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Determination of apparent diffusion coefficient in balls made from haddock mince during brining

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A R T I C L E I N F O

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NaCl
PubChem CID:5234
Sodium alginate, Protanal LF 10/60S12727 G 0.65
PubChem CID: 6850754
Calcium carbonate (CaCO3 precipitate, Merck)
PubChem CID: 10112
Glucono -δ- Lactone
PubChem CID: 7027

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A B S T R A C T

Salting is one of the main processes of preservation in meat and fish industry. Knowledge of how salt affects the muscle microstructure is needed both to model diffusion and to obtain the desired salt concentration in the product. Diffusion of sodium chloride was studied in a gelled minced fish ball-brine system. Systems with both closed circulation of the brine and static conditions were used to study and compare the salt transport process. Effective diffusion coefficients (De) for diffusion of sodium chloride into fish balls made from fresh and frozen haddock mince were determined. A numerical calibration of an analytical model based on Fick's second law was performed, in which salt diffusion follows a non-steady-state process.

Critical experimental parameters for the estimation of diffusion coefficients were: size of balls, initial solute concentration in the bulk of brine, freezing of the material before the treatment, and stirring of the brine.

The result of experiment shows that a simple fish ball–brine system can be used to model mixing of salt in brining processes.

1. Introduction

Salting is one of the oldest methods of food preservation (Albarracín et al., 2011; Nguyen et al., 2011). Sodium chloride concentration influences the properties of food systems, including water holding properties, viscosity, texture, emulsification, by influencing the properties of the proteins (Costa-Corredor et al., 2010; Nguyen et al., 2010). In addition, salt is important for taste. The daily intake of salt is around 8–11 g/day, which is more than twice the amount estimated as necessary (Brandsma, 2006; EFSA, 2005). Since excess of NaCl intake has negative health effects, dietary advice is to reduce the amount of consumed salt (Bona et al., 2007; Desmond, 2006; EFSA, 2005; FSA, 2003; Gibson et al., 2000; IFST, 1999; Tilstone et al., 1993).

Industrially prepared foods contribute with 70–80% of the daily intake of salt (FSA, 2003; WHO, 2006). There is therefore an interest in developing products with reduced salt content (Ruusunen and Puolanne, 2005; Crank, 1975), while retaining high quality and safety in the end products (Bona et al., 2007). Stricter regulations, and more focus on quality and traceability, increase the demand for scientific verification of product claims. Applying scientific methods to document and model food processing operations can provide competitive advantages to the manufacturers (Cawse, 2011; Coleman and Montgomery, 1993), especially when modifications of raw materials and process parameters are used to create new products and optimise existing processes (Datta et al., 2007).

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Studying and modelling technological processes in laboratory conditions (for instance simulation of salt diffusion) may allow better control of food processing, increasing productivity and improving the quality of the products (Bona et al., 2007). For the process of salting, it is important to understand the distribution and mobility of salts in the product, as these parameters influence the release of ions from the matrix and thereby the salt perception (Floury et al., 2009b; Graiver et al., 2009).

Many studies have focused on the diffusion of salt in muscle foods (Graiver et al., 2009), in which effective diffusion is an important mass transfer mechanism, responsible for sodium and chloride transport (Barat et al., 2003; Doulia et al., 1993). Mass transport between solid food and brine is generally controlled by the diffusion rate of the solutes. Diffusion rates are calculated using effective diffusion coefficients of solutes into the solid (Floury et al., 2009b). Since food materials are often irregular in shape and can present various inner regions of different composition, these aspects give some extra challenges to the mathematical modelling, and various approaches have to be applied to deal with the heterogeneity of the materials (Alizadeh et al., 2009; Aursand et al., 2008; Gallart-Jornet et al., 2007c; Goñi and Purlis, 2010.; Graiver et al., 2009). In particular, an accurate geometrical description is of great importance when the aim of modelling is to obtain internal profiles of temperature, concentration and/or pressure, since properties like local surface area and volume, as well as (apparent) density, influence gradients of physical quantities. In foods with heterogeneous structure, it is often difficult to estimate the volume into which the solute can penetrate accurately; e.g., tissue composition can affect effective diffusion coefficients (D_e) by increasing the length of the pathway of salt ions. A tight network of fibres and proteins, high content of lipids and low water content are also factors reducing diffusivity rate (Gallart-Jornet et al., 2007c), also affected by the physical state of the material (Cierach and Modzelewska-KapituŁA, 2011; Floury et al., 2009a; Puolanne et al., 2001).

Hashiba and co-workers modelled the dual mode of diffusion and absorption of NaCl through the tissue as diffusion through an heterogeneous medium. The muscle is modelled as consisting of two types of bulk water, with different diffusion rate in the two phases. The main part of water in tissue is present in small droplets (1–2 μm), where diffusivity of the ions is approximately equal to the one in pure water. In the so-called water swollen protein region, where water is bound to protein chains, the diffusivity is considerably reduced (Hashiba et al., 2009, 2007). However, in their model of salting of different fish, Zugarramurdi and Lupin assumed that the flesh in cut fish only acts as an inert support, and that the influence of the inner membranes is negligible (Zugarramurdi and Lupin, 1980).

Earlier studies (Graiver et al., 2006; Wang et al., 2000) have shown that salt diffusivity is affected by the NaCl concentration because the NaCl concentration affects the microstructure of muscle. Thus, knowledge on how salt affects this microstructure is needed both to model diffusion and to estimate the desired salt concentration in the product. At low salt concentrations the tissue gains water (salting in), with maximum water uptake observed at NaCl concentration of 5–6% (Offer et al., 1989; Offer and Trinick, 1983), while higher salt concentrations in the brine (above 9–10%) gradually lead to dehydration (Minh et al., 2011; Thorarinsdottir et al., 2011). The increase in water holding capacity is related to an expansion of the myofibrillar network, coupled to protein solubility. Increase in water binding in salted muscle foods is attributed to enhanced electrostatic repulsion, leading to swelling of the proteins, and a more open network capable of retaining more water. A tight network of fibres and proteins, high content of lipids and low water content are also factors reducing diffusivity rate (Gallart-Jornet et al., 2007c).

From a physical point of view, curing of meat is affected by diffusion and osmosis, where the driving force of the mass exchange is the chemical potential of the substances involved in the process. Absorption and migration rates of salt ions depend not only on external factors including curing method, time, temperature, brine concentration, and pH, but also on internal factors like chemical composition and biochemical state of the muscle, microstructure, direction of muscle fibres, viscoelastic properties, and how water is distributed in the muscle (Offer and Trinick, 1983).

Size and shape of the penetrating ions and the diameter of their hydration coats also affect the process of diffusion. According to various studies, since the effective diffusivity coefficient (D_e) for Cl^- in water is higher than for Na^+, chloride ions in NaCl solutions should diffuse faster than sodium ions (Gekas, 1992; Handbook of Chemistry and Physics, 2005). This would lead to a charge gradient in the solution, due to the slower movement of the chloride ions while the sodium ions move more rapidly in the medium. Effective diffusion coefficient for NaCl in infinite dilution is close to the average of D_e for Cl^- and Na^+.

The large number of factors influencing diffusion rate (Lorén et al., 2009; Westrin et al., 1994) in foods have led to a wide range of different observations of diffusion coefficients (Cierach, and Modzelewska-KapituŁA, 2011). Data on salt diffusivity in different food matrices are available in literature (Graiver et al., 2006; Jittinandana et al., 2002; Wang et al., 1998), where the system used to determine diffusion is crucial, since there is no method suitable for all purposes (Westrin et al., 1994).

A key prerequisite for modelling mass transfer is the knowledge of boundary conditions. To estimate salting time, it is necessary to take into account the nature of the ions used in the process, along with their diffusivity, temperature and concentration (Cierach and Modzelewska-KapituŁA, 2011; Costa-Corredor et al., 2010; Floury et al., 2009a; Puolanne et al., 2001).

The aim of this study is to develop a simple model system to determine diffusion coefficients during controlled brining of minced foods, and to use this model to study the effect of freezing on fresh and chilled raw materials, and of diffusion rate on salt concentration and stirring. Fish balls, traditional products in Norway, have been chosen for the research. We chose gelled fish balls as the model system, because mathematically well characterized, and structurally homogeneous.

2. Material and methods

2.1. Modelling diffusion of salt in the fish ball model

Two different models of meat or fish tissue structure are usually employed when considering transport mechanisms:

1. Muscle is a network of permeable membranes composed of large organic molecules, thus the transport mechanism may be described by Fick's laws of diffusion;
2. Muscle consists of impermeable barriers forming a complex capillary system, thus salt can be transported by diffusion through the water inside the capillaries.

While minced meat and fish have complex structure, the whole process is usually considered as molecular diffusion. Therefore, the concentration-profile method has often been used to determine diffusivity; Doulia et al. (1993) have used a method based on the exact solution of the Fick equation for a semi-infinite medium (Doulia et al., 1993).

The effective diffusion properties is an important mass-transfer