight loss, press juice and texture) when processing with the ohmic heating. The maturation step is a common unit operation used both as a buffer and pretreatment before heating of shrimps in the industry to promote the peeling in the later stages. The overall intention was to identify the possible process conditions for industrial implementation of ohmic heating and verification of the feasibility of the unit operation. The responses chosen for the experiment were: the time until a core temperature of 72 °C was reached (standard processing conditions), press juice, weight loss and texture of the cooked shrimp.

2. Materials and methods

2.1. Ohmic heater

The ohmic heater used in this study was built by BCH ltd. (Lancashire, UK). The unit consists of a holding cell made of W500 grade polyethylene with variable size adjustment and mountings for temperature loggers (K-type). The ohmic heater unit can maximally supply a 230 voltage using alternating current (60 Hz, sinusoidal). Titanium electrode was used which has high corrosion resistance in chloride environments (Samaranayake and Sastry, 2005). The distance between the electrodes was set at 12 cm apart; the width of the chamber was 9.5 cm and the liquid height including shrimp was approximately 4.5–5 cm.

2.2. Raw materials

Raw frozen shrimps (*Pandalus Borelias*) were supplied by Royal Greenland A/S (DK). The shrimps were kept in cold storage (−18 °C) until testing at the Technical University of Denmark, Lyngby. The individual shrimp weight varied from approximately 8-13 g.

2.3. Experimental procedure

The shrimps were matured in accordance with the following procedure: first the shrimps were defrosted in tap water and then placed in a specified brine solution for 24 h at refrigeration temperature of 0–5 °C.

The concentration of the brine solution was prepared as weight of salt to the total volume of water and salt ($m_{salt}/v_{water+salt}$) with the specific brine concentration shown for each of the experimental conditions in the reported results tables. The water was normal tap water at approximately 15–20 °C. 20 shrimps were heated in each experimental run, which approximately corresponds to a total weight of 220 g shrimps. For the ohmic heating process a new brine solution corresponding to the maturation brine concentration was prepared, and together with the shrimps added to the ohmic heater. The ratio of shrimp to brine used in the ohmic heater was approximately 1:2 in the weight respectively. The placement of the shrimps was in a parallel position of the body with the electrode plates and the shrimp inserted with a thermocouple was placed perpendicular to the bottom of the cell with the head pointing up (the exact thermocouple placement within the shrimp for each experiment is described in 2.6, 2.7 and 2.8). The shrimps and brine were then heated with the ohmic heater until a measured core temperature in the shrimp of 72 °C was reached. The time, temperature and electrical current were recorded during ohmic heating of the shrimps. After the ohmic heating the shrimps were cooled in excess ice water for five minutes. The weight of each batch was recorded before the heat treatment and immediately after cooling for the assessment of weight loss. The shrimps were then placed in plastic bags. The samples were allowed to thermoset in the water at room temperature (20–25 °C) for an hour before texture profile analysis (TPA) and press juice measurements (PJ) were performed. The electrical current was used for calculating the conductivity of the shrimp and brine mixture using Eq. (1).

$$\sigma = \frac{I}{AE} \tag{1}$$

where the conductivity σ ($S\ m^{-1}$) is calculated from the measured current I, the area of submerged electrode A and the electric field strength E.

2.4. Texture profile analysis (TPA) and press juice (PJ) measurements

Two shrimps from each experimental run were peeled before the TPA and PJ measurements, respectively. The measurement protocols are the same as used by Erdogdu & Balaban (2000) and Niamnuy et al. (2007). For both the TPA and the press juice measurements a Texture Analyzer XT. Plus (Stable Micro Systems Ltd. UK) was used with a cylindrical probe with Ø of 4 cm on plane