PhD. thesis

PLANNING THE HEAT TREATMENT OF MEAT PRODUCTS

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1. The aims of the research

The investigation of theme chosen for this PhD work is grounded that the heat treatment is a daily activity at a meat processing factory and it is the bottle-neck in the production process mostly. Beyond these the companies would like to produce products with longer and longer shelf life in equipment with great and greater capacity, then the produced amounts of products has to be delivered longer and longer distance. In this way remarkably economic damage and food safety risk can be the resulted by the under processed products could result According to this we like to investigate

- How can be used the data gathered from the production of the company for estimating the parameters needed for planning. The accuracy and reliability of these procedures
- Complex evaluation of the different heat treatment methods and schedules according to the modern requirements.
- The validation of the heat treatment principles and the relationship among each other
- Weighing of the parameters affecting the heat treatment
- Influence of the errors in parameters on the measure of the heat treatment and quality of the finished product

2. Preceding of the dissertation

This research is commenced by 3 reasons. The 1st was that I met a lot of problems relating to the heat treatments in the course of the industrial measurements e.g. quality problems, introduction of ISO systems (deviant processes and correcting actions of the mistakes), economic-capacity problems, energy use. The 2nd is that despite the well founded theoretical background there is no agreement in the target microorganism and its D and z values. The 3rd was that the industrial circumstances of the heat treatment were very fluctuating. I met different equipments within the finials or even within a factory and heat treatment schedules taken over more or less critic and confirmed by only few own measurements for the same product. Despite of the existing ISO systems the occurring parameter fluctuations was not investigated soundly and applied severe over processing. This situation can be seen well in the figure 1. With the decreasing measure of the heat treatment the real safety commence to decrease only slowly, and then radically. If we get into the elliptic area in the middle of the Figure 1, refused and accepted product can be produced by lot to lot. Even under processing can be experienced caused by the till acceptable parameter fluctuation. At the end the factory returns to the surplus over processing. Without analysis of this elliptic area the factories does not know its width and which parameters causes the problems. The more decrease the parameter fluctuations the less over processing needed in the course of the heat treatment (Figure 1).

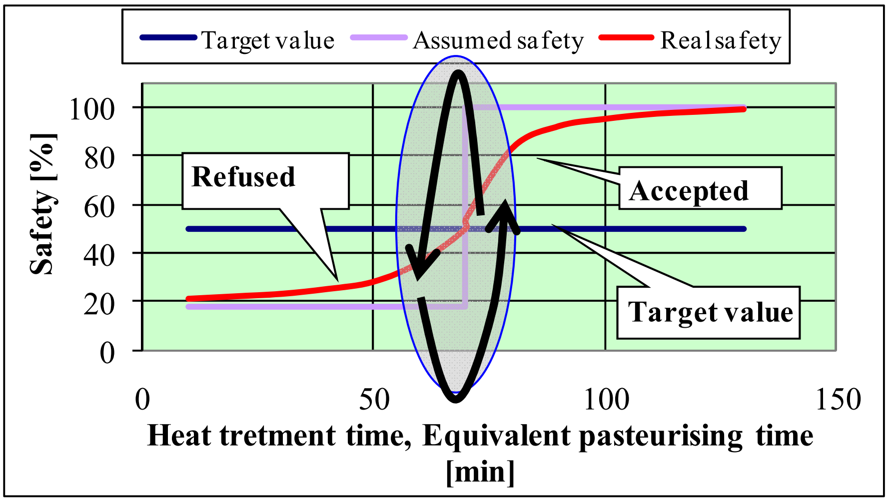

Figure 1 Development of the safety in dependence on the measure of heat treatment

3. The methods of the research

I chose the meat products; semi preserved hams and cooked sausages for the investigations. The semi preserved hams were produced by the tumbling processing technology having the PFF value of 18-20 %. The raw materials were stuffed into Pullman and oblong cans. The meat batters of cooked sausages (Frankfurter, cold cuts) were produced by fractional comminution and then it is stuffed into water impermeable casing with D=25.4; 40; 65; 80 and 100 mm diameter. For the measurement of the surface heat transfer coefficient I used bentonite suspension filled into metal cylinder (65x200 mm) insulated at both end aluminium block of 20x100x200 mm. The prepared semi preserved hams were heat treated in autoclave (STOCK AN4, 4 cages) and in cooking chamber (VEMAG), meanwhile the cooked sausages in cooking chamber (VEMAG and ATMOS) at 72-80°C ambient temperature. The heat treatment was stopped at reaching a definite core temperature (69-78°C). The temperatures were measured with ELLAB CTF 9008 and ELLAB CTF 9004 temperature measuring units equipped with ELLAB PCLINK 92 software (measuring time intervals: 15;

30; 60s) and with SSA-TS, DT-19, DC-19 and SD4 temperature sensors, and EBRO EBI-2T-313 computer programmable data loggers equipped with EBRO EBI Winlog 2.1 software and with EBRO 2800-0204 temperature sensors.

For the determination of the surface heat transfer coefficient I used Nusselt function, The ratio method of BHOWMIK and HAYAKAWA (1979) and the lumped capacity method UNO and HAYAKAWA (1980) and a calculation methods of LÖRINCZ and LENCSEPETI (1973).

For the determination of the thermal parameters of the products I used the ARMFIELD HT1 Thermal Conductivity Meter and the Sweat (1975) equation for the determination of the thermal conductivity. The determination of the thermal diffusivity was carried by Ball method with linear and robust regression and by the FDE-ISS method with least squares. The thermal diffusivity was determined from the chemical composition as well (RIEDEL 1969, CHOI and OKOS 1983, HERMANS 1969).

The initial and boundary conditions were supervised within industrial circumstances as follows: Relation of the conduction and convections, homogeneity on the base of chemical composition, geometric measures, constant-variable thermal parameters, finite-infinite Biot number. The calculations were carried out with FDM method for 12D destroy including cooling.

The effect of the parameter fluctuations on the heat treatment were calculated by the Monte-Carlo method (n=1000) with applying the parameters of D Streptococci (T_{ref}=70, z=10°C, D_r=2.95 min).

The microbial aspects of the planning were investigated for the several Streptococcus strains having different D_r and z values first. Then the multiplication during the come up and holding time was analysed by the method of DANTIGNY (1997) (T_{min}=10°C, T_{opt}=37°C, T_{max}=40°C). The possible destroy during the cooling was calculated for Streptococcus with parameters of T_{ref}=70, z=10°C, D_r=2.95 min (REICHERT 1979, 1988).

The effect of the parameter influence and sensitivity on the heat treatment was calculated according to the principles of Experimental Design (KEMÉNY and DEÁK 2002). The error calculations for the thermal diffusivity and lumped capacity methods were carried by the error propagation principles (KEMÉNY and DEÁK 2002).

In the course of the energetic calculations the use of the heat transfer was investigated by the FDM method with the determination of the surface heat transfer coefficient limit and with the simply change of the can orientation.

4. The main statements of the dissertations

The investigation of the development of the initial and boundary conditions revealed that the most frequently used initial and boundary conditions are fulfilled or approximated well even in case of the parameter regions applied in industrial circumstances. It is a big advantage that the surface heat transfer coefficient fall in the same region both in autoclaves and cooking chambers coinciding with the measured values of laboratory thermostats making the transfer of the laboratory measurements into the practice easier.

On the contrary both the factory control and parameter determinations could be questionable by the development of the initial and boundary conditions. From the normal and acceptable fluctuations large oscillations or even the deviant (USDA) processes could be reached as well. In the last two cases the parameter estimations and heat treatment control measurements are more and more difficult. According to my experience the factories are operating in the region of the middle (2s) and large (3s) deviations regions, involving several processes which can be considered as deviant. The reason of the fluctuations can be due to the lack of technology discipline, not real neglects (e.g. initial temperature has no effect) supply fluctuations (e.g. cooling), technical state (e.g. elongating come up time). Then again if the ambient and core temperature, to be registered compulsory, would be evaluated then these mistakes could be revealed and filtered, or rather the processes could be corrected by alternative heat treatment schedules based on calculations (e.g. fatter raw materials, another initial temperature etc.).

Nevertheless it has been shown by the Monte-Carlo calculations that the large parameter fluctuations in the operation have to be terminated because either the process supervising or the parameter estimations could not be carried out reliably Figure 2 and Figure 3). The Monte-Carlo calculations did not deliver statistically proved distribution, either normal or differing from normal, despite the large sample number (n=1000) (Figure 2 and 3).

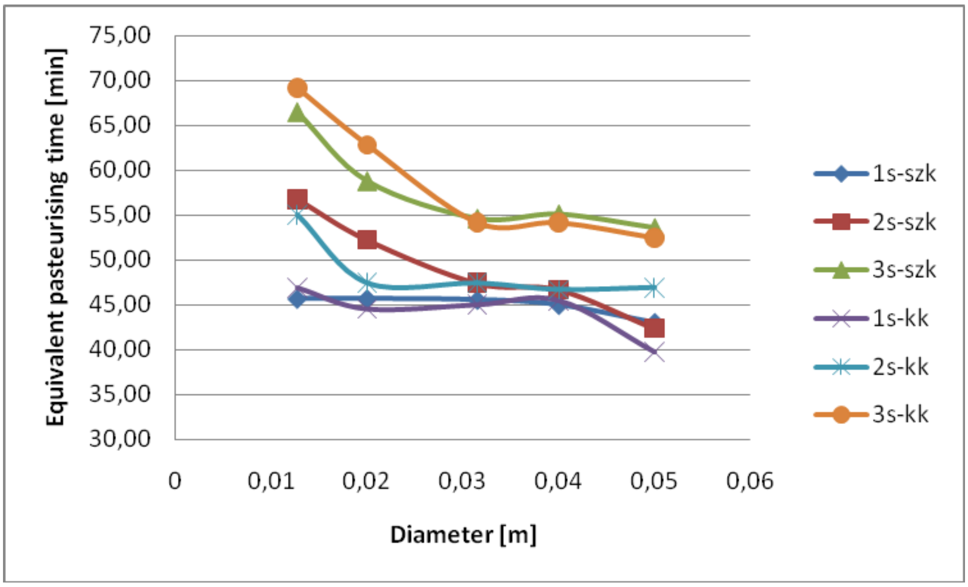

Figure 2 Development of the average pasteurisation equivalent unit sin case of fre (szk) and forced convection (kk) in dependence of the size (1s= small fluctuation, process, 2s medium fluctuation process, 3s large fluctuation process

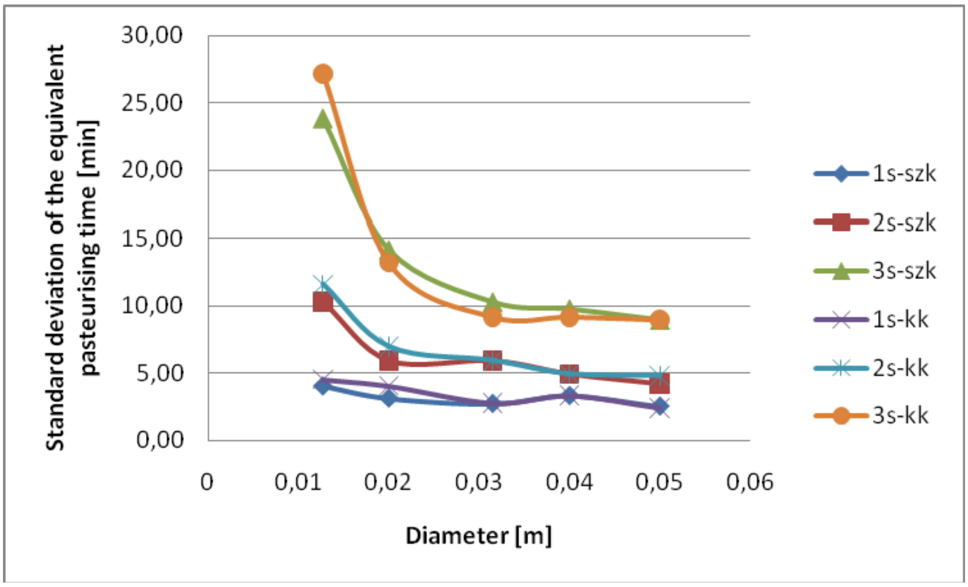

Figure 3 Development of the standard deviation unit sin case of fre (szk) and forced convection (kk) in dependence of the size (1s= small fluctuation, process, 2s medium fluctuation process, 3s large fluctuation process

Regarding the microbial consideration I could conclude that the moist resistant strains of the Streptococci cannot be destroyed by the heat treatment schedules applied today. The overcooking of the product would be resulted by the higher degree of heat treatment. Because microbial deterioration is rare they occur only in small number in the population. The multiplication during the come up and holding phase is in longer processes significant, e.g. in case of larger diameter (D> 60 mm), low ambient temperature and surface heat transfer coefficient. The “mm/min” heat treatment principle has to be corrected because it gave the expected results only in case of 40 mm diameter.

Our energetic results showed that remarkably energy saving can be reached by changing the can orientation and by reasonable choosing the parameters (e.g. surface heat transfer coefficient) at large containers mainly.

In the course of the sensitivity and parameter effect investigations I experienced that the accurate size and ambient temperature had the greatest importance in the heat treatment processes then the thermal parameters, depending on the chemical composition, came before the surface heat transfer coefficient and initial temperature. In the parameter effect investigations I have experienced only linear behaviour excepting the parameter of ambient temperature in slow processes (low surface heat transfer coefficient and ambient temperature and outermost sizes).

The calculations in stepwise heat treatment showed that the ambient temperature would be held between 55-60°C (at the beginning) and 72-74°C (final limiting ambient temperature) for holding good quality and minimising capacity loss.

5. The new and novel results of the dissertation

5.1 Determination of thermal parameters

5.1.1 In the industrial circumstances the thermal diffusivity values can be determined with an accuracy as published in the literature/laboratory if the parameter fluctuations are hold in low level

5.1.2 The determination of the thermal diffusivity highly dependent on the initial and boundary condition of the measurements and on the temperature sensor placement error. Therefore the determinations based on infinite series solution (ISS) gives remarkable differences even if the measurement errors on the base of error investigation are low. The main reason of it the different development of the average temperatures during the holding/cooling phase (Table 1).

5.1.3 The thermal parameter calculations carried out with the equations independent on the temperature were not validated. They are capable to estimate the cooling time. The thermal diffusivity region of $1.3\text{-}1.5\cdot10^{-7}$ m^2/s is applicable for the estimation of the equivalent pasteurising time (Figure 4-5 and Table 1).

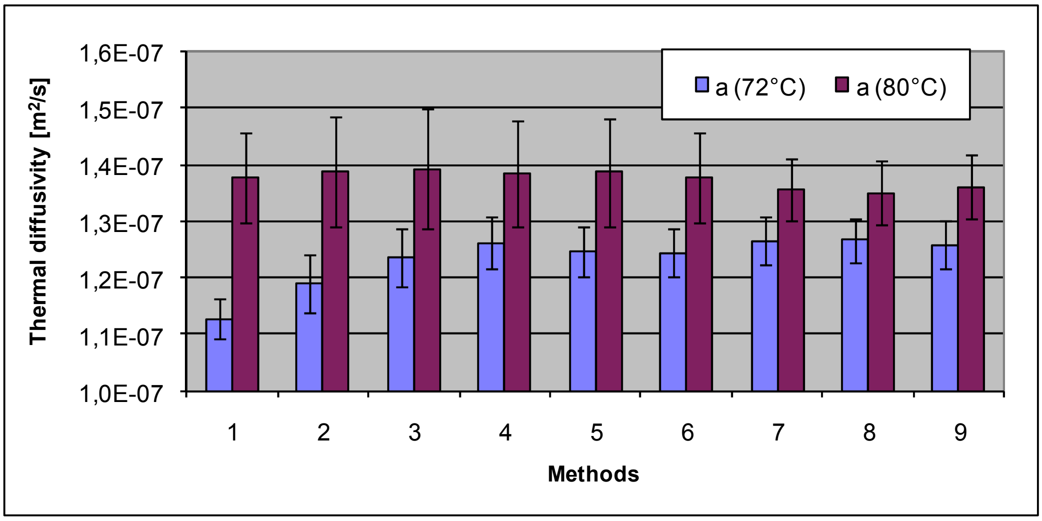

Figure 4 Development of thermal diffusivity at different ambient temperature (12 lb ham) by robust regression (Rajkó 1994), Eszes & Rajkó 2004)

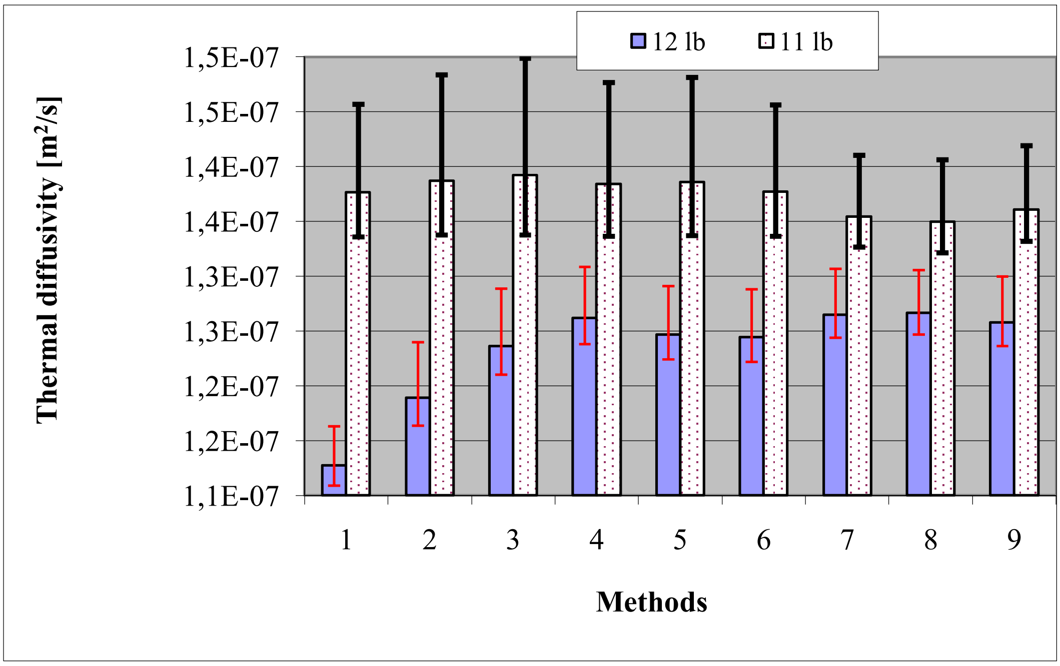

Figure 5 Development of thermal diffusivity in 12 and 11 lb cans (12 lb ham) by robust regression

Table 1 Thermal diffusivity of cooked sausages and semi preserved hams (ISS method)

Packaging	**Holding**		**Cooling**	
	Mean [m^2/s](10^{-7})	SD [m^2/s](10^{-9})	Mean [m^2/s](10^{-7})	SD [m^2/s](10^{-9})
11lb pullman	1,404	5,48	1,161	6,8
12lb oblong	1,305	7,40	1,130	6,50
Veronai cooked sausage	1,300	1,72		
Vadász cooked sausage	1,334	4,08		
Zala cooked sausage	1,371	4,68		
Olasz cooked sausage	1,338	2,31		

5.1.4 On the base of the error investigation I have determined that the thermal diffusivity determination goes hand in hand with higher error under D=80-100 mm but above this diameter the efforts made for decreasing error are not in proportion with the improving the accuracy. In this way I refined the proposal of LARKIN and STEFFE (1982) (Figure 6).

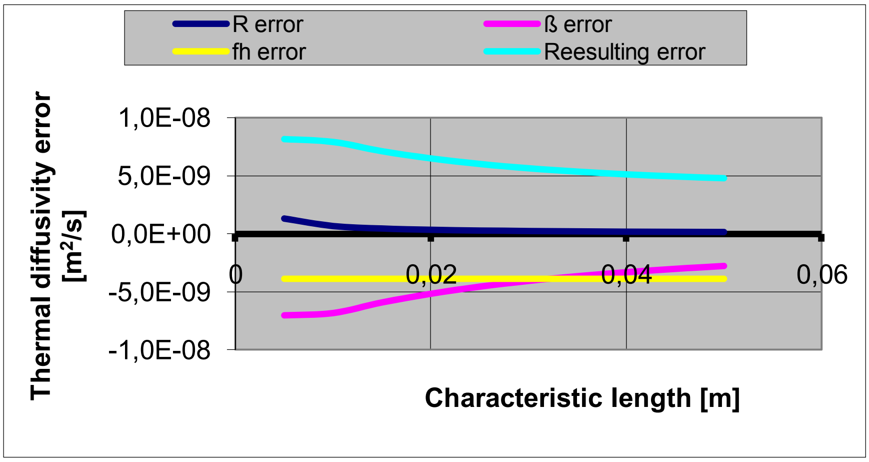

Figure 6 Development of the error in thermal diffusivity determination ont he base of the PFLUG equation in dependence on the size, heat transfer intensity and Ball slope index (ß =characteristic root, R radius)

5.1.5 The density determination of the can be carried out by mass and volume measurements with less error compared to the calculation from chemical composition, if we adjust the accuracy onto the package/can size. So it can be determined by 0.1 % error and can be considered as constant (Figure 7).

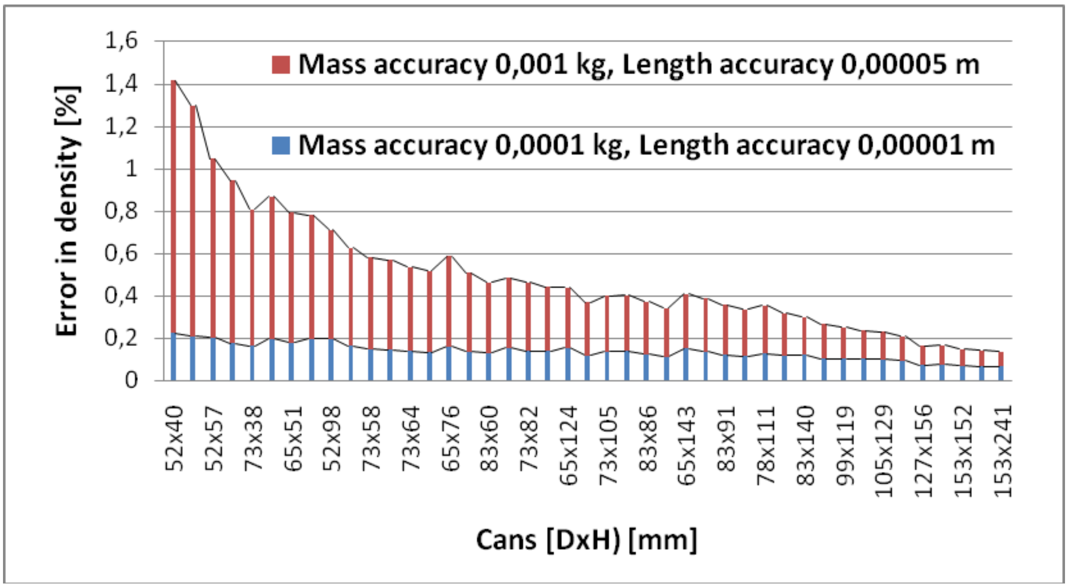

Figure 7 Decreasing the error of density measurement

5.1.6 Introducing the error investigation the temperature estimation accuracy I lowered the under ±1°C even in case of extreme values as well (Figure 8).

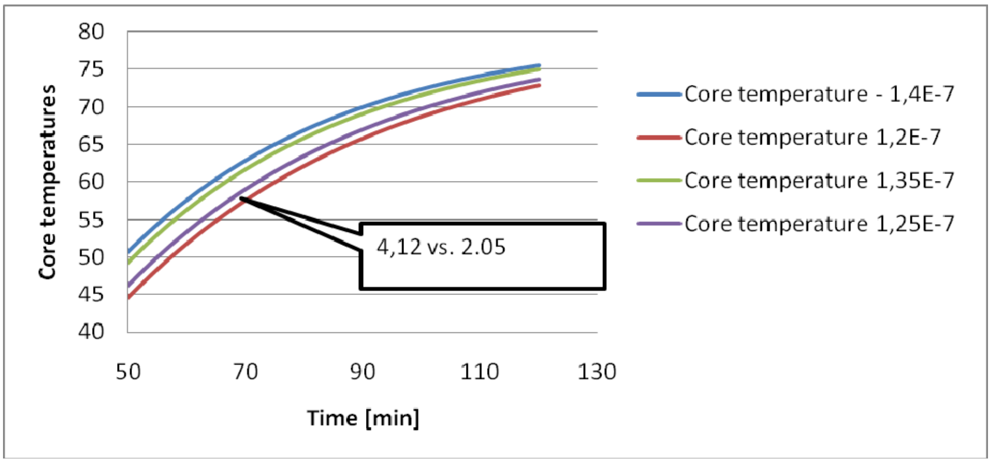

Figure 8 Temperature estimation calculated with decreased fluctuations ont he base of error calculation

5.2 Food safety considerations

5.2.1 On the base of the D_r and z values of the most resistant Streptococcus strains can be hardly destroyed according to the heat treatment stopping principles applied today. Since I do not know about large number of microbial deterioration cases their count and occurring frequency may be very low or they are absent in the population (Figure 9).

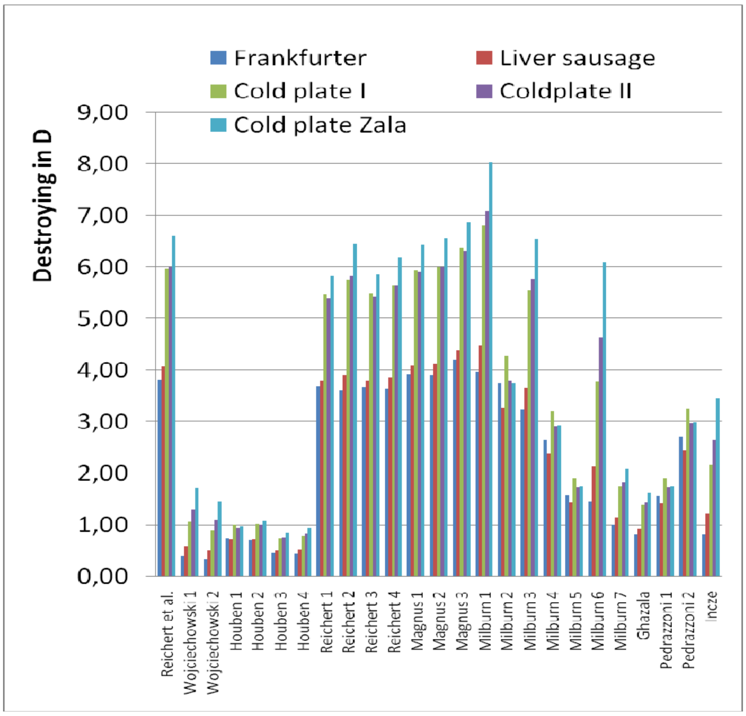

Figure 9 Destroying the different bacterial strains during the holding time

5.2.2 The bacterial growth during the come up and holding time is minimal under d<50 mm and it is under the detection limit. On the contrary the bacterial count can be increased by 1.5-2 times of its original value if d>50 mm and the process is slow. In this way the bacterial count of 10^6/g considered as conservative may be true even in case of raw materials with relatively good hygienic conditions and on the base of order about the allowable and tolerable bacterial counts as well (Figure 10).

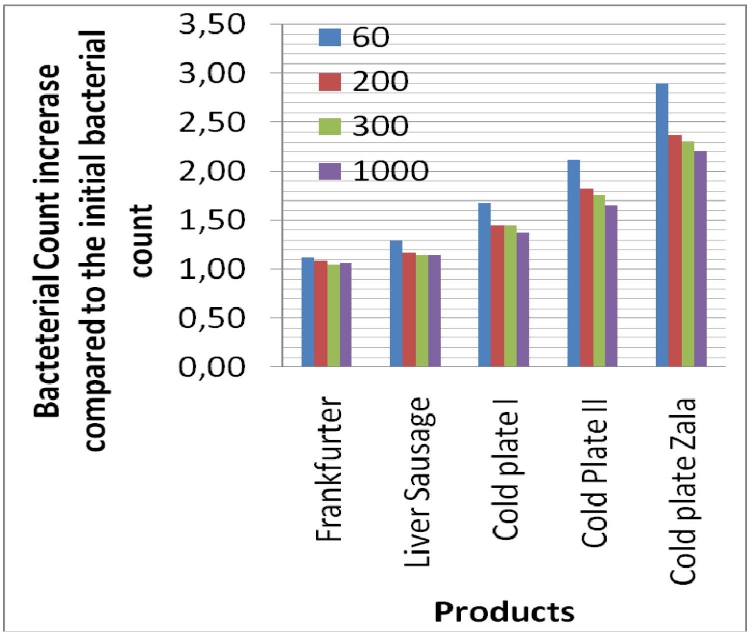

Figure 10 Development of the bacteial count during holding time (ambient temperature 76°C) in case of different surface heat transfer coefficients (W/m^{2}K)

5.2.3 I have found linear relationship between the target core temperature and ambient temperature; if we consider 12D bacterial destroy involving the cooling. I have given correction factors for the target core temperature vs. product diameter (Figure 11-12).

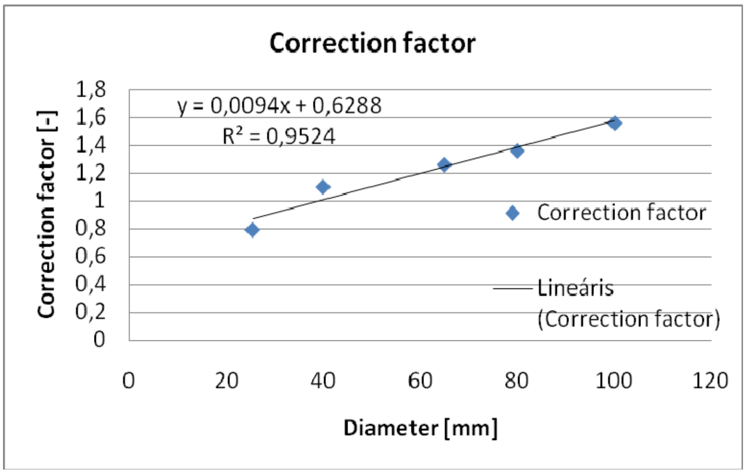

Figure 11 Validation of the „mm/min" heat treatment principle (ambient temperature 76°C)

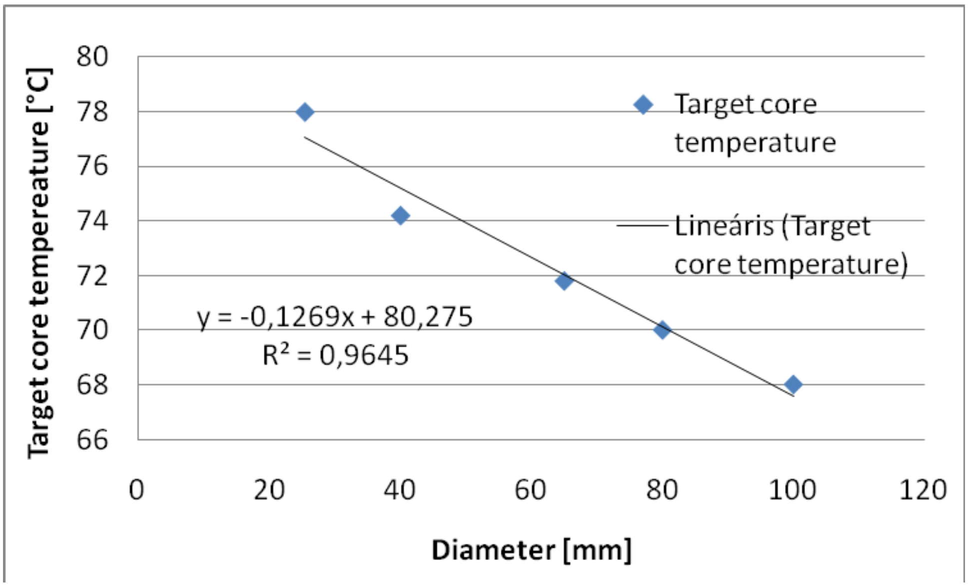

Figure 12 Target core temperature for reaching P=36 min heat equivalent at 76°C ambient temperature

5.2.4 In case of the semi preserved hams packaged into large cans the target core temperature of 69°C gives adequate bacterial destroy only till 76°C ambient temperature.

5.3 Engineering and calculation considerations

5.3.1 Both the bacterial calculations and the statistical parameters of Monte-Carlo calculation showed that diameter about of 50 mm is a dividing line in case of heat treatment. The products have another behavioural pattern under and above it.

5.3.2 The distributions have not given clearly normal or notable not normal distributions even in case of 1000 running (Figure 13-15).

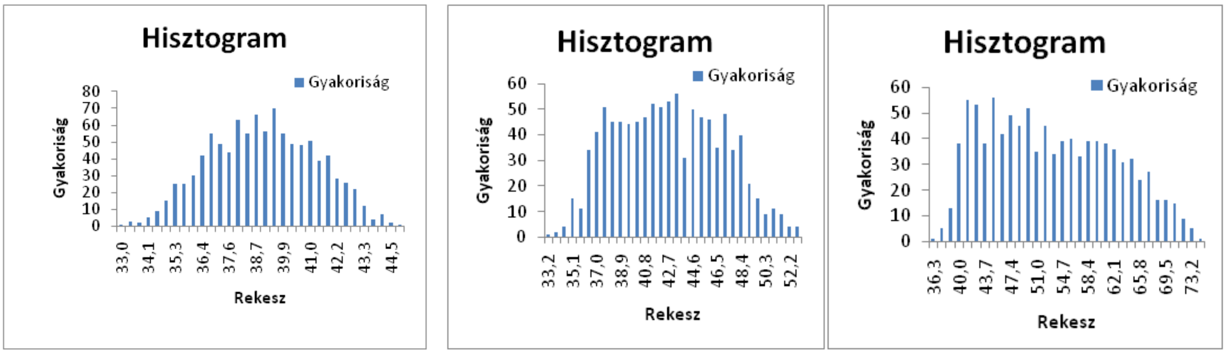

Figure 13 Distributions in case of small medium and large parameter fluctuations (D=80 80 mm)

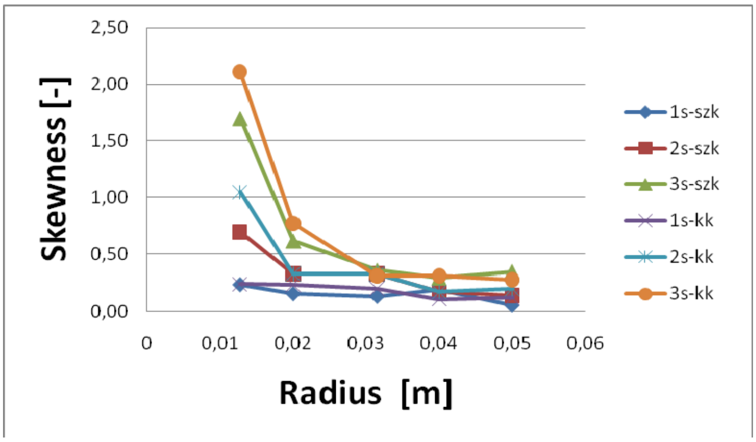

Figure 14 Development of the skewness in case of free (szk) and forced (szk) convection (kk) in dependence of the size (1s= small parameter fluctuation process, 2s medium parameter fluctuation process, 3s large parameter fluctuation process)

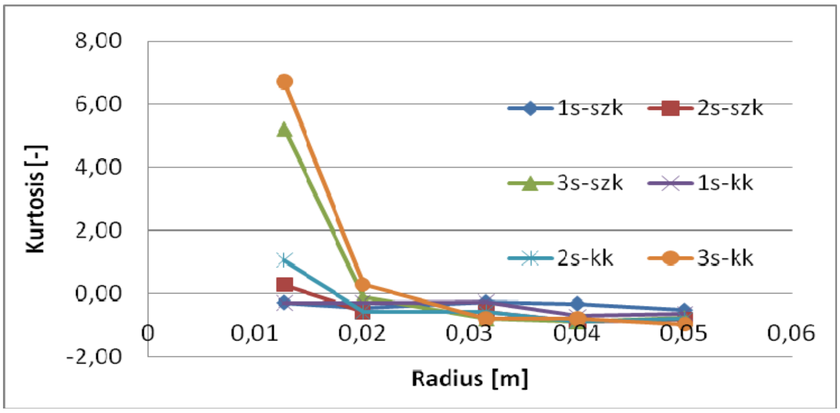

Figure 15 Development of the kurtosis in case of free (szk) and forced (szk) convection (kk) in dependence on the size (1s= small parameter fluctuation process, 2s medium parameter fluctuation process, 3s Large parameter fluctuation process)

5.3.3 I propose the change of the orientation for approaching the optimum heat treatment, namely the shortest characteristic length of the object has to be reached by the highest surface heat transfer coefficient available in the heat treatment equipment. In this way The holding can be shortened and the volume average C value can be decreased (Figure 16).

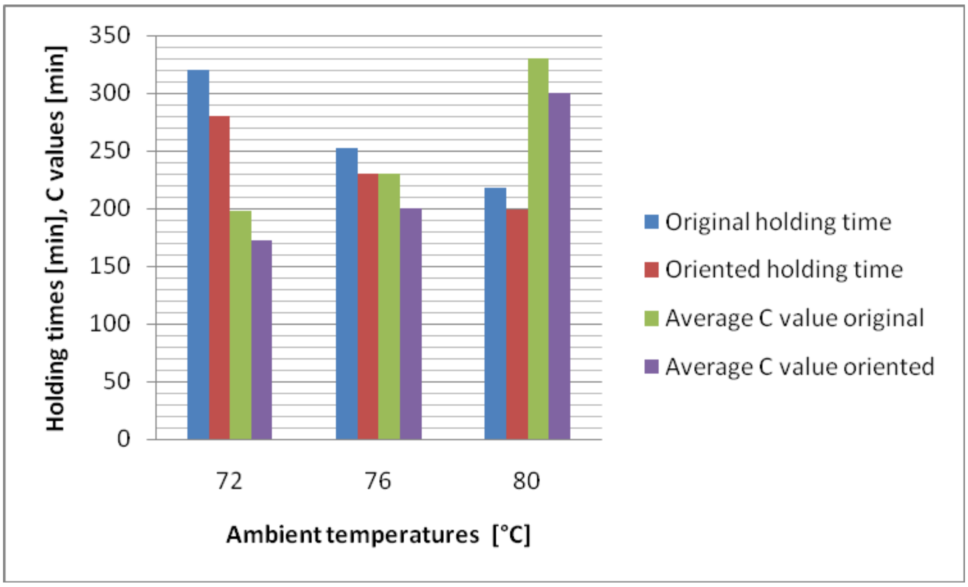

Figure 16 Development of the holding time and volume average C value int he original and in the oriented case for semi preserved ham

5.3.4 The energetic calculations showed that the surface heat transfer coefficient is worthy to increase till about 200 W/m^2K 200 W/m^2K in case of meat products (Figure 17).

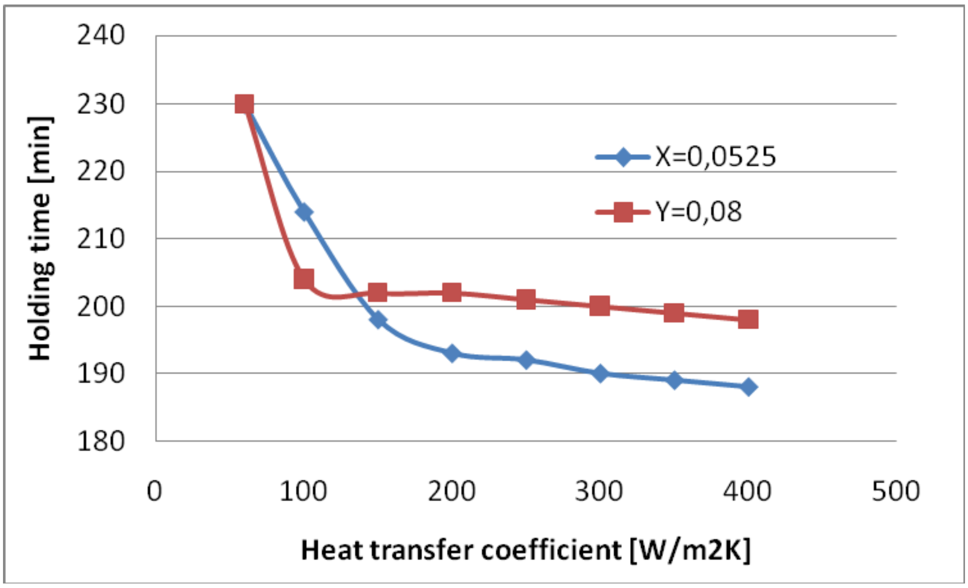

Figure 17 Effect of the surface heat transfer coefficient ont he holding time

5.3.5 The sensitivity investigations showed that the parameters have a linear behaviour in the investigated regions in case of small and medium parameter fluctuations. I have experienced parabolic influence only at the ambient temperatures and with large parameter fluctuations (Figure 18-19).

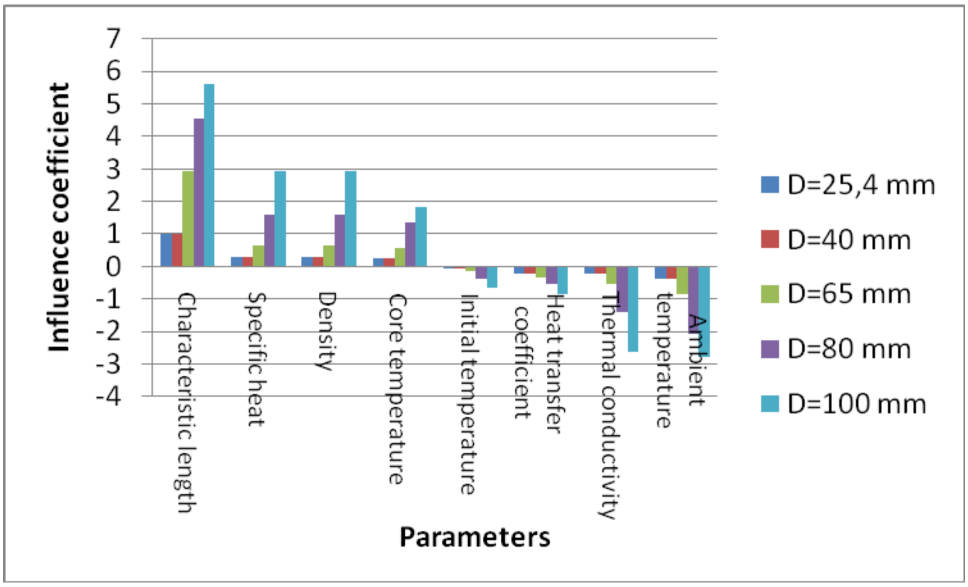

Figure 18 Effect of fluctuations on reaching the target core temperature (D=80 mm)

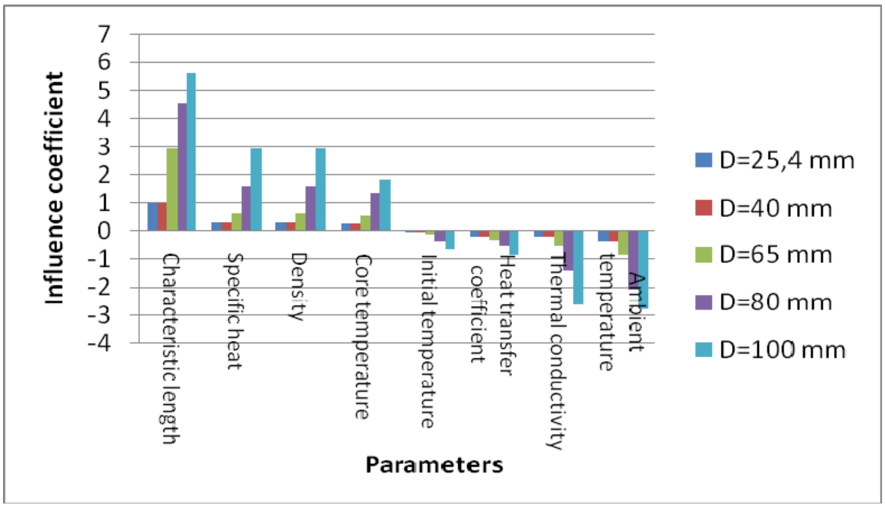

Figure 19 Measure of the parameter influence at different cooked sausage diameters

5.3.6 It is reasonable to hold the ambient temperature of the step-wise heat treatment between 55-60°C (1st stage) and 72-74°C (final limiting stage).

6. Utilisation of the results in the practice

- The measurements for decreasing the parameter fluctuations can be ranked according to the ranking of the parameter influences.
- I have given correction factors for „mm/min” heat treatment principles
- I have given a function for the target core temperature vs. diameter for the 12D bacterial destroy.

- I have given the relationship between the holding vs. diameter
- I refined the conditions needed for accurate parameter estimation
- A metodika alapján meghatározható az ésszerűen vállalható és vállalandó hőkezelés túlbiztosítás.

7. Publications in the theme of the dissertation

Dissertation

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2. **Eszes F.,** Fenyvess,y J. *(2005):* Energia és vízfelhasználás csökkentése a húsiparban. (Decreasing the Energy and Water Use in the Meat Industry) Acta Debreciensis VOL 18. pp. 24-28.
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