JOURNAL OF ENGINEERING annals OF FACULTY OF ENGINEERING HUNEDOARA

HEAT TREATMENT OPTIMIZATION OF CANNED MEATS IN TERMS OF THE RESOURCE UTILIZATION AND THE QUALITY OF THE PRODUCTS

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Abstract:
Heat treatment of canned food products, particularly canned meat products, requires considerable energy as the cans need sterilization. A heat treatment with a long time span and with a temperature of around 120°C will consume considerable quantities of fuel.
The heat treatment is used to avert microbiological danger. The operation regulation has to be defined in a way which produces a microbiologically reliable product, without harming its organoleptic peculiarities, substance, taste and flavour with an oversized treatment. In the interest of safety we have to define the extent and the time span of the heat effect leading to the destruction of the microbiological pathogens with the use of engineering calculations, modelling and computer simulation. We also have to secure the observance of the regulations obtained this way for the sake of the higher quality and the less resource utilization. This observance ability is answered with the help of our developed model for the computer simulation of heat treatment processes.
Keywords:
autoclave, heat treatment, modelling, simulation

1. INTRODUCTION

Heat treatment provides increased shelf life and is a defensive measure against microbiological hazards. Thus, inappropriate handling and violation of the operation regulation might have serious consequences. Therefore, heat treatment is a crucial point of food safety. With longer heat treatment the risk is decreased. However, if the heat treatment is too long, the quality of the product may decrease; the smell, the taste and the substance is in danger (liver products might develop distinctive colours and meat products might drip liquids etc.). Therefore the operation regulation and the control should be designed in a way so that the operation fulfils both safety and quality.

Heat treatment of canned goods and especially of meat products requires large quantities of energy as these products require long treatment at around 120 degree Celsius. Reducing the use of natural resources is an important goal in industrial processes – a few years ago this only meant saving energy, today it includes the paradigm of environment management and the paradigm of sustainable development – the goal is to reduce the energy usage or at least to produce more products without increasing energy usage [3]. Although reduction in the use of these resources (water, electricity, heat energy) obviously decreases the cost of manufacturing and increases the economy of manufacturing, it is not trivial to implement in many production plants as the cost of these resources is not calculated or measured at all, thus wasting resources is not visible. Similarly, increased quality and nutrition parameters might also remain undetected.

Insulating the heat treatment equipment is easy, but it requires changes in the technological process which raises food safety problems. Moreover, production plants are uneager to change the technological processes. Another problem is the high initial cost of measuring equipment and the required periodical replacement of sensors. The result is that only the most important data is collected. In heat treatment, this data is the core temperature and the outer temperature. In the field of heat treatment, general heat loss was an important field around 1970 [4, 5, 8]. Around 1980, the heat utilization and heat intake ratio were important issues [1, 6, 7]. If the insulation is changed on the equipment, the technological processes must be changed in accordance with engineering calculations. Because of the above mentioned reasons, and because of the many parameters and many different processes, modelling and simulation should be combined with engineering calculations. The intensity and the length of the heat treatment must be calculated in a way to effectively neutralize microbiological hazards, and the resulting requirements must be implemented and monitored in order to achieve a higher quality.

In this work, we demonstrate the mathematical model of the steam requirements of a heat treatment process and a simulation application which incorporates the model and is capable of determining the collective resource usage of parallel heat treatment processes.

2. THE STUDY

2.1. Heat treatment values and calculations of the length and temperature of heat treatments

The neutralization of micro-organisms with heat treatment is studied since 1920. The most important micro-organisms' neutralization with wet steam can be expressed with a negative exponential equations (the correspondence and acceptability of the kinetic description of the primary reaction is based on the biological reason that supposedly wet steam denaturises vital proteins according to the monomolecular reaction) which means that consecutive identical heat treatments leave the same proportion of the initial number of micro-organisms alive.

For a given micro-organism and a given temperature, *D* denotes the required time to destroy 1 log cycle (90%) of the microorganism and *z* denotes the heat increment required to reduce *D* by a magnitude. The heat treatment value is denoted with *F* and is the value used for the longest time. F_0 is the same as *F* but implies *z=10 °C* for a given heat treatment, for a micro-organism with *z=10 °C*, the temperature changes on the slowest heat point of the treated object have the same neutralizing effect as keeping the temperature on *121.1 °C* for F_0 minutes. The efficiency of heat treatments can be compared using F_0.

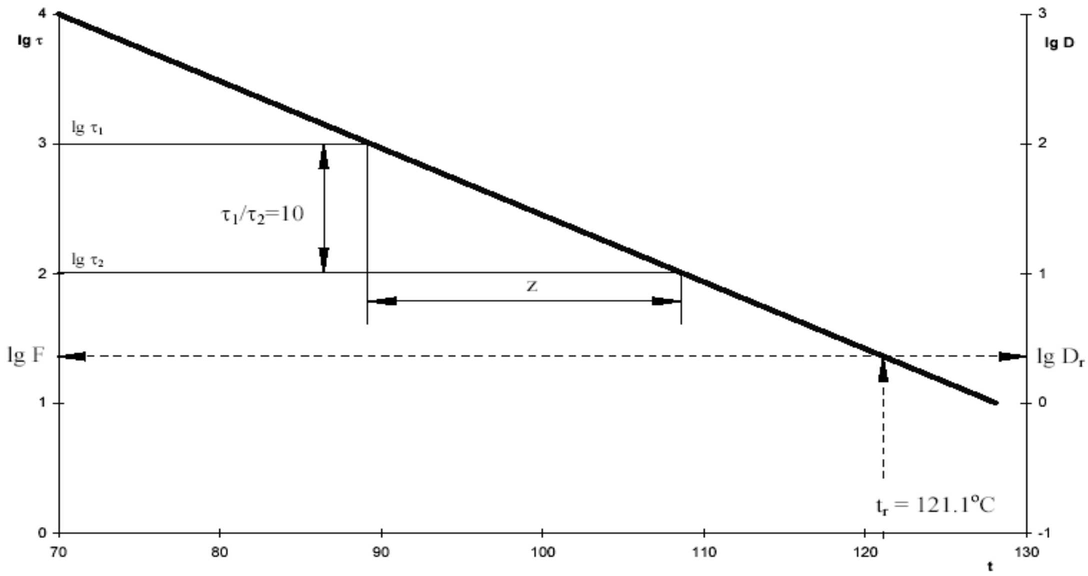


Figure 1. Neutralization of micro-organisms depending on the temperature

Figure 1 demonstrates the difference in temperature denoted by *z*, which reduces the thermal death time to one tenth. We might also plot a curve that is parallel with the thermal death curve with the help of the decimation times. As the decimation time measures the heat resistance of a micro-organism, this curve is referred to as heat resistance curve. We can calculate the formula of the equality of thermal death curve from the gradient and a point of the curve. A special point, according to international agreements, is the thermal death time at *121.1* °C (250 Fahrenheit) which is referred to as F-value. The *D*-value of the heat resistance curve plotted with the decimation times at *121.1* °C (reference temperature, t_r) is denoted by D_r.

We calculate the desired temperature of the sterilization bath (pasteurization bath, autoclave) and the desired length of the heat treatment with the help of the thermal death curve – referred to as the sterilization formula in the industry – if we know the temperature curve of the slowest heating point of the product, referred to as heat penetration curve in the industry.

The temperature of the slowest heat point of the product to be treated can be plotted against the time; this is the heat penetration curve. The curve displays the temperature change according to the three phases: heating, maintaining temperature, cooling. To design the heat treatment, the longest τ time required to destroy the required proportion of the micro-organisms relevant to the product on a feasible *t* temperature must be known. That is, the thermal death curve, similar to the one on *Figure 1* must be known.

We can calculate the relative neutralization speed for different *t* temperatures if we know the value of F and z, relative to the value of F/τ at $121.1\ °C$. To calculate the requirements of the heat treatment, the so-called sterilization curves are plotted from known heat penetration curve and the z-value from the micro-organism's thermal death curve. Such a sterilization curve is demonstrated in *Figure 2*. On Figure 2, the heat penetration curve used to calculate the points of the sterilization curve is also displayed (with $z=10\ °C$).

To calculate the sterilization curve, we plot the relative thermal death speed (F/τ) instead of the temperature against the axis of heat treatment time. The integral of the sterilization curve is the sterilization value (F_0 value) which is in F-units.

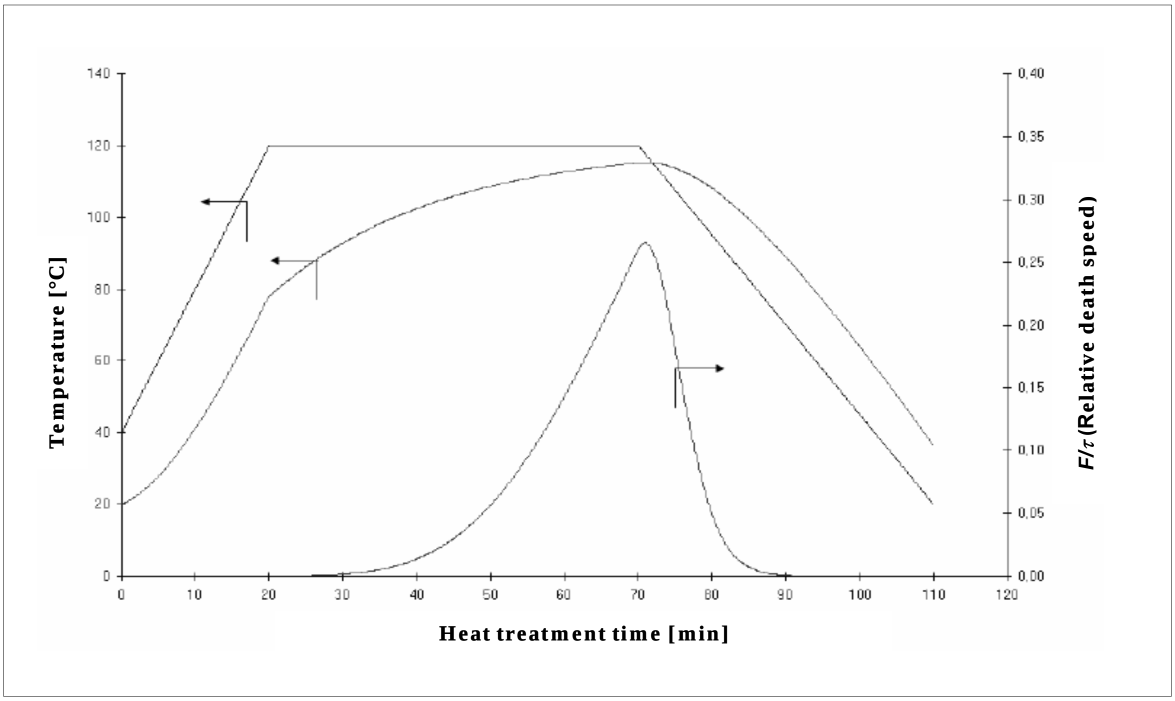


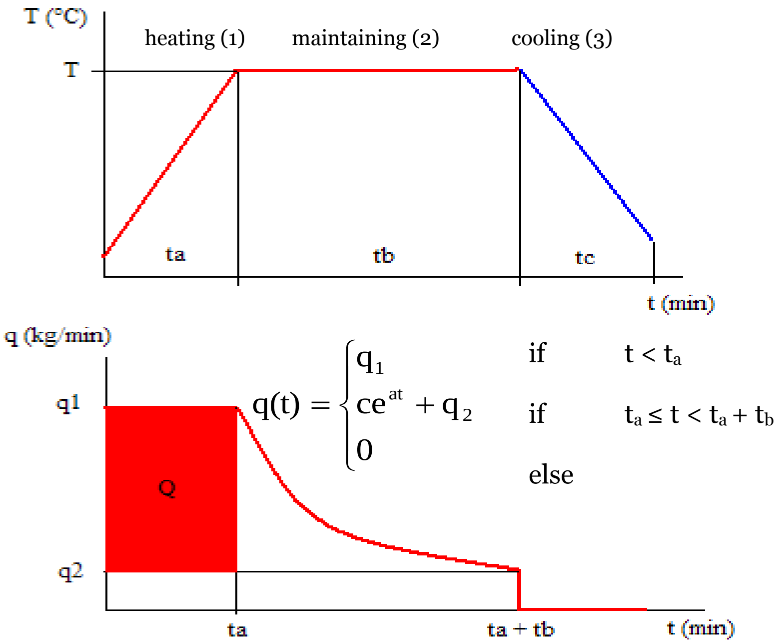
Figure 2. Plotting a sterilization curve from a heat penetration curve

As the z-value of the thermal death curve of Clostridium botulinum spores is between $14.7\text{-}16.3\ °F$, depending on the product, and the z-value of the thermal death curve of the internationally accepted reference spores of the putrefactive anaerobe bacteria strain Clostridium sporogenes P.A. 3679 is between $z=16.6\ °F$ and $z=20.5\ °F$. That is the reason of using an average value of $z=18\ °F=10\ °C$ in calculations. For C. botulinum spores, the highest registered D-value was 0.21 minutes on $121.1\ °C$. A worldwide standard for food products with a pH greater than 4.5 (for example, meat products) is to require a heat treatment that reduces the number of C. botulinum spores by twelve magnitudes. This is known as the 12D-concept. For that a $12*D$ minute long heat treatment is required which is $12*0.21=2.52$ minutes on $121.1\ °C$ (so, the F-value of C. botulinum spores is 2.52 minutes). The required length of the heat treatment for other temperatures can be calculated according to the information above with $z=10\ °C$.

2.2. Modelling the steam usage of a heat treatment

Heat treatment is performed in closed, pressurized units (autoclaves) from which typically 10 to 20 units are needed for treating canned food arriving from different production flows with a different flow rate and with different sizes and geometry [2]. The heat treatment in an autoclave is started when it is full with products requiring the same heat treatment. This results in a lower relative energy usage. An automated control system controls the temperature by regulating the amount of steam input (for heating and for keeping a temperature) and water input (for cooling).

On the upper part of Figure 3, the required temperature is displayed (as calculated from the sterilization curves). On the lower part of Figure 3, the required amount of steam is displayed (to be calculated later).



$$q(t) = \begin{cases} q_1 & \text{if} \quad t < t_a \\ ce^{at} + q_2 & \text{if} \quad t_a \le t < t_a + t_b \\ 0 & \text{else} \end{cases}$$

Figure 3. Development of temperature and steam mass flow in function of time

Product-dependent data calculated from the sterilization curves:

- T: required temperature (°C)
- t_a: heating time (minutes)
- t_b: heat keeping time (minutes)
- t_c: cooling time (minutes)

The parameters of the $q(t)$ steam mass flow (kg/minute) are yet to be calculated:

- Q: Steam required for heating (kg), a product-independent constant
- q_2: steam mass flow loss (kg/minute), a product-independent constant
- c, a: The curvature parameters of the $q(t)$ function, the first is independent of the product and the second depends on the first.

3. ANALISES, DISCUSIONS, APPROACHES, INTERPRETATIONS

3.1. Mathematical model for steam mass flow

When modelling real-world phenomenon, considering every condition is impractical, if not impossible. For a simpler model, or even for a feasible model we must omit details that are (thought to be) less important. On the other hand, we should not over-simplify our model. We have to identify the parameters of the phenomenon and the connections between them.

In an autoclave, we have to determine the required steam mass flow, as a function of time, for a given heat treatment. The steam mass flow loss (***q_2***) is the amount of heat exiting on the hull of the equipment which depends on the insulation of the equipment from the internal temperature and from the external temperature. On the other hand, individual autoclaves can be modelled as identical and all products are treated on almost the same temperature, so q_2 can be modelled as a product-independent constant during the whole heat treatment.

The amount of steam required for heating (Q) depends on the quantity of the product and from the difference of the maximum temperature and the initial temperature. As these are almost identical for every product, Q is also a product-independent constant.

Knowing q_2, Q and t_a, the steam required for one time unit of the heating phase, the steam mass flow (q_1) can be calculated:

$$q_1 = q_2 + \frac{Q}{t_a} \qquad (1)$$

In the second phase of the heat treatment, the heat keeping phase, the temperature of the cans converges to the internal temperature of the autoclave, thus the required steam mass flow is exponentially reducing from q_1.

The curvature can be described by either the a or c parameter of the exponential arc, and the other can be calculated from the constraint that the arc starts from the value q_1 at the beginning of the heat keeping phase (at the t_a time instance). For example, for an arbitrary negative a:

$$q(t_a) = c \cdot e^{at_a} + q_2 = q_1 \Rightarrow c = \frac{q_1 - q_2}{e^{at_a}} \tag{2}$$

3.2. The adjustment of the parameter of the mathematical model

Using our results above, we can calculate the required steam mass flow for a single autoclave from three arbitrary chosen parameters (q_2, Q, a). Now, which value combination of these parameters will result in the best model? To answer this question, we have to compare our measurements of the real process and the calculated process and find the parameter values with the smallest error. However, we do not have measurement data and the production plant is not planning to buy expensive measuring equipment to find the best model which can be simplified. As the gas usage of the furnace that produces the steam is measured, and we can calculate the gas usage of our model, we can calibrate our model based on the error in the gas usage between the simulated process and the real process. For that, we had to create a computerized simulation tool that is able to calculate the total gas usage for every minute of a 24-hour period, calculated from the total steam requirement (as in Figure 4) which is calculated from the individual steam requirements of the simulated heat treatments.

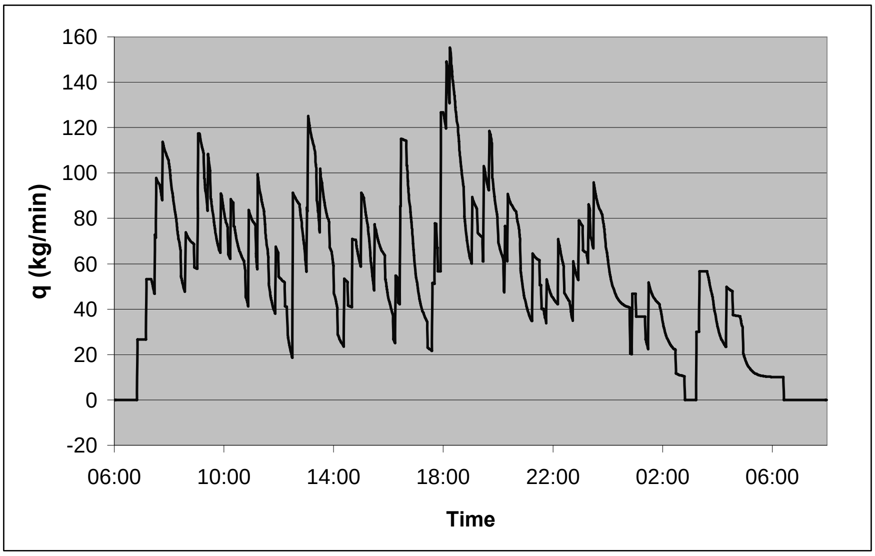


Figure 4. Total steam requirements of multiple autoclaves operating simultaneously

4. CONCLUSIONS

By comparing the simulated gas usage and the measured gas usage for the past heat treatments, the parameters of our mathematical model can be adjusted. At this point, the future gas usage can be calculated as well on a minute scale, thus we have an opportunity to prevent wasteful gas usage caused by an inefficient, unbalanced gas usage. That can be achieved by delaying some of the heat treatments in the heat treatment plan or production programming at the production lines. For this, we need adequate computer software and applications which requires further research.

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