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Freezing and thawing of processed meat in an industrial freezing tunnel

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ABSTRACT. Freezing is a commonly used preservation method in the meat industry. The understanding of the product behavior during the freezing process can assist in a better process management and quality control. This work reports the study of freezing and thawing of three types of processed meat in order to determine process parameters in an industrial forced-air freezing tunnel at -30ºC. Chicken sausages (frankfurter type), mortadela (bologna type) and mechanically deboned chicken meat (MDCM) were studied. Products were placed in several layers in corrugated cardboard boxes (CCB) for sausages and mortadela. MDCM was placed in a nylon box. Temperature sensors were inserted in the products and the freezing and thawing curves were obtained. Freezing curves were used to determine the freezing time (t_f), initial freezing point (T_f) and final freezing point (T'_m). Products placed in different layers in the CCB had significantly different freezing times, being the higher rates for products placed in more external layers than internal ones. The external layers of product were subjected to heat transfer by convection showing its importance to decrease freezing time. The results strongly suggest that products placed in different layers could have distinct quality properties and also play a key role in the freezing process efficiency.

Keywords: freezing curve, processed meat, freezing properties, freezing tunnel.

Congelamento e descongelamento de carnes processadas em túnel industrial

RESUMO. Na indústria da carne o congelamento é o método de conservação de uso geral. O conhecimento do comportamento do produto durante esses processos podem ajudar a uma melhor gestão de processos e controle de qualidade. Este trabalho reporta o estudo do congelamento e descongelamento de salsichas de frango (tipo salsicha), mortadela (tipo de Bolonha) e carne de frango mecanicamente desossado (MDCM), que visa a determinação dos parâmetros de processo em um túnel de ar forçado industrial de congelamento a -30ºC. Os produtos foram colocados em várias camadas de caixas de papelão ondulado (CCB) para salsichas e mortadela. MDCM foi colocado numa caixa de nylon. Os sensores de temperatura foram inseridos nos produtos e as curvas de congelamento e descongelamento foram obtidas. As curvas de congelamento foram usadas para determinar o tempo de congelação (t_f), ponto de congelamento inicial (T_f) e ponto de congelação final (T'_m). Os produtos colocados em diferentes camadas apresentaram tempos de congelamento significativamente diferentes, sendo as maiores taxas aplicáveis aos produtos colocados em camadas mais externas do que internas. As camadas externas de produto foram submetidas à transferência de calor por convecção, exibindo sua importância para diminuir o tempo de congelação. Os resultados sugerem que os produtos colocados em diferentes camadas podem apresentar uma qualidade distinta e também desempenham um papel-chave na eficiência do processo de congelamento.

Palavras-chave: curva de congelamento, carne processada, propriedades de congelamento, túnel de congelamento.

Introduction

Meat products are highly perishable food requiring a preservation method to extend its shelf life (LINDINO; NUNES, 2011). Freezing is a safe and a commonly used preservation method for meat products in general. However, this alternative can become expensive due to energy consumption and could also drastically affect the product quality if it is performed in an inadequate or uncontrollable way. During freezing of foods, the product is cooled to temperatures below 0ºC and water is converted from liquid to ice. However, water in food converts into ice at different temperatures as meat contains different solutes (RIBERO et al., 2007).

Time-temperature curves also referred as freezing curves are obtained experimentally to determine some thermophysical properties, such as initial freezing point (T_f), freezing end point (T'_m) and freezing time (t_f).

Initial freezing point is defined as the temperature which the first ice crystals start to form, i.e., ice crystals and liquid water exist in equilibrium (IBARZ; BARBOSA-CÁNOVAS, 2003; MILES et al., 1997; RAHMAN et al., 2009; RIBERO et al., 2007). T'_m is "[…] the point when the cooling rate is highest or the end of the plateau after freezing started since this indicates that freezing is completed" (RAHMAN et al., 2009, p. 162). Freezing time is an important property to establish the residence time for the food product and also to design freezing systems (HELDMAN; LUND, 2007). It is defined as the time required for a product at the freezing temperature to reach an expected final temperature at the geometric center (HELDMAN; LUND, 2007; IBARZ; BARBOSA-CÁNOVAS, 2003).

Freezing tunnels using forced-air convection are commonly used in industrial freezing process to ensure a high quality product by fast freezing. Several researches on freezing of foods to measure thermophysical properties have been conducted in laboratory scale apparatus and other forms of experimental setup using chest freezers (MATUDA et al., 2011; RAHMAN et al., 2003, 2002; RIBERO et al., 2007). Other works predicted the freezing properties using models based on food composition (MILES et al., 1997; MURIKAMI; OKOS, 1996; VAN DER SMAN; BOER, 2005). Little is known on the freezing properties of processed meat, as obtained in an industrial scale unit. This study focused on measuring the freezing properties (initial freezing temperature, end point of freezing, freezing time) of processed meat products (sausages, mortadela and mechanically deboned chicken meat - MDCM) in an industrial forced-air freezing tunnel.

Material and methods

Materials

Three types of processed meat product - chicken sausage (frankfurter type), mortadela (bologna type) and mechanically deboned chicken meat (MDCM) - were supplied by a national meat processor (Brasil Foods, Rio Grande do Sul State, Brazil) and used for the experiments. Four different types of chicken sausages, labeled as SL1, SL2, SL3 and SL4 were used in this work. Two types of mortadela were used and labeled as M1 (chicken meat) and M2 (pork meat). Each unit of M1 had a diameter of 61.5 mm, a length of 180 mm totaling 0.5 kg of product. Each unit of M2 had a diameter of 73 mm, length of 235 mm totaling 1 kg of product. The product to be frozen in the tunnel was placed in primary and secondary packaging due to equipment design and product quality. Products packaging was setup as following: 1) Chicken sausages: primary and secondary packaging was a plastic film and corrugated cardboard box (CCB), respectively. Each primary packing of SL1, SL2, SL3 and SL4 had a different number of sausage units placed in layers wrapped by a plastic film with distinct total weight (SL1: 48 units of sausages placed in 3 product layers totaling 2 kg of product in each primary packaging, SL2: 10 units distributed in 3 layers totaling 340 g, SL3: 10 units of sausages placed in 2 layers totaling 340 g, SL4: 27 units placed in 3 layers totaling 918 g). SL1, SL2, SL3 and SL4 had a total of 20 kg, 8.16 kg, 8.16 kg and 11.02 kg of product placed in each CCB, respectively. 2) Chicken mortadela: polyamide casing was the primary packaging and CCB was the secondary one. M1 and M2 had a total of 12 kg and 10 kg of product placed in the CCB, respectively. 3) MDCM: Product was packaged in a polyethylene bag and placed in a plastic container. MDCM had 20 kg of product. Chemical analyses were carried out to provide the product composition on water content, protein, lipids, ash, salt (NaCl) and starch for sausages and mortadelas. Lipids, protein and water content were determined for MDCM. Water content, protein, lipids, ash and salt were determined according to IAL (2005) and Brasil (1981). Starch analysis was performed as described by Mayrhofer (1901). Statistical analysis (LICODIEDOFF et al., 2013) was conducted by using Tukey Test at 95% of confidence level to determine significant differences among products.

Freezing and thawing curves (time-temperature plots)

An automatic forced-air freezing tunnel (TC-2214, Recrusul, Brazil) was used to perform the freezing of meat products. This equipment has multiple levels with a loading/unloading system so that the product is automatically transported from the start point to its end point. Evaporators using forced counter flow convection perform the freezing. This freezing system is used to refrigerate and freeze packaged food products. Its freezing capacity varies from 6000 to 20000 kg h^{-1}. A temperature data logger containing eight channels (MultiPaq21, Datapaq, Wilmington, MA), with ± 0.2°C precision, were used to obtain the time-temperature plots for sausages and mortadela. A two-channel temperature data logger, with a precision of ± 0.5°C (Testo 175, Testo, Lenzkirch, Germany) were used for MDCM. The temperature data loggers used in the experiments are designed to withstand freezing temperatures up to -40°C. A temperature data logger containing multiple channels allows measuring the temperature from up to eight positions simultaneously. The setup to obtain the time-temperature plots was done as following: 1) sausages CCB, the temperature sensors were positioned randomly within the product package, on the surface and the internal middle point of the package. 2) mortadela CCB: A temperature sensor was inserted in the geometric center of each product unit. The product units containing the channels were placed in different layers inside the boxes. 3) MDCM: one sensor was inserted in the geometric center of the product.

The packaged product was placed inside a nylon container. The CCB containing the products with the data logger installed were loaded into the freezing tunnel and temperatures were recorded each minute during the experiments. Similarly, the MDCM packages were loaded into the freezing tunnel and temperatures were recorded at each five-minute. One sensor was place outside the product boxes, but inside the tunnel during the experiments for the air-tunnel temperature registration. The temperature of the meat products at the end of the experiments were approximately -30°C. The data were obtained using data acquisition software (DataPaq Insight Food Tracker, Wilmington, MA). All measurements were performed in duplicate. Thawing curves for all products were obtained after the freezing processes. Boxes containing products were unloaded from the tunnel and placed at a temperature controlled room (above 10ºC) or in a domestic refrigerator (5 to 8ºC).

Initial and end freezing point from freezing / thawing curves

The initial freezing point and end freezing point for all meat products studied were obtained from the extrapolation of the temperature plateau to the cooling curve as described by Ribero et al. (2007). Temperature as a function of freezing time of products was obtained by using the central difference approximation, as presented in Equation 1.

$$\frac{dT}{dt} \cong \frac{T(k) - T(k-1)}{2 \cdot (t(k) - t(k-1))} \quad (1)$$

where T(k) and T(k-1) are the discrete temperature points measured at time t(k) and t(k-1),

Freezing and thawing data obtained experimentally were treated with a 'smooth' algorithm from *Matlab 7.0* software. *Robut Loess* algorithm, which uses a non-linear quadratic fitting (window size was 5% of the original data size), was used. The freezing time for the products studied was obtained from the freezing curves. Freezing time was defined as the required time for the internal temperature reach -18°C (0°F) which is the recommend temperature for frozen foods.

Results and discussion

Composition Analysis

Chemical composition for sausage; mortadela and MDMC sausages are shown in Table 1. The results obtained from SL1, SL2, SL3 and SL4 sausages have significant differences for starch, lipids, protein and NaCl content. According to Singh and Heldman (2008), water content presents a greater influence in thermo-physical properties than other chemical contents. M1 and M2 mortadela have significantly different composition for starch, ash and lipids. In addition, they not presented significantly difference in water content. Consequently, it can be assumed that these two products have small differences in their thermo-physical properties. Table 1 also shows chemical composition for MDMC. It can be seen that MDMC had a little chemical composition difference due to its small standard deviation.

Freezing curves

The freezing curves for sausages, mortadela and MDMC are shown in Figures 1, 2 and 3, respectively. Only SL3 and M2 curves are shown as results were similar among products. Figure 1 shows five freezing curves obtained from the four temperature sensors placed into the product and the sensor placed outside of the product in order to measure the temperature inside the freezing tunnel. Two thermocouples were placed in external layers, and the other two in the internal layers of product. The data from thermocouple marked as 'Tunnel' in Figure 1 is the temperature profile for the freezing tunnel during the experiment. It was observed a constant behavior for the temperature inside the tunnel with time.

As expected freezing times were lower for the external layers than internal ones, since freezing was conducted by forced air convection and heat transfer by conduction. Forced air convection improved the freezing rates and decreased the freezing time of the product compared to the products placed in internal layers. Freezing curves for the external layers showed a characteristic behavior for fast freezing while the other two freezing curves could be described as a slow freezing process. Typical slow freezing shows a plateau with little change of temperature due to phase change (freezing of water). The thermocouples placed in more internal (geometrical point considered) layers of the product were only subjected to heat transfer by conduction what explains the slow freezing behavior.

Table 1. Composition of frankfurter sausages; bologna sausages and MDMC (percentage weight basis)*.

Frankfurter sausage	Starch (%wt wt^{-1})	Ash (%wt wt^{-1})	Lipid (%wt wt^{-1})	Protein (%wt wt^{-1})	Water (%wt wt^{-1})	NaCl (%wt wt^{-1})
SL1	3.00 ± 0.32 ^{a}	0.99 ±0.08 ^{a}	17.20 ±0.81 ^{a}	13.26 ±0.12 ^{a}	62.49 ±0.77 ^{a}	1.77 ±0.06 ^{a}
SL2	1.32 ± 0.32 ^{b}	0.99 ±0.08 ^{a}	18.08 ±0.81 ^{a}	12.30 ±0.12 ^{b}	63.46 ±0.77 ^{a}	2.13 ±0.06 ^{b}
SL3	8.21 ±0.37 ^{c}	0.78 ±0.09 ^{a}	12.02 ±0.93 ^{b}	10.29 ±0.14 ^{c}	63.38 ±0.89 ^{a}	2.23 ±0.07 ^{b}
SL4	2.97 ±0.32 ^{ad}	0.89 ±0.08 ^{a}	15.81 ±0.81 ^{a}	13.28 ±0.12 ^{ad}	63.32 ±0.77 ^{a}	2.02 ±0.06 ^{b}
Bologna sausage	Starch (% m m^{-1})	Ash (% m m^{-1})	Lipid (% m m^{-1})	Protein (% m m^{-1})	Water (% m m^{-1})	NaCl (% m m^{-1})
M1	4.29 ± 0.34 ^{a}	0.88 ±0.11 ^{a}	18.72 ±0.29 ^{a}	11.80 ±0.10 ^{a}	58.77 ±0.14 ^{a}	3.58 ±0.04 ^{a}
M2	6.19 ± 0.34 ^{b}	4.39 ±0.11 ^{b}	15.57 ±0.29 ^{b}	11.84 ±0.10 ^{a}	59.10 ±0.14 ^{a}	3.45 ±0.04 ^{a}
MDMC	Lipid (% m m^{-1}) 17.84 ± 0.51		Protein (% m m^{-1}) 13.73 ± 0.47		Water (% m m^{-1}) 67.37 ± 1.89	

*Data are means of duplicate measurements. a-d Different letters are indicating significant differences with $p < 0.05$.

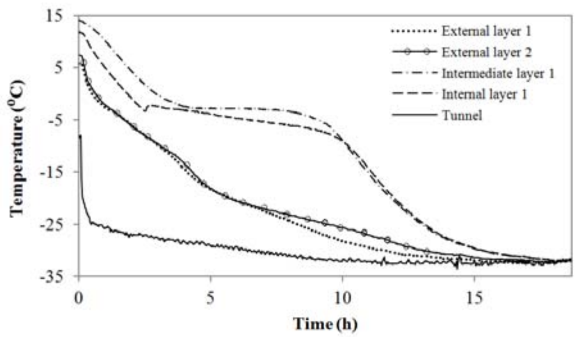

Figure 1. Freezing curves for frankfurter sausage SL3.

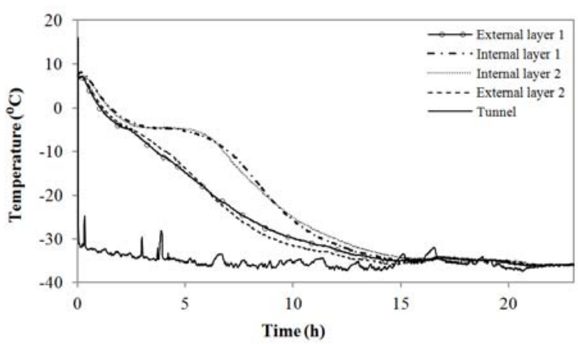

Figure 2. Freezing curves for bologna sausage M2.

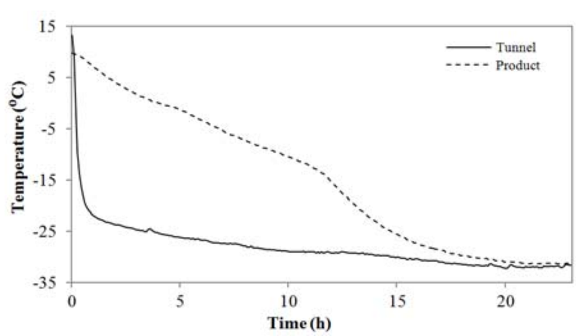

Figure 3. Freezing curve for MDCM.

Figure 2 shows the freezing curves of four thermocouples placed within two external and other two internal layers of mortadela. In addition, the thermocouple marked as 'Tunnel' was used to measure the temperature inside the freezing tunnel. The results for mortadela were similar to ones observed for sausages. The external layers showed typical curves for fast freezing. Thermocouples placed in the internal layers of mortadela showed slow freezing behavior, in which they did not suffer heat transfer by convection. As expected, heat transfer by convection is essential in order to obtain fast freezing conditions. Similarly to Figure 1, the freezing curves for mortadela showed freezing time differences for products placed in different layers inside the cardboard box. This difference could result in similar products inside the same box showing distinct quality properties since fast freezing contributes to products having better quality than products subjected to slow freezing.

Figure 3 shows the two freezing curves for MDCM. A thermocouple was placed in the geometric center of the product. Temperature inside the freezing tunnel was measured by another channel marked as 'Tunnel'. The MDCM freezing curve does not have a defined plateau; however, it shows a slight change at approximately 0°C. According to Karel (1975), the typical fast freezing curve shows this behavior at 0°C. It was also observed that the temperature steadily decreases at -15°C (12h) which is probably a super-cooling phase and the end point of freezing.

The results showed that heat transfer by convection is important to decrease freezing time and improve freezing rate. Freezing rates will be larger for products placed in external layers than internal ones. Consequently, same products placed in different layers inside the cardboard box can have distinct freezing times. As freezing rate is directly related to quality, the products subjected to a higher freezing rate (external layers) could have a better quality than products frozen at a lower freezing rate (internal layers).

Freezing time

Table 2 shows the freezing time of the sausages. Sausage SL4 was significant different from the other three types of frankfurter sausages having a freezing time of 11.32 hours compared to 8.37 hour for sausage SL3. Sausage SL1, SL2 and

SL3 did not show significant difference among them. SL4 has a similar composition to other three sausages; therefore composition did not affect freezing time. SL4 product was placed in a distinct secondary packaging, referred as CCB3. Three types of corrugated cardboard box dimensions were used in this study. CCB3 is smaller in length and width than CCB1 and CCB2; however it has a larger height (155 mm) than the other boxes (110 mm). As C4 has a small dimension, we can suppose primary packaging of products was close together resulting in a low heat transfer by convection and increasing freezing time.

Table 2. Freezing times*.

Product		Freezing time (h)	
Frankfurter sausage	SL1	9.05 ± 0.47^a	
	SL2	9.10 ± 0.46^a	
	SL3	8.37 ± 0.51^a	
	SL4	11.32 ± 0.91^b	
Layer		Freezing time (h)	
Frankfurter sausage	L1 (internal)	10.47 ± 0.45^a	
	L2 (internal)	11.09 ± 0.48^a	
	L3 (external)	7.05 ± 0.31^b	
Product		Freezing time (h)	
Bologna sausage	M1	21.36 ± 0.96^a	
	M2	8.83 ± 0.46^b	
Layer		Freezing time (h)	
		M1 (closed CCB)	M2 (open CCB)
Bologna sausage	L1 (internal)	21.65 ± 1.48^a	9.60 ± 0.39^a
	L2 (external)	21.16 ± 1.36^a	7.69 ± 0.82^b
Product		Freezing time (h)	
MDMC	-	11.94 ± 1.77	

*Data are means of duplicate measurements. a-d Different letters are indicating significant differences with $p < 0.05$.

Freezing time was significantly different in the external layer of frankfurter sausage (Table 2). The external layer L3 had a freezing time of 7.05 and was significantly different than internal layers (L1 and L2). This behavior was already seen when analyzing the cooling curves for frankfurter sausage (Figure 1) in the previous section. It confirms the positive effect of heat transfer by forced air convection on improving freezing time.

Freezing times for two different types of bologna sausage M1 and M2 are also shown in Table 2. Freezing times for M1 and M2 were 21.36 and 8.83, respectively. M1 was place in a closed CCB and had no influence of forced air convection as opposite to M2 which was placed in an opened CCB. As expected, they were significantly different and M1 had a much higher freezing time than M2. Table 2 also shows the influence of the different layers of products for M1 and M2. The two layers of M1 were not significantly different between them as it had no influence of convection heat transfer. On the other hand, the internal layer of M2 was significantly different than the external layer. The internal layer of product (L1) took approximately 2 hours longer to reach -18ºC compared to the external layer. Lastly, freezing time for MDMC was 11.94 ± 1.77 hours and was within the range of the results found for the other products. The results show that secondary packaging has a strong influence on freezing time, especially concerning the effect of forced air convection on freezing rate.

Initial freezing point and end point of freezing

The temperature profile and freezing rate ($dT\ dt^{-1}$) for frankfurter sausage SL1 is shown in Figure 4. This figure indicates the initial freezing point and end point of freezing, referred as point ‘A’ and ‘B’, respectively. In the beginning of the experiment, temperature higher changes occured until it reached point ‘A’ when it remained approximately constant at a freezing rate ($dT\ dt^{-1}$) closed to zero. This point sets the initial freezing phase of the product and the initial freezing point of -2.1ºC. The end point of freezing is obtained when the freezing rate is decreased, referred as point ‘B’ in the figure. End point of freezing for sausage SL1 was -9.6ºC. The second phase of freezing occurs within the range of points ‘A’ to ‘B’, and freezing of water mostly occurs at this phase.

Figure 4 also shows the temperature profile and freezing rate for sausage SL1 at different temperature sensor position in order to confirm the results found in the previous figure. As explained previously, thermocouples where placed in external and internal layers of the product. Initial freezing temperature and end point of freezing were determined for each channel (temperature sensor) and are marked as point ‘A’ and ‘B’, respectively. There is a time difference to reach the initial freezing point and end point of freezing between the sensors (Figure 4). Freezing time was already discussed through Table 2, and Figure 4 results are expected. This is the effect of forced air convection which external layers are subjected to. Table 3 summarizes the results found in Figure 4. Initial freezing point (T_f) and end point of freezing (T'_m) was -2.28 and -9.48ºC, respectively. T_f and T'_m had very small standard deviations for different sensors used in this product, as observed in Table 3. Even though sensors were placed in different layers of product, T_f and T'_m did not vary significantly among them. This result is expected, since T_f and T'_m are not a function of position, then the results show the methodology used in this study is satisfactory to infer the initial and the end of freezing time.

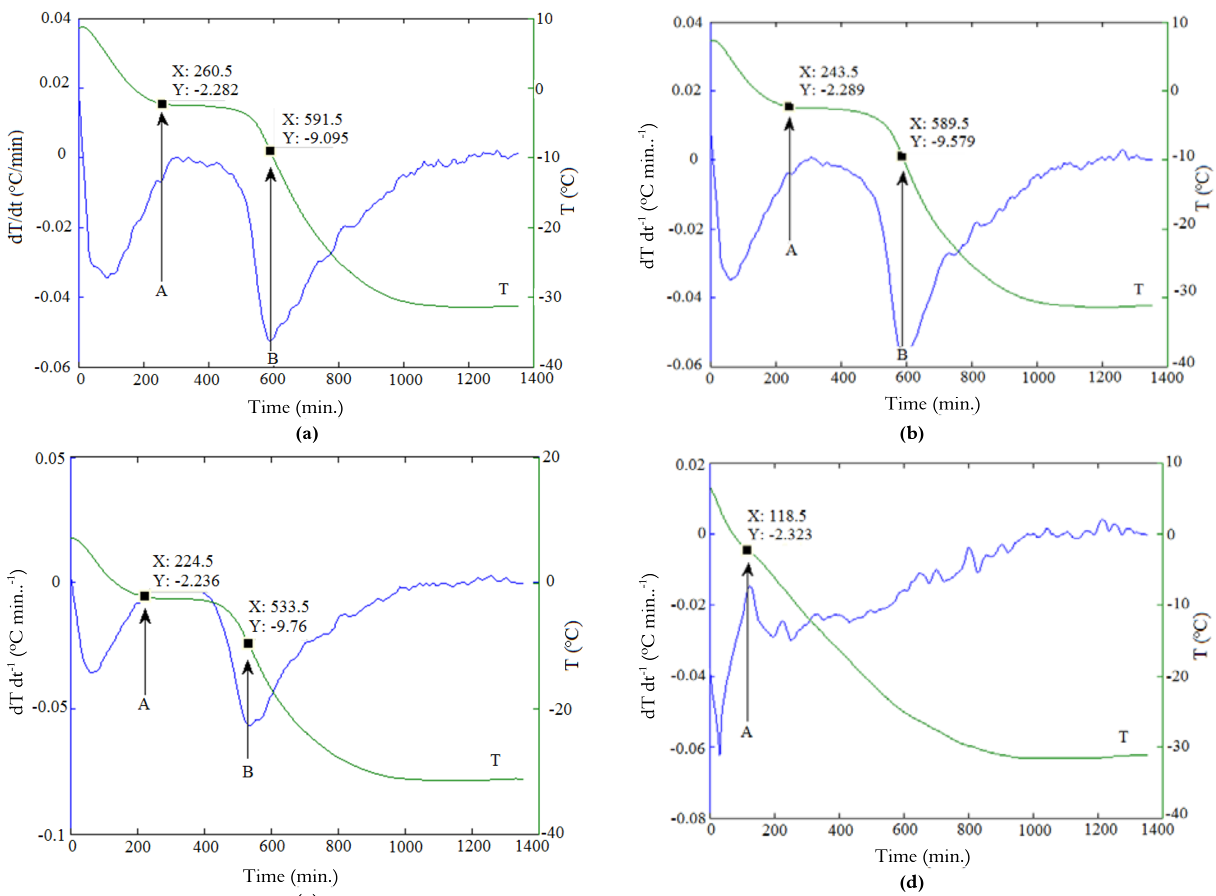

Figure 4. Temperature profile and freezing rate for frankfurter sausage SL1 at (a) Channel 1; (b) Channel 2; (c) Channel 3; (d) Channel 4.

Table 3. Initial freezing point and end point of freezing for frankfurter sausage SL1 at different channel positions.

Channel	T_f [ºC]	$T'm$ (ºC)
1	-2.28	-9.10
2	-2.29	-9.58
3	-2.24	-9.76
4	-2.32	-
AV ± SD	-2.28 ± 0.04	-9.48 ± 0.34

AV represents the average of the channel values. *SD* represents the standard deviation of the channel values.

Table 4 summarizes the initial freezing temperature and end point of freezing for the seven products studied. T_f and T'_m for frankfurter sausages were -2.49ºC and -9.71ºC, respectively. Even though frankfurter sausages had small chemical composition differences and were packaged distinctly, T_f and T'_m similar results were obtained for the products (SL1, SL2, SL3 and SL4). Initial freezing temperature and end point of freezing for mortadela (bologna) were -4.46 and -10.14ºC, respectively. MDCM presented an initial freezing temperature of -0.43ºC and end point of freezing of -4.46ºC. It can be seen that frankfurter, bologna and MDCM had very different initial freezing temperature and end point of freezing (Table 4). Freezing times were also different for the three types of products (Table 2). The initial freezing temperature of MDCM was closer to the freezing point of water than the other products. This result is expected when analyzing the water content of the three products. MDCM has higher water content (67%) compared to frankfurter (~63%) and bologna (~59%). In addition, bologna has the lowest water content and showed the highest initial freezing point (-4.46ºC). The previous results indicate that water content strongly influences the initial freezing point.

Table 4. Initial freezing point and end point of freezing for frankfuter. bologna and MDCM.

Product	T_f (ºC)	T'_m (ºC)
SL1	-2.28	-9.48
SL2	-2.56	-9.65
SL3	-2.67	-10.82
SL4	-2.43	-8.89
AV ± SD	-2.49 ± 0.17	-9.71 ± 0.81
M1	-4.85	-11.50
M2	-4.06	-8.78
AV ± SD	-4.46 ± 0.56	-10.14 ± 1.92
MDCM (AV ± SD)	-0.43 ± 0.02	-4.46 ± 0.30

AV represents the average of the channel values. *SD* represents the standard deviation of the channel values.

Thawing curves

In this work, frozen products were placed in a cold room and temperature was recorded in order to study the thawing process and to obtain the thawing properties. Thawing curves for frank sausage SL3 is shown in Figure 5. Five channels were placed in internal, intermediate and external layers. A channel monitored the room temperature which averaged 13ºC. The external layer had the lowest thawing time. This result is expected since the external layer was subjected to heat transfer by convection besides conduction. The intermediate layer had a lower thawing time than the internal one. Products placed in the internal layers require more time to thaw than the ones placed in the external layer. The five thawing curves show a slope increase at -5ºC which probably sets the phase change transition of water. Thawing curves for bologna M1 is shown in Figure 6. A channel monitored the room temperature which was around 5ºC. It is important to notice that this product is in a closed CCB box with no convection influence. On account of the closed box, the three thawing curves showed similar behavior. This result confirms that a CCB box with a lid reduces drastically the external heat transfer. The thawing curves for MDCM showed similar behavior to the other products and were not illustrated in this paper.

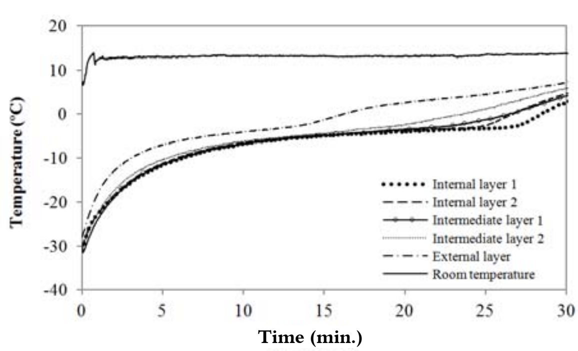

Figure 5. Thawing curves for frankfurter sausage SL3.

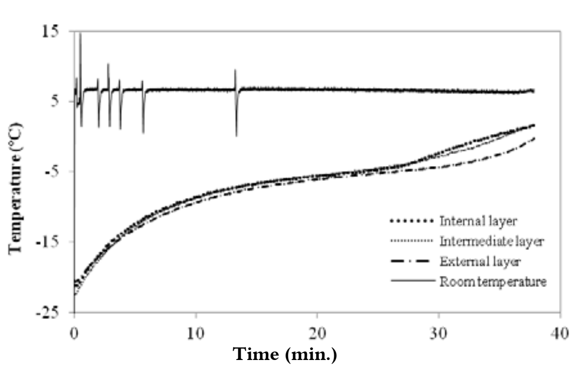

Figure 6. Thawing curves for bologna sausage M1.

Thawing properties (initial and end thawing point)

Figure 7 shows the initial thawing points and end points of thawing for frankfurter SL3. Points 'C' and 'D' indicates initial thawing temperature and end point of thawing, respectively. Same procedure was conducted for the other products and figures are not shown.

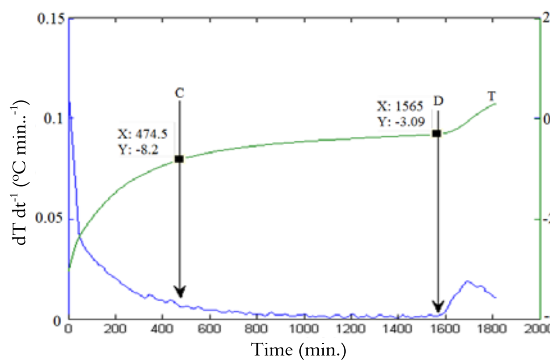

Figure 7. Temperature profile and thawing rate for frankfurter sausage SL3. Points 'C' and 'D' indicates initial thawing temperature and end point of thawing.

Table 5 shows the initial thawing point and end point of thawing for frankfurter, bologna and MDCM. Even though, SL2, SL3 and SL4 have a small chemical composition difference and were placed in different packaging, these variables did not interfere in initial and end point of thawing for each frankfurter sausage. As this type of experiment in an industrial set has not been applied so far, the previous results found reinforces the method reliability to determine the initial and end point of thawing. It is important to note that initial and end point of freezing (Table 4) have similar values to initial and end point of thawing (Table 5). The reverse processes are in agreement, giving substantial support to the method used to determine the initial and end point of freezing and thawing. The initial freezing points of the products studied are different among themselves, as reported in Table 5. This is probably a result of the water content of each product.

Table 5. Initial thawing point and end point of thawing for frankfuter. bologna and MDCM.

Product	T_i (ºC)	T'_m (ºC)
SL2	-8.21	-2.46
SL3	-8.19	-3.13
SL4	-7.44	-3.32
AV ± SD	-7.95 ± 0.44	-2.97 ± 0.44
M1	-8.01	-4.34
M2	-10.23	-4.75
AV ± SD	-9.12 ± 1.57	-4.54 ± 0.29
MDCM (AV ± SD)	-3.85 ± 0.15	-0.55 ± 0.01

AV represents the average of the channel values. *SD* represents the standard deviation of the channel values.

Conclusion

This study allowed a better understanding of the freezing process of processed meat in an industrial freezing tunnel. We found that using temperature data loggers to obtain the experimental freezing and thawing curves was an efficient, reliable and low cost method. Convective heat transfer plays a key role at decreasing freezing times as it was observed for products placed in more external layers.

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