PE4.116 Modelling of heat transfer and prediction of freezing time in food products 433.00

Marcin B Andreasen (1) marcin.andreasen@teknologisk.dk, L Reinholdt(1), ,
(1)Danish Technological Institute, Denmark

The use of the finite-element method for understanding and analyzing the freezing process of wrapped chicken is in focus in this paper.

The model takes the influence of the thermal properties and operating conditions on the advance of freezing front and temperature distribution inside the product into account. Modelling was restricted to a two dimensional analysis with no mass transfer of the unbound water during food processing.

The calculations were carried out on commercial software called Comsol Multiphysics. The thermal properties of the chicken were described by major components found in food (water, protein, fat, carbohydrate, fibre and ash) in conjunction with temperature-dependent mathematical models of the thermal properties of the individual component.

Index Terms: **Food processing, food freezing, process time, food quality**

I. INTRODUCTION

Computer simulations are being used increasingly to design and improve food processes. The increase of computational power and better understanding of the physical phenomena during food processing make the mathematical models an attractive tool when optimizing the processing chain.

The objective of this work is to demonstrate the possibilities computer-aided simulations can offer by developing a numerical model that can be used to predict heat transfer during food freezing, to estimate the freezing time as well as to predict the levelling temperature at different operating conditions for different foodstuff products.

II. MATERIALS AND METHODS

Chicken is taken as a point of departure for the study. The chicken is wrapped in plastic packaging with the dimensions shown in figure 1. The geometry of the chicken was simplified to quadratic shape. Based on the mass fraction of the different components of the chicken (see table 1) the initial freezing temperature of the chicken was found to be -2.9^{o}C. The initial temperature of the chicken in the simulations is set to 5^{o}C.

	Mass fraction
Water	65.55 %
Protein	18.6 %
Fat	15.06 %
Carbohydrate	0.0 %
Fiber	0.0 %
Ash	0.79 %

Table 1 Composition data of the chicken

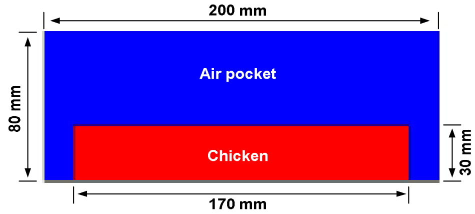

Figure 1 *Chicken as simulated in the model.*

The package with the chicken is submitted to freezing. Two main freezing processes have been investigated; convective freezing and immersion freezing. That is done by applying suitable conditions on the boundary of the package, as shown in table 2. Further simplifications to the model were that the heat transfer through the air gap is simplified and modelled as pure conduction in stagnant air.

	Temperatur e	Heat transfer coef.	Method
Model 1	-35 [C]	40 [W/m^{2}K]	Convective freezing
Model 2	-50 [C]	40 [W/m^{2}K]	Convective freezing
Model 3	-20 [C]	2000 [W/m^{2}K]	Immersion freezing (bottom)
Model 4	-20 [C]	2000 [W/m^{2}K]	Immersion freezing (full submerged)

Table 2 *Simulated freezing processes and applied boundary conditions.*

III. RESULTS

In figure 2, the temperature plot is shown at different times during the freezing period of 2 hours.

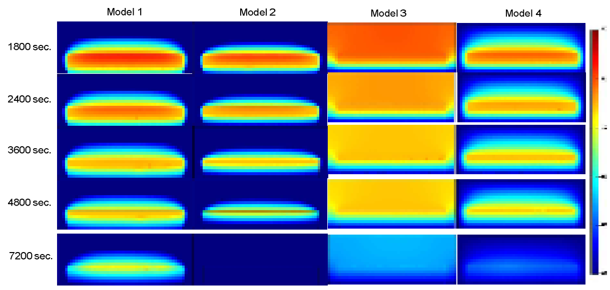

Figure 2 *Temperature plots at different freezing times.*

The figures clearly show the difference between the different freezing methods. The figure plots also clearly show that temperature gradients inside the chicken are present. That is more obvious when looking at point temperatures inside the chicken as shown in figure 3.

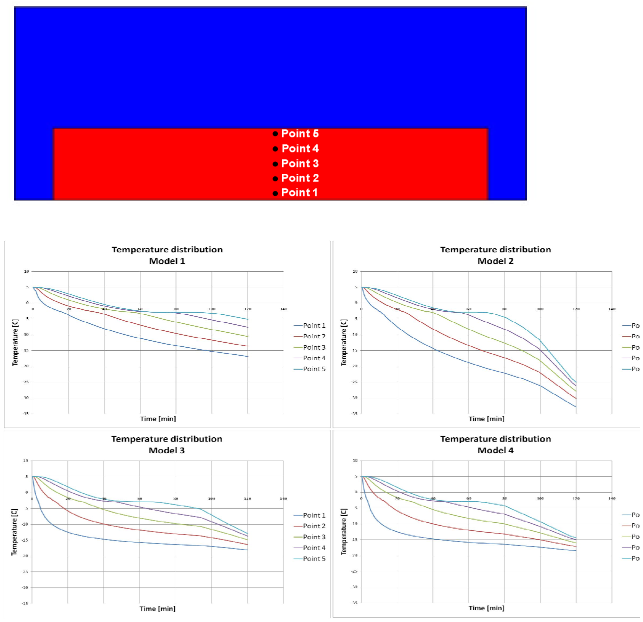

Figure 3 *At the top: location of the points; at the bottom: temperature as a function of time.*

An important parameter during food freezing is the levelling temperature which is defined as an equilibrium temperature of the chicken after the freezing period has ended. The stabilised temperature was achieved by applying adiabatic boundary conditions after e.g. a freezing period of 30 minutes and then waiting for the temperature inside the chicken to stabilize at a fixed level. The results are shown in table 3 and plotted in figure 4.

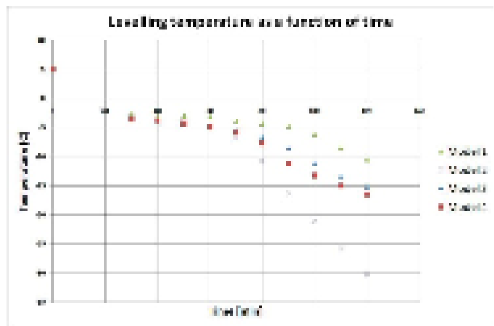

Figure 4 : *Levelling temperature as a function of time*

Freezing time	Levelling temperature			
	Model 1	Model 2	Model 3	Model 4
0 [min]	5,0 [C]	5,0 [C]	5,0 [C]	5,0 [C]
30 [min]	-2,8 [C]	-3,3 [C]	-3,6 [C]	-3,6 [C]
40 [min]	-3,0 [C]	-3,5 [C]	-3,8 [C]	-3,8 [C]
50 [min]	-3,0 [C]	-4,1 [C]	-4,2 [C]	-4,4 [C]
60 [min]	-3,1 [C]	-5,0 [C]	-4,7 [C]	-4,9 [C]
70 [min]	-3,8 [C]	-6,7 [C]	-5,5 [C]	-5,8 [C]
80 [min]	-4,3 [C]	-10,7 [C]	-6,8 [C]	-7,7 [C]
90 [min]	-4,8 [C]	-16,3 [C]	-8,7 [C]	-11,2 [C]
100 [min]	-6,1 [C]	-21,0 [C]	-11,3 [C]	-13,2 [C]
110 [min]	-8,5 [C]	-25,8 [C]	-13,5 [C]	-15,0 [C]
120 [min]	-10,5 [C]	-30,2 [C]	-15,3 [C]	-16,4 [C]

Table 3 *Levelling temperature.*

IV. Conclusion

A finite-element model was developed. The model allows for the evaluation of freezing times and temperature profiles during freezing. The model can be used for different food products simply by changing the composition data of the constituents in the product. The model is yet to be validated with the experimental measurements. Nevertheless, the results show promising tendencies.

The computer-aided simulations give the opportunity to obtain improved understanding of the physical phenomena occurring inside the food products. Modelling of the heat transfer inside the food products is the first step towards obtaining that understanding. Other vital issues are i.a. dehydration of the food during freezing and storage and estimation of the weight loss.

REFERENCES

[1] ASHREA (2006), ASHREA Handbook – Refrigeration, Chapter 9 – Thermal Properties of foods, ASHREA.

[2] Fricke B. A., Becker B. R. (2002), Evaluation of thermophysical property models for foods, ASHRAE Transactions. Vol. 108, no. 1, pp. 261.

[3] Puri V.M., Anantheswaran R.C. (1993), The Finite-Element method in food processing: a review, Journal of Food Engineering 19 p. 247-274.

[4] Delgado A.E., Da-Wen Sun (2001), Heat and mass transfer models for predicting freezing processes – a review, Journal of Food Engineering 47 p. 157-174.

[5] Cogne C., Andrieu J., Laurent P. Besson A. Nocquet J. (2003), Experimental data and modelling of thermal properties of ice creams, Journal of Food Engineering 58 p. 331-341.

.