Estimation of NaCl apparent diffusivity of beef connective tissue sheets

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Abstract— **The apparent diffusion of NaCl in meat tissue has been assessed by many authors but the specific resistance due to connective tissue and fat is unknown. Brining trials were carried out with cubes excised from *triceps brachii* beef muscles which contained a thick fatty connective tissue sheet (FCTS). Unidirectional NaCl transfer was promoted orthogonally to the FCTS and both Na^+ and Cl^- profiles were measured at 6 days. These profiles were calculated considering Fick diffusion theory and using a numerical model which took in account sample heterogeneity and time-variation of boundary condition. Various couples of values of the apparent NaCl diffusivities in meat tissue and FCTS were tested to fit the measurements: NaCl apparent diffusivity in FCTS is about 5 times lower than in meat tissue.**

Keywords— **Salt, Beef, Diffusion, Connective tissue.**

I. INTRODUCTION

Curing, marinating, brining of meat promote water and salt transfers which affect both safety and taste of meat products. Thus, many authors have assessed NaCl apparent diffusivity in beef and pork meats from laboratory experiments using Fick's theory. In these works spatial homogeneity of both structure and composition of the transfer medium was assumed. Values between 1 and 2.5 10^{-10} m^2/s were reported by some works [1, 2, 3] but other works indicated values from 3 to 7 10^{-10} m^2/s [4, 5, 6]. These differences cannot be explained by differences in temperature or animal specie. Furthermore, Broyart et al. [7] showed that the apparent NaCl diffusivity in an actually homogeneous proteinous gel (gelatine) is between 3 and 5 10^{-10} m^2/s.

Meat tissue structure is obviously not homogeneous and rather complex. From a mass transfer viewpoint a rough description of this structure could be: (i) a continuous network of connective tissue which surrounds meat fibres (*endomysium*) and more or less important bundles of fibres (*perimysium* and *epimysium*), (ii) the thickness of these sheets of connective tissue varies from a few micrometres to about two millimetres and (iii) connective tissue is intimately associated with adipose tissue which makes it more hydrophobic. As a consequence, fatty connective tissue sheets (FCTS) may act as mass transfer barriers since Na^+ and Cl^- ions move into water.

Our aim was to estimate the specific transfer resistance property of FCTS.

II. MATERIALS AND METHODS

A. Experiments

Samples: Two cubic samples (50 x 50 x 50 mm) of meat were excised from a *Triceps Brachii* beef muscles of a two years old Charolais. These cubes were cut so that a thick fatty connective tissue sheet (FCTS) be approximately parallel to two faces (figure 1).

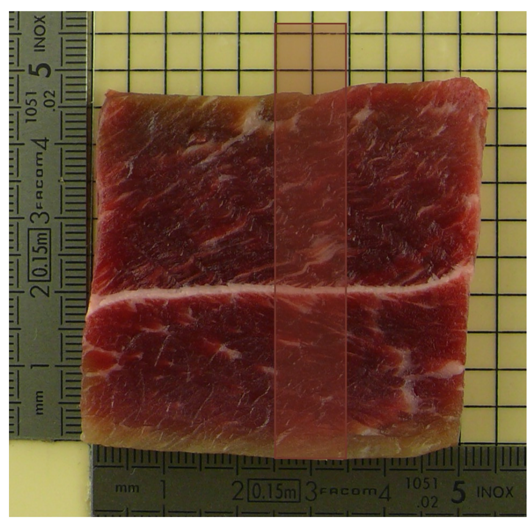


Figure 1: Cross section of one meat cube indicating the FCTS position. NaCl transfer was promoted from the bottom to the top and ions profiles were measured in the core sample delimited by the brown area.

Brining: The cubes were placed into plastic boxes having the same dimensions than the cubes. Five faces were therefore insulated and one face was put into contact with a solution of NaCl at 4°C for a few days to promote unidirectionnal ions migration. Then, 3D Magnetic Resonance Images (MRI) of Na^+ distribution in the meat cubes were measured for qualitative verification of unidirectional transfer (results not shown); during this period the samples were not in contact with the brine. Table 1 sums up the conditions for the two experiments.

Measurement of Na^+ and Cl^- content profiles: core samples (50 x 10 x 10 mm) which main direction was orthogonal to the brined face were cut from 1 cm thick slices far enough from the lateral cube faces to avoid any possible edge effect due to brine transfer by capillarity between meat and plastic walls. This core sample was cut into slices about 2 mm in thickness, orthogonal to the mass transfer direction and chloride and sodium ions contents were measured using a chloride analyzer (Sherwood, MHII-926) and a flame photometer (Jenway, clinical PFP7), respectively. High resolution (40 pixels/mm) numerical photographs of the slices (figure 1) were enlarged to measure the FCTS thickness (Table1)

Table 1: Experimental conditions and samples characteristics.

	TRIAL	
Name	Cube 1	Cube 2
Brine concentration (g/L)	134	127
Equilibrium NaCl content at meat surface (% w/w)	10.5	10
Brining time (h)	140.5	164.5
Rest period for MRI (h)	21.5	21.5
Core sample length (mm)	50	51
FCTS thickness (mm)	1.0	1.5
Distance of FCTS from brined face (mm)	22	18.5

B. Calculations

Mathematical model: numerical models based on a Fick approach were elaborated using the samples characteristics given in table 1. The finite element method was used; meshing and solving were performed with Comsol Multiphysics® v3.5a software. Unidirectionnal dimensional mass transfer was considered and the samples were divided into 3 parts: meat tissue, FCTS and meat tissue. The number of finite elements was about 100 with 10 for the FCTS.

The NaCl content in the sample at time t = 0 was nil. The apparent NaCl diffusivities in meat tissue (Dm) and in FCTS (Df) were assumed constant.

During the brining period the NaCl content at the extremity in contact with brine was set at the equilibrium value (Table 1) assuming the same NaCl concentration into meat water and brine. An insulation boundary condition was applied to the opposite face. During the rest period the two extremities were assumed insulated.

Simulation calculations were performed using various (Dm, Df) couples: Dm from 4.2 to 6.9 10^{-10} m^2/s and Df from 0.6 to 3.3 10^{-10} m^2/s. For each couple a fitness index (S) was computed; it is equal to the sum of squares of the differences between the measured and the calculated NaCl content profiles at the end of the rest period.

III. RESULTS

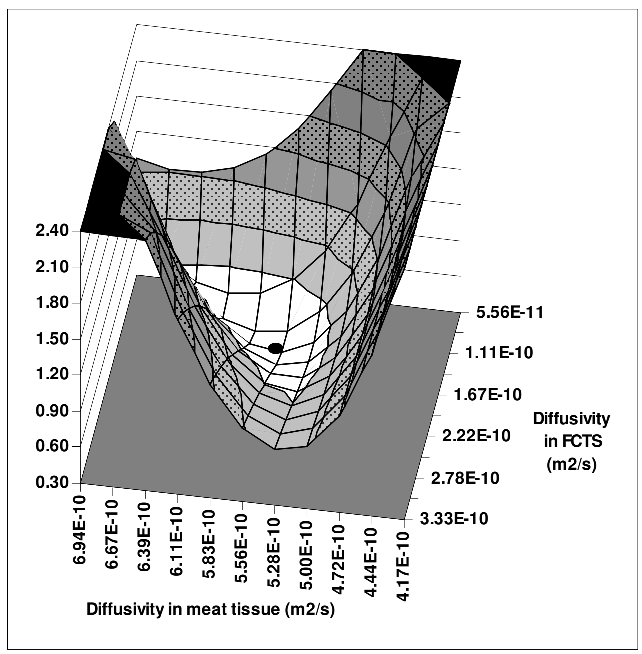
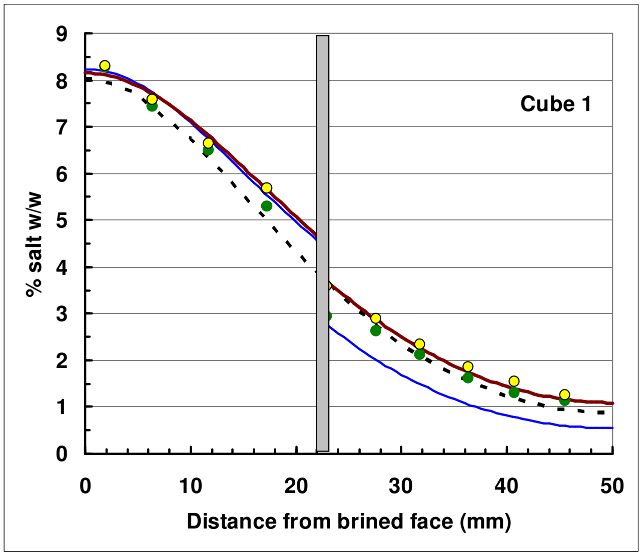


Figure 2: Variation of S in function of the (Dm, Df) couple (cube 1, minimum indicated by the black point).



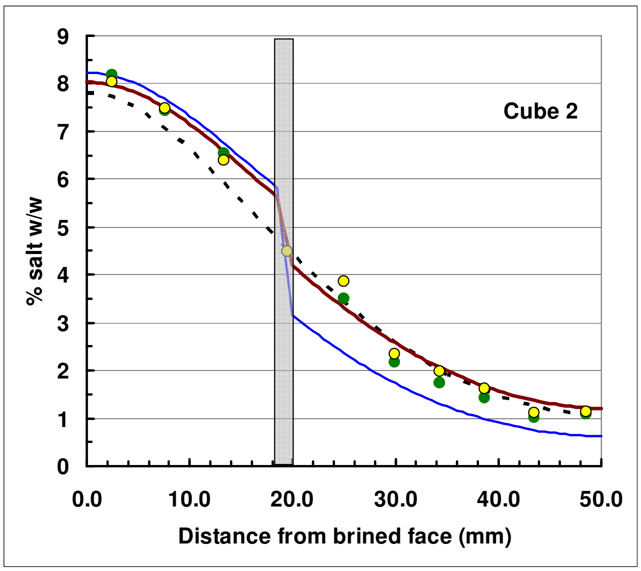


Figure 3: Comparison of the measured NaCl content profiles (assessed from Na^+, yellow points, or from Cl^-, green points, analyses) with the calculations according to 3 assumptions : (1) dotted black Dm = Df = 5.1 10^{-10} m^2/s, (2) blue curve Dm = 5.1 10^{-10} m^2/s and Df = 0.1 Dm (3) brown curve Dm = 5.6 10^{-10} m^2/s and Df = 0.2 Dm.

The two cases studied gave similar results.

Figure 2 shows an example of the variation of the fitness index. The minimum S value, or best fit, is indicated by the black point. However a larger area (white, $0.3 < S < 0.6$) should be considered to take into account NaCl measurement accuracy (± 0.2 % w/w): it is rather large and flat, meaning that the predictive capacity of the mathematical model is equivalent for several couples of diffusivity values. A detailed examination of the figures indicated that Df is approximately 5 times lower than Dm.

To test the above conclusion NaCl contents profiles at the end of the rest period were calculated using 3 different assumptions:

- Df is equal to Dm ,
- Df is 10 times lower than Dm,
- Df is 5 times lower than Dm.

Figure 3 shows a comparison of these calculations with the measured NaCl content profiles which were derived from either Na^+ or Cl^- content measurements. As already observed [6] the measurements show that diffusions of Na^+ and Cl^- ions are similar in meat.

It should be note that in all cases the decrease of the NaCl content during the rest period close to the brined surface, from about 10 to 8 % (w/w), is well represented by the calculations.

When Dm is equal to Df the best fit is obtained with an apparent NaCl diffusivity of 5.1 10^{-10} m^2/s. It is clear in that case that the calculated profiles between the brined face and the FCTS do not agree with the measurements.

Accumulation of ions in front of the FCTS needs to assume a much lower diffusivity in the FCTS than in the meat tissue. The comparison of the calculated with the measured NaCl content profiles behind the FCTS shows that a division of Dm by 10 is too important; the amount of measured salt is higher than predicted then. A Dm/Df ratio equal to 5 is the most probable value; in that case a higher value of Dm (5.6 10^{-10} m^2/s) gives the best fit.

In fact meat tissue also contains a network of thin connective tissue sheets which surround the bundles of fibres and which were not explicitly taken into account in the present numerical models. These thin sheets may have the same mass transport property than the thick ones considered in this work. Therefore their content variability may partly explain the differences in the published values of apparent NaCl diffusivities in meats. The results of Filgueras *et al.* [8] who observed Na^+ and Cl^- distribution at the microscopic level show that adsorption of these ions to collagen fibres are stronger than to other proteins; this observation is in coherence with a decrease in the apparent NaCl diffusivity in FCTS.

Our results must be considered as a rough estimation. To refine this assessment it would be interesting to measure NaCl content profiles (1) with a better spatial resolution and (2) using a non invasive and non destructive technique so that a series of profiles is obtained on the same sample at different times. This can be achieved using Magnetic Resonance Imaging and experiments are in progress in our laboratory.

IV. CONCLUSION

It has been shown that connective tissue affect NaCl transfer in meat. In thick sheets of fatty connective tissue the apparent Na^+ and Cl^- apparent diffusivities are approximately 5 times lower than in meat tissue. Studies are in progress to improve Df assessment accuracy and to check if thin sheets have similar transport property.

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