Application of unsteady-state heat transfer equations to Portuguese traditional meat products from *Monchique* region

J.A. Pereira[1*], S. Ferreira-Dias[2] & T.J.S. Matos[3]
[1]Escola Superior de Tecnologia da Universidade do Algarve, Campus da Penha, 8005-139, Faro, Portugal.
[2]Instituto Superior de Agronomia, DAIAT, Centro de Estudos de Engenharia Rural, Technical University of Lisbon (UTL), Tapada da Ajuda, 1349-017, Lisbon, Portugal.
[3]Instituto Superior de Agronomia, UTL, Tapada da Ajuda, 1349-017, Lisboa, Portugal; Faculdade de Medicina Veterinária, CIISA, UTL, Rua da Universidade Técnica - Pólo Universitário, Alto da Ajuda, 1300-477 Lisbon, Portugal.
*Email: japer@ualg.pt

Abstract

Traditional meat products from *Monchique* region of Portugal, *Morcela de arroz* (MA) and *Farinheira de milho* (FM), are very popular cooked blood sausages produced following empirical procedures. Application of unsteady state heat transfer equations (USHTE) to determine temperature profile inside of the product (during thermal processing) is of great importance to ensure safety and to process optimisation. The objective of this study was to characterize the thermal process and to evaluate the adequacy of USHTE using Heisler charts. For these products (cylindrical geometry), thermal and physical data were collected from literature. The convection-heat transfer coefficient was calculated using the natural convection about vertical cylinders equation. Products (5 MA and 5 FM) were processed according to the traditional method using local producer facilities. Heat penetration curves were registered with thermocouples in the centre of the products and in the heating fluid. Temperatures were recorded every minute. For both MA and FM, a very good fit of USHTE to the experimental time/temperature data was observed.

Introduction

In the food industry, a large number of problems occur during heating or cooling periods where heat is transferred under unsteady state conditions. Perishable ready-to-eat meat products have to be subjected to adequate thermal treatment in order to prevent the presence of pathogenic microorganisms and to reduce the risk of microbial or enzymatic degradation during transport and storage. In Portugal, traditional meat products are mainly produced in rural areas. They consist of fashionable food products in urban centres, whose market has been largely increasing (Martins, 1992; Ferreira *et al*., 2007). *Morcela de arroz* (MA) and *Farinheira de milho* (FM) are among these products. *Morcela de arroz* or *molho* is a very popular cooked blood sausage produced in the *Monchique* area of Algarve, south of Portugal. It is made with ground pork lean (*longissimus dorsis)*, rice, pig raw blood, ground onion, garlic and spices (ground cumin, ground pepper, springs of parsley and/or mint) all stuffed in natural casings (pork stomach, pork or cattle intestine), tied with thread and then boiled for about 90 min in the *molho de moura* (a sauce prepared with water, whole onions and garlic, springs of parsley and laurel leaves). *Farinheira de milho* is another type of cooked blood sausage produced in the same area of Portugal. It is made with chopped pork meat, mesenteric fat, corn flour, garlic and spices (ground cumin and ground pepper). The mixture is then scalded in boiling *molho de moura* (after being used for *morcelas* boiling) which is poured out over the mixture. The mixture remains inside the *molho de moura* for about 10 min, and pig raw blood is added and mixed. The mixture is then stuffed into natural cotton bag named *talêgo* or in natural casings (pork intestine). Casings are sewed with cotton line and then boiled in the *molho de moura* for about three hours.

The aim of this study was (i) to characterise the unsteady heat transfer profile during the traditional processing of these products and (ii) to assess the adequacy of unsteady-state heat transfer equations (USHTE) using Heisler charts.

Material and methods

MA, stuffed in cattle intestine, and FM, stuffed in *talêgo*, were processed according to the traditional method using local producer facilities (Idália Duarte e António Sequeira Duarte, Lda, Sítio da Serra, Monchique). From batches of 111 MA and 52 FM, 5 units of each were randomly used for this study. Their average dimensions and weight are presented in Table 1. Heat penetration curves were registered with thermocouples (ellab, Roedover, Denmark) placed in the central area of each of these products and also in the heating fluid (pan). The thermocouples were connected to a data acquisition system (ellab, Roedover, Denmark) outside the cooking pan (0.715 m in diameter and 0.565 m in height), with temperatures recorded every minute. Products were weighed and measured (diameter and length) prior to cooking. Sufficient amount of heating fluid (*molho de moura*) for covering the products was put into the pan. The heating fluid was heated until reach process temperature before placing the products for cooking. After cooking, products were air cooled at room temperature. For both products, a cylindrical geometry was considered, thermal and physical properties were collected from literature (Earle, 1988; Geankoplis, 1993; McCabe et al., 1993) and the adimensional numbers were calculated using these values (Table 2). The convection-heat transfer coefficient (h_c) was calculated using the following natural convection about vertical cylinders equation (Earle, 1988): (Nu) = $0.53(Pr.Gr)^{0.25}$ for $10^4 < (Pr.Gr) < 10^9$.

Table 1. Dimensions and weight of the studied products

	FM_1	**FM_2**	**FM_3**	**FM_4**	**FM_5**	**MA_1**	**MA_2**	**MA_3**	**MA_4**	**MA_5**
Diameter[1] *(m)*	0.0670	0.0637	0.0655	0.0658	0.0665	0.0506	0.0587	0.0557	0.0482	0.0524
Length (m)	0.450	0.445	0.445	0.245	0.250	0.180	0.170	0.170	0.0801	0.0815
Weight (kg)	1.415	1.405	1.395	0.695	0.695	0.402	0.421	0.394	0.169	0.144

[1] - Average diameter, calculated from diameter measured in the middle and on both extremities of the products.

Table 2. Thermal and physical properties of the studied products (Earle, 1988; Geankoplis, 1993; McCabe et al., 1993)

	FM	**MA**
□ *(Kgm^{-3})* [1]	1070.0	1070.0
Cp ($JKg^{-1}K^{-1}$) [2]	$3.350x10^3$	$3.350x10^3$
k ($Jm^{-1}s^{-1}K^{-1}$) [3]	0.480	0.480
α (m^2s^{-1}) [4]	$1.339x10^{-7}$	$1.339x10^{-7}$
β (K^{-1}) [5]	$6.986x10^{-4}$	$6.986x10^{-4}$
Gr [6]	$1.053x10^8$	$5.055x10^7$
Pr [7]	1.799	1.799
Nu [8]	62.173	51.753
h_c ($Jm^{-2}s^{-1}K^{-1}$) [9]	94.581	100.548

[1]- density; [2]- specific heat; [3] - thermal conductivity; [4] - thermal diffusivity; [5] - thermal expansion coefficient; [6] - Grashof number; [7] - Prandtl number; [8] - Nusselt number; [9] - convection-heat transfer coefficient.

Results and discussion

Both products have long thermal processes. For FM, the average total time of thermal processing was 297.0 min and an average time of 168.8 min was necessary to reach the average processing temperature of 98.4 ºC at the slowest heating point. For MA, the average total time of thermal processing was 195.8 min and an average time of 90.0 min was needed to reach the average temperature of processing of 97.0 ºC at the slowest heating point. For both products, the experimental and predicted time/temperature values are presented in Table 3. For the 5 FM, the differences between experimental and predicted temperatures were 0.3; 0.5; 0.3; 0.2 and -0.1 ºC, respectively (Table 3). For the 5 MA, these differences were 1.1; 1.2; 0.0; 0.4 and -0.1 ºC, respectively (Table 3). These results showed very small differences between the experimental and predicted temperatures for both types of products, indicating a very good fit of USHTE to the experimental data as well as the adequacy of the thermal and physical properties collected from the literature (Earle, 1988; Geankoplis, 1993; McCabe et al., 1993) and used in the calculations. For the 5 FM, differences between the experimental and predicted times were 0.4; -9.2; -4.3; 0.8 and 22.1 min, respectively (Table 3). For the 5 MA, these differences were -0.9; -1.3; 9.4; 2.6 and 15.8 min. For both products, and considering the duration of the thermal process, the results indicated a good prediction accuracy of the model used.

Table 3. Dimensionless parameters of the unsteady-state conduction charts (1/Biot number, Y[1], X[2]), heating fluid temperature (T_∞), initial temperature (T_0), experimental time (t exp.) and temperature (Texp.) and predicted time (t pred.) and temperature (T pred.) of the studied products

	FM_1	**FM_2**	**FM_3**	**FM_4**	**FM_5**	**MA_1**	**MA_2**	**MA_3**	**MA_4**	**MA_5**
T_∞	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0
T_o	26.4	25.4	26.1	25.2	25.2	17.4	16.3	19.8	22.2	17.5
texp.(min.)	163.0	167.0	171.0	176.0	167.0	90.0	95.0	92.0	87.0	86.0
$1/Bi_{cilynder}$	0.151	0.159	0.155	0.154	0.153	0.189	0.163	0.171	0.198	0.182
$Y_{cilynder}$	0.012	0.011	0.008	0.007	0.004	0.031	0.047	0.027	0.010	0.011
$X_{cilynder}$	1.170	1.250	1.813	1.312	1.374	1.120	0.875	1.050	1.240	1.190
tpred.(min.)	163.4	157.8	166.7	176.8	189.1	89.1	93.7	101.4	89.6	101.8
Texp. (ºC)	98.1	98.2	98.4	98.5	98.7	96.5	95.1	96.9	98.2	98.1
$X_{cilynder}$	1.167	1.323	1.282	1.306	1.214	1.131	0.887	0.953	1.204	1.005
$Y_{cilynder}$	0.008	0.004	0.004	0.004	0.006	0.017	0.033	0.028	0.010	0.023
$1/Bi_{plate}$	0.023	0.023	0.023	0.041	0.041	0.053	0.056	0.056	0.119	0.117
X_{plate}	0.026	0.027	0.028	0.094	0.086	0.089	0.106	0.106	0.436	0.416
Y_{plate}	1.000	1.000	1.000	0.950	0.950	0.990	0.980	0.980	0.550	0.550
Tpred. (ºC)	98.4	98.7	98.7	98.7	98.6	97.6	96.3	96.9	98.6	98.0

[1]- fractional unaccomplished temperature change; [2]- Fourier number.

Conclusions

The traditional method of thermal processing is long for both products. USHTE predicted very well the temperature and time of thermal processing of FM and MA.

References

Earle, R. L. (1983).Unit Operations in Food Processing. 2nd Edition, Pergamon Press, Oxford, UK.

Ferreira, V.; Barbosa, J.; Silva, J.; Felício, M.T.; Mena, C.; Hogg, T.; Gibbs, P. & Teixeira, P. 2007. Characterization of alheiras, traditional sausages produced in the North of Portugal, with respect to their microbiological safety. *Journal of Food Control,* 18, 436-440.

Geankoplis, C. J., (1993). Transport Processes and Unit Operations. 3rd Edition, Prentice-Hall International Inc., New Jersey, USA.

McCabe, W. L.; Smith, J. C. & Harriott, P. (1993). Unit Operations of Chemical Engineering, 5 th Edition, McGraw-Hill, Inc., New York, USA.

Martins, M. C. 1992. Estudo de um produto cárneo de humidade média salpicão-tecnologia e características. *Veterinária Técnica*, 2, 18-20.