PE4.57 Modelling mass transfer during the wet cooking of beef meat 199.00

Samuel Oillic (01-feb) samuel.oillic@clermont.inra.fr, Eric Lemoine(1), Stéphane Portanguen 2, Jean-Bernard GROS 3 Alain Kondjoyan 2
(1)ADIV
(2)Institut National de la Recherche Agronomique, UR370 Qualité des Produits Animaux, INRA
(3)Laboratoire de Génie Chimique et Biochimique, Université Blaise Pascal

***Abstract*— Cooking losses due to protein denaturing-contracting have been predicted by a coupled heat-mass transfer model for beef cuts which size and temperature were ranging from two millimeters to seven centimeters and from 60°C to 90°C respectively. Temperature gradients due to heat conduction were calculated in the meat using a finite elements method in three dimensions. The local cooking losses were predicted by a first order kinetic model using previous simulated temperature histories. Cooking losses are well predicted on a limited range of sample size while model has to be adapted for wider size ranges.**

[1]Institut National de la Recherche Agronomique, UR370 Qualité des Produits Animaux, INRA, F-63122 Saint Genès Champanelle, France

S.Oillic is the corresponding author and is with INRA-QuaPA address above (phone + 33 (0) 4 73 62 45 28; fax + 33 (0) 4 73 62 40 89 e-mail: samuel.oillic@clermont.inra.fr)

[2]ADIV (Association pour le Développement de l'Institut de la Viande), 10 rue Jacqueline Auriol - F-63039 Clermont-Ferrand Cedex 2, France

[3]Laboratoire de Génie Chimique et Biochimique, Université Blaise Pascal, 24, avenue des landais, B.P. 206 – F-63174 Aubière Cedex, France

***Index Terms*— beef, cooking, modeling, cooking losses, water.**

I. INTRODUCTION

MORE and more meat is processed in industrial plants. Cooking loss is important for the processor because it determines directly process yield. It is also important for the consumer since it modifies product tenderness and juiciness. Product tenderness is in fact affected by water loss in two ways: (i) it modifies directly meat mechanical properties and (ii) juiciness affects the perception of tenderness by consumer. Models of water transport in meat have already been developed which consider transport as only being the result of surface evaporation and internal diffusion. But it is known for long that up to 45% of the initial meat weight can be lost during the cooking of beef without any evaporation [1]. Under most situations cooking loss is mainly due to protein thermal denaturing and contracting. This phenomenon is commonly said to be dependent on the type of muscle and on the way meat is cut (fibers direction, ratio of fiber lengths to sample thickness…) [2]. But results also prove that differences due to meat cutting are often small when the thermal history is similar [2]. In fact up in most of studies time-temperature history is only known globally. This lack of knowledge of the thermal gradients prevented to separate the differences due to thermal history from those coming from muscle type and the cutting. In this study thermal gradients are measured and simulated inside three pieces of beef meat of different dimensions. A simple cooking loss model is applied which takes into account the temperature gradients. Differences between model predictions and experimental cooking losses are discussed.

II. MODELING APPROACH

The first phase of the modeling process was to calculate in 3 dimensions the local temperature kinetics inside the sample using finite element method (Comsol Multiphysics 3.4, Sweden 2007). Internal heat transfer was considered as purely conductive and the boundary condition was either that of a convective flux and described by a Newton law or that of a known temperature in the case of meat slices.

Cooking losses were calculated as a function of time using a simple first order kinetic model (1) based on the local water concentration X; $X_\infty(T)$ being the water concentration at equilibrium. The dependence of the reaction rate on temperature was given by an Arrhenius law (2), the local temperature being calculated by the heat transfer model described previously.

$$\frac{dX}{dt} = -k(T)\cdot\left(X - X_\infty(T)\right) \qquad (1)$$

$$k = k_0 \, e^{\left(\frac{-E_a}{R \cdot T}\right)} \qquad (2)$$

The integration of equation 1 from initial time to end of cooking gives the final local water concentration. (Eq. 3) knowing the initial water content X_0.

$$X = X_0 + \int_{t=0}^{t} k(T) \cdot \left(X_\infty - X\right) dt \qquad (3)$$

Meat cooking losses were calculated in percents from (4) using the spatial average of all the local water concentrations $\overline{X}$:

$$\mathrm{CL} = 100 * \frac{\mathrm{X}_0 - \overline{\mathrm{X}}}{1 + \mathrm{X}_0} \qquad (4)$$

In some cases CL was also directly calculated from the average meat temperature and relations (1,2). $X_\infty(T)$ was measured at 40, 60, 70, 80 and 90°C by leaving pieces of meat during a very longtime in the water bath at constant temperature. For intermediate temperatures X_∞ was assessed using interpolation.

Values of k_0 and E_a were obtained by minimization (Nelder-Mead method) of the sum of squared differences (SSD) between calculated and experimental cooking losses. The fmincon function in Matlab 7.0 was used to find the minimum of the SSD. The minimization process was stopped when SSD variation during the last 20 calculation steps was less than 0.1% of the SSD value.

III. MATERIALS AND METHODS

A. Superheated steam heating

Longissimus thoracis muscle was taken from carcass,aged for 12 days under vacuum-packed conditions, cut in 2 mm slices and frozen and stored at -20°C. Samples were subjected to superheated steam jets [3] to avoid evaporation. The temperature of the impinging jet was 165°C and the distance between jet and sample adjusted between 36 and 345 mm to obtain variable sample temperature. The exact temperature value of the impinging jet was measured second-by-second using a 0.5 mm-thick calibrated type K thermocouple positioned 3.0 mm above the middle of the sample surface. The temperature at the sample surface was measured using a calibrated digital IR pyrometer [3]. At the end of the heat treatment, the sample surface was rapidly cooled by sliding the sample beneath a jet of cold air. Samples were weighed before and after the treatment to determine the water loss.

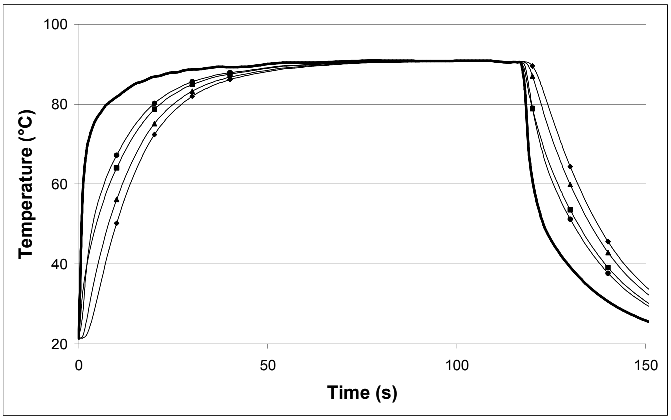

Figure 1. Temperatures in a 2 mm slice of meat. Measured surface temperature (Bold line) and simulated temperature at different depths: 0.25 mm (round), 0.75 mm (square), 1.25 mm (triangle) and 1.75 mm (rhombus).

B. Water bath heating

Pieces of meat were cut from previous muscle in cuboids of two dimensions: 1 x 1 x 7 cm and 7 x 7 x 7 cm respectively. These pieces of meat were immersed in a water bath for a given time. Two water bath temperatures: 70°C and 90°C were used for the smallest samples while the biggest ones were only treated at 90°C. Each piece of meat was weighted before and after the heating treatment.

Numerical simulation of temperature gradients inside the meat pieces requires the knowledge of the convective heat transfer coefficient. The value of this coefficient was determined by a classical transient heating method [4]. Aluminium blocks of the same dimensions as the meat samples were heated in the water bath at different temperature. Temperature kinetics were measured at the centre of the aluminium blocks by thermocouple and used to determine the heat transfer coefficients.

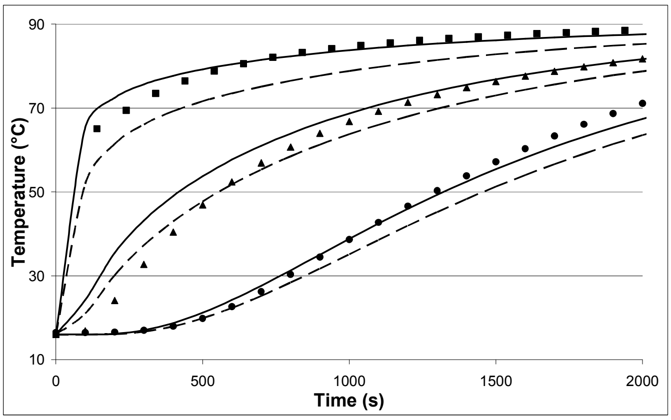

Figure 2. Measured and simulated temperatures in a 7 x 7 x 7 cm piece of meat cooked in a 90°C water bath. Symbols represent experimental values at different depths: 2 mm (squares), 8 mm (triangles) and 31 mm (rounds). Lines represent simulated values at the same depths for a 250 $W.m^{-1}.K^{-1}$ (Dotted lines) and a 2500 $W.m^{-1}.K^{-1}$ (Full lines) convection coefficient.

IV. RESULTS AND DISCUSSION

A. *Thermal study*

1) *Slices under steam jet*

Simulated temperature calculated using the measured surface temperature as a boundary condition is given in Figure 1. After one minute, temperature in the slice is uniform so for longer treatment, times it can be considered as being the value of the surface temperature. However as cooking losses were also measured for short treatment times, the simulated temperatures were used instead of the surface temperature to calculate these losses. As slices were very thin only the spatial average of these simulated temperatures was used to calculate directly the average cooking loss.

2) *Water bath*

Measured heat transfer coefficients are about 2700 $W.m^{-1}.K^{-1}$ for the 1 x 1 x 7 cm pieces and about 2500 $W.m^{-1}.K^{-1}$ for the 7 x 7 x 7 cm pieces (Table 1). Maximal values of these coefficients calculated from Jakob's correlation [5] are 1874 $W.m^{-1}.K^{-1}$ and 1452 $W.m^{-1}.K^{-1}$ respectively. These correlations values are significantly lower than the measured ones. This difference can be explained by the fact that our situation corresponds to the lower part of the validity range of Jakob's correlation which exact experimental conditions remain unknown. Moreover Jakob's correlation is given for an infinite fluid domain (size of the piece negligible in front of flowing dimensions) which was not true in our case for the 7 x 7 x 7 cm pieces of meat. In this case the immersing of the meat piece leads to flow blockage and thus to the increase of the flow velocity and of the heat transfer coefficient value.

Size (cm)	**Water Bath Temperature (°C)**	**Calculated Convection Coefficient**		**Meausured Convection Coefficient (W/(m².K))**
		u = 1 cm/s	**u = 10 cm/s**	
1x1x7	70	320	1599	2693 ± 104
	90	375	1874	2741 ± 371
7x7x10	70	248	1239	2530 ± 56
	90	290	1452	2488 ± 239

Table 1. Convection coefficients measured with pieces of aluminium in a water bath and calculated with Jakob correlation [5] for 70°C and 90°C.

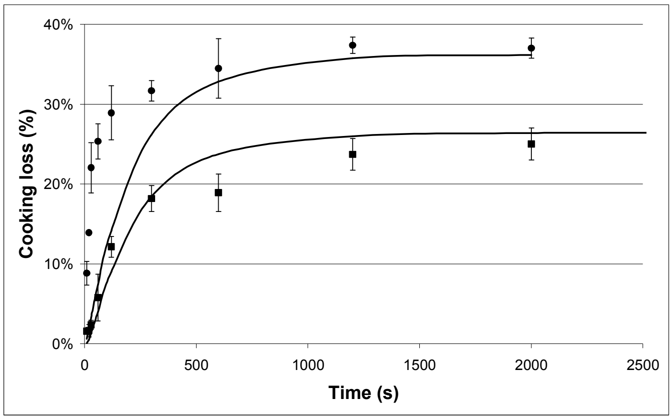

Figure 3. Cooking losses of 2 mm slices of beef meat heated with steam. Symbols represent experimental values for a surface temperature of 70°C (Squares) and 90°C (Rounds) Lines are the calculated values.

Temperatures were simulated in the 7 x 7 x 7 cm piece of meat using both the lowest transfer coefficient value determined from Jakob's correlation and the average value measured by us in the water bath (2500 $W.m^{-1}.K^{-1}$). Both simulations were compared to three of the measured temperatures in figure 2. Results prove that calculated results are not so sensitive to transfer coefficient values due to the preponderant effect of the internal transfer on samples of big size. The results simulated using the measured heat transfer coefficient are logically in better agreement with the experimental temperature at the surface and at the core of the product while the situation is not clear between these two locations. This unclear situation is probably due the difficulty of positioning accurately the thermocouple in this intermediate situation and to the thermocouple moving due to the meat thermal contraction.

B. Cooking losses

In meat slices cooking losses were calculated on average using only the mean product temperature. On the contrary in meat pieces cooking losses were calculated in 1000 equivalent points (125 points in 1/8 of the piece) using the local temperature simulated with the measured transfer coefficient value (Figures 3,4,5). Cooking losses were also directly calculated from the average meat temperature to determine the difference due to these two methods. Model's parameters were adjusted using the experimental data from the slices and the 1 x 1 x 7 cm meat piece. Obtained values were k_0 = 0.02 s^{-1} and E_a = 5000 $J.mol^{-1}.K^{-1}$. Differences between simulated and calculated cooking losses are given in Table 2. For the longest treatment times the differences between simulations and calculations are less than 4% and a unique X_∞ value can be taken whatever sample dimensions. This is in accordance with literature results of juice losses during very long cooking treatments only depending on cooking temperature and not on product size [1]. For shorter and more practical conditions cooking losses depend both on sample size and time-temperature conditions. As model parameters (k_0 and E_a) were mostly fitted on the 1 x 1 x 7 cm results, agreement between predictions and measurements is without any surprise very good in this case (Tab. 2) while experimental results are underestimated by the model on slices (Fig 3, Tab. 2) and overestimated on the 7 x 7 x 7 cm meat pieces (Fig. 5, Tab. 2). This trend was expected as model does not take into account juice expelling outside the sample. It is logical that the thicker the product the longer is needed for juice to be expelled. However in this study experiments were performed for the extreme variation of the sample size encountered in practice from a "beef carpaccio to a roast". Thus it will be possible in the future to adapt the model and the approach for a better prediction of cooking losses. Calculating the cooking losses using only the average sample temperature and not the temperature gradient leads to wrong predictions for the 1 x 1 x 7 cm sample while it compensates a little the prediction on the 7 x 7 x 7 cm sample. Thus taken into account temperature gradient is required at least for the medium size meat products.

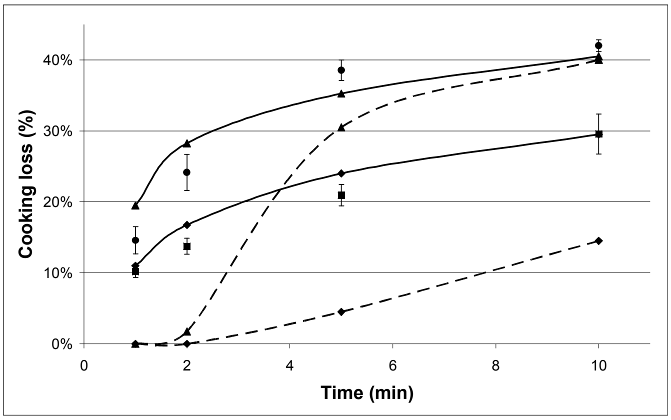

Figure 4. Cooking losses of 1 x 1 x 7 cm pieces of beef meat cooked in 70°C water bath (Squares) and 90°C water bath (Rounds). Lines are values simulated from local time-temperature history (full lines with rhombus for 70°C water and with triangles for 90°C water) and from average time-temperature history (dotted lines with rhombus for 70°C water and with triangles for 90°C water).

Time	0,2 cm Slices	1x1x7 cm pieces	7x7x7 cm pieces
t1	-5,5%	4,9%	16,2%
t2	-1,7%	4,1%	13,6%
t3	-1,6%	-3,3%	4,0%
t4	-0,9%	-1,5%	-3,1%
Average Deviation	-2,4%	1,1%	7,7%
Maximal Deviation	-5,5%	4,9%	16,2%
Standard Deviation	2,1%	4,1%	8,9%

Table 2. Differences between simulated and measured cooking losses for several sizes of beef meat samples heated at 90°C and different times. For slices times are 300, 600, 1200 and 2000 seconds, for 1 x 1 x 7 cm pieces times are 60, 120, 300 and 600 seconds. For 7 x 7 x 7 cm pieces, times are 1000, 2000, 3000 and 6000 seconds.

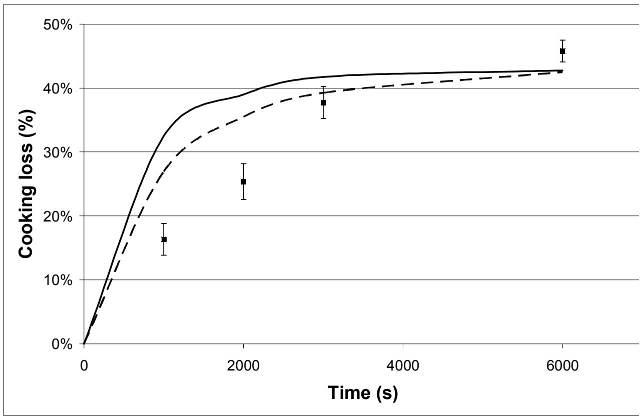

Figure 5. Cooking losses for 7 x 7 x 7 cm pieces of beef meat cooked in a 90°C water bath. Experimental values (square), simulated losses from local temperatures (full line) and simulated losses from average temperature (dotted line)

V. CONCLUSION

Cooking losses due to protein denaturing-contracting can be predicted by a simple mass transfer model providing that the temperature gradients in the meat be taken into account. For a wide range of sample size predictions tend to underestimate cooking losses on small samples and overestimate them on big samples. This can be corrected in the future by using different sets of k_0 and E_a parameters for different ranges of sample size. Calculation of evaporation will be added to the heat-mass transfer model to simulate dry cooking. This transfer model will be combined with quality models developed in the ProSafeBeef project [6, 7] in order to predict the quality of the cooked beef meat obtained under practical situations [8,9]

ACKNOWLEDGEMENT

This research is supported by ADIV, by the French government and by a ProSafeBeef project grant under the European Commission Sixth Framework Programme (Food-CT-2006-36241).

REFERENCES

[6] Laroche, M. (1982). Pertes de jus pendant le chauffage de la viande. – II. Comparaison viande hachée – morceau. LebensMittel Wissenschaft und Technologie. 15, 131-134

[7] Bouton, P.E., Harris, P.V. and Shorthose, W.R. (1976). Factor influencing cooking losses from meat, Aplied Science and Engineering, Journal of food science 41, 1092-1095

[8] Kondjoyan, A., & Portanguen, S. (2008). Prediction of surface and "under surface" temperatures on poultry muscles and poultry skins subjected to jets of superheated steam, Food Research International, 41(1), 16-30.

[9] Ghisalberti, L. and Kondjoyan, A. (1999). Convective heat transfer coefficients between air flow and a short cylinder- Effect of air velocity and turbulence. Effect of body shape, dimensions and position in the flow, J. Food Engineering, 42, 33-44.

[10] Jakob, Max (1949) Heat Transfert vol 1, Wiley In Ozisik, M. (1985) Heat transfer, a basic approach McGraw-Hill, inc. (p. 381)

[11] Kondjoyan, A., Chevolleau, S., Grève, E., Gatellier, P., Santé-Lhoutellier, V., Bruel, S., Touzet, C., Portanguen, S., & Debrauwer, L. (2009). Formation of Heterocyclic Amines in slices of *Longissimus thoracis* beef muscle subjected to jets of superheated steam (accepted for publication in Food chemistry DOI: 10.1016/j.foodchem.2009.02.081).

[12] Portanguen, S., Lebert, A., Kondjoyan, A. (2009). Effect of animal diet and muscle type on the evolution of the colour of cooked beef meat. In the same congres

[13] Realini, C, Pérez-Juan, M., Picouet, P., Kondjoyan. (2009). Effect of age and power on beef meat quality cooked in a domestic microwave oven. In the same congress

[14] Realini, C, Pérez-Juan, M., Picouet, P., Kondjoyan. (2009). Determination of the temperature gradient and cooking loss during microwave heating of beef roasts using a domestic oven. In the same congress