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DETERMINATION OF THAWING TIMES OF LEAN BONELESS BEEF FROZEN AT VARIOUS TEMPERATURES AND THE COMPARISON OF EXPERIMENTAL RESULTS WITH MATHEMATICAL MODELS

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SUMMARY : *In this experiment, lean boneless beef samples in different thickness (20, 30 and 40 mm) were frozen at -18, -20, -22 and -24 °C until their internal temperature reached -12 °C and then they were thawed at 10 or 22 °C in order to determine their thawing times of the samples were compared to the mathematical prediction equations of thawing times which have been proposed by some researchers, to determine the best mathematical prediction model for these experimental conditions. The results of this research indicated that freezing temperatures showed no effects on thawing times. With the 40 mm thick samples, the mathematical prediction equation of thawing times, suggested by Cleland and Earle (1982) and Cleland et al. (1986 a) showed good agreement with the experimental data at both thawing temperatures, while Pham's (1986) mathematical prediction model were in reasonable agreement with the experimental data of 20 mm thick samples.*

Keywords : Lean beef, thawing time, thawing time estimation.

INTRODUCTION

Freezing, today, is one of the most common meat preservation methods. In Turkey, this technique is also frequently used to preserve carcasses or chunked carcass parts (Gökalp, 1989). Frozen meat and meat products normally have to be thawed before further processing and consuming. Thawing speed and consequently

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time required to thaw frozen food is influenced by several factors such as size, shape and physico-chemical attributes of the frozen food, design and thermal assets of packagin material, temperature differences between frozen food and thawing environment and energy transfer techniques utilized (Ilıcalı, 1989). Determination of thawing time is important in order to maintain the quality of the product and the optimum use of thawing space, as well as effective administration of the institution using the thawed products (Cleland et al., 1986 a). In order to produce further processed meat products or to consume frozen meats, it is often thawed under several conditions such as 23 °C or room temperature in areas which have appropriate air circulation (Succar, 1977; Noniuo and Hayakawa, 1986) or in water having a temperature of 35 to 45°C (Cleland et al., 1986 a) or under refrigeration. However, to maintain the quality of a meat product, the temperature of thawing should be approximately 10 °C (a refrigeration room) or the second choice would be ambient or room temperature (Gökalp, 1989).

Mascheroni and Calvelo (1982) reported that the first mathematical prediction equation of freezing and thawing times of food products was prepared by Plank (1913), then Plank revised his origanal model by considering the alteration of initial and ultimate temperatures of products in 1941 and 1963. The principal new experimental modifications on Plank's (1913) model have been suggested by James and Creed (1981), Cleland and Earle (1982), Cleland et al. (1986 b), Pham (1986) and Ilıcalı (1989). Additionally, Bonacina et al. (1974), Schwartzberg (1978) and Talmon and Davis (1981) have prepared some alternative numerical methods in order to determine the thawing times of foods. To determine the thawing times of meat which was frozen as carcass or tissue having a rectangular shape package, then "finite differences method" has also been suggested by Cleland et al. (1984), Suziki and Singh (1985) and Mannapperuma and Singh (1989).

Bakal and Hayakawa (1973), James and Creed (1981) and Cleland et al. (1986 b), have reviewed the mathematical models and methods used previously and they noted that experimental methods under specified conditions of interest could present more accurate results than the theoretical models and this is the ultimate purpose of this research.

The objective of this research work was to experimentally determine the thawing times under different experimental conditions and to comapare these results with models developed by other researchres. Therefore, the primary objective of this work was to determine the thawing times of frozen stored, lean, boneless beef in the

Shape of an infinite slab which represents frozen meat product condition of several countries including Turkey, and to determine the best mathematical prediction equation for this type of meat product by comparing the thawing times observed under these conditions with the different suggested mathematical models.

The other aims of this work were to determine (1) if thawing times were different for meats frozen at different temperatures, (2) since meat quality is superior at a thawing temperature of 10 °C, one of the additional objective was to determine the real time differences between 10 and 22 °C thawing temperatures of frozen meat and this time factor is important for the meat industry in Turkey, (3) the thawing times of meats frozen at higher temperatures will be identified, and subsequent research will evaluate meat frozen at lower temperatures in order to compare their quality differences.

MATERIAL AND METHODS

Materials

In this research, semitendinosus muscle section from young beef carcasses held at 4 °C for 24 h after slaughtering were used as meat samples. To freeze the meat samples, a freezer which has a ± 0.5 °C sensitivity was employed. Also, during freezing, polyethylene bags having about 0.302 W/m °C thermal conductivity were utilized to prevent moisture loss from the surface of the meat by sublimation (De Michelis and Calvelo, 1982). Temperatures were measured by using constantan-copper thermocouples having 0.2 mm diameter and they were connected to a digital scale milivoltmeter which had a ± 0.01 mV sensitivity and the mV measurements were transformed to degrees celsius by using an appropriate table (anon., 1976).

To prepare a cell in which the samples were placed in order to determine thawing time, polystyrene insulation material which was 5 cm thick and had about 0.036 W/m °C thermal conductivity was used (Kakaç, 1982).

Also, to determine the surface heat transfer coefficient (h) and to construct an appropriate thawing model for the thawing process, an aluminum block with 99.9 % purity, 2707 kg/m^3 density and about 204 W/m°C thermal conductivity was used as a standard in this experiment. The thermal caharcteristics of meat which are used to peridict thawing times with mathematical equations are as fallow (Mascheroni and Calvelo, 1982);

C_{p1} = Specific heat above freezing of meat samples (3506j/kg= $3.65x10^6$j/m^3).

C_{ps} = Specific heat below freezing of meat samples (1825j/kg = $1.90x10^6 j/m^3$)

k_l = Thermal conductivity above freezing of meat samples (0.51W/m°C).

k_s = Thermal conductivity below freezing of meat samples (1.55W/m°C).

T_e = Freezing point of meat samples (-1.8 °C).

T_i = Initial temperature of thawed meat samples (-12 °C)

T_r = Final center temperature (0 °C)

L_H = Latent heat of meat samples ($2.09x10^8 j/m^3$)

Methods

Determination of Surface Heat Transfer Coefficients for Thawed Meat Samples

An aluminum block model as suggested by Hung and Thompson (1983) was prepared and four of its sides were insulated with 5 cm thick polystyrene to allow only the top and bottom to be the primary heat transfer surfaces. As with the meat the aluminum block was covered with a polyethylene film. The model prepared from aluminum (Fig. 1) was also chilled to -12 °C and then subjected to heating temperatures until it reached 0 °C. The meat samples were treated in the same manner. The heating times obtained versus In $\{(T_i - T_T) / (T - T_T)\}$ dimensionless temperature were plotted (Fig. 2) and the slope (m) was calculated by regression analysis. The h values were calculated by inserting the slope values in to the Hung and Thompson's (1983) equation.

$$h = -\frac{\rho . V . Cp . m}{A} \quad (1)$$

h = Surface heat transfer coefficient (W/m^2 °C) W = Energy exchange between the system and its surroundigns (Watt = Joule/second).

ρ = Density (kg/m^3)

V = Volume (m^3)

C_p= Specific heat (j/kg °C)

m = Slope of the curve

A = Surface area (m^2)

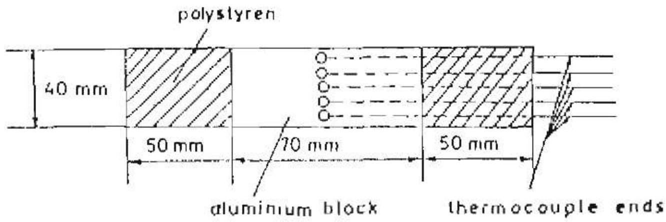

Figure 1. Aluminum model prepared as stated by Hung and Tompson (1983) and the placement of the thermocouple ends.

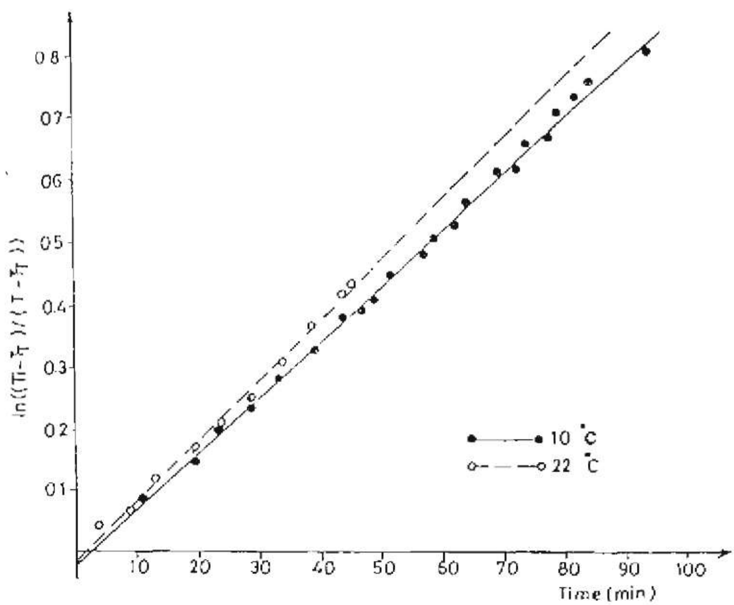

Figure 2. Relationship between time and dimensionless heat exchange of aluminum model at 10 and 22 °C heating environment.

T : Temperature in any given moment

T_T: Heating temperature of environment

T_i : Initial temperature of aluminum block (°C).

To illustrate the influence of different experimental conditions, h values of 13.2 W/m^2 °C and 24.5 W/m^2°C were obtained from meat samples thawed at 10 and 22 °C, respectively Cleland et al. (1968 a).

Preparing of Meat Models for the Freezing and Thawing Experiments

The semitendinosus muscles from the young bull carcasses were dissected to the approximate size and shape in all treatments. Total moisture of the samples was determined according to Ockerman (1976) and fat content was determined by the ether extraction method described by Gökalp (1986). After determining the moisture and fat content of the meat, the muscle was uniformly cut into pieces of 20, 30 and 40 mm thickness with a 7 cm width and a 8.6 cm length, by using a sharp knife on a cutting board. Then the meat models as described by Hung and Thompson (1983) were prepared by covering the four sides of the meat section with a single layer of polystyrene having a 5 cm thickness in order to allow the major heat transfer to occur only from the top and bottom surfaces (Fig. 3).

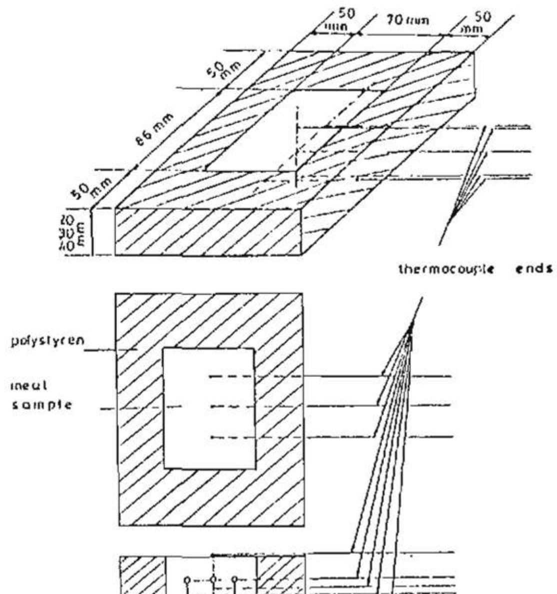

Figure 3. Experimental meat sample prepared as stated by Hung and Thompson (1983) and the placement of the Thermocouple ends.

The temperature measurements of the meat models prepared earlier were recorded by placing 5 individual constantan-copper thermocouples with 3 thermocouples placed in the center horizontal plane (2 cm apart) in the meat section and one each was placed on the upper and lower tissue surfaces. Temperatures were measured with a milivoltmeter as mV reading. The meat model samples as described by Hung and Thompson (1983) were frozen at -18, -20, -22 and -24 °C until their internal temperature reached -12 °C and then these meat samples were thawed at 10 °C (in a cooler) or 22 °C (in a lab.) without forced air circulation. During the thawing process mV readings were recorded at 5 min intervals until the samples' internal temperature reached 0 °C.

Mathematical Equations for Thawing Time Predictions

In order to evaluate the mathematical prediction equations of thawing times of meat, 4 different mathematical models which were developed by various researchers or teams were evaluated in the present research. For this calculation, Plank's (1941) prediction equation as given by Pham (1984) was evaluated as well as equations suggested by Cleland Earle (1982), Cleland et al. (1986 a) and Pham (1986).

RESULTS AND DISCUSSION

Result Of Surface Heat Transfer Coefficient (h)

As described in the method section, serial calculations were done with the aluminum block in order to obtain the h value. The values of 15.09 W/m^2 °C and 15.58 W/m^2 °C for h were attaired for the 10 and 22 °C thawing temperatures, respectively. Then, these h values were inserted into the prediction equations used to calculate thawing times.

Experimental Results Of Thawing Times

For the meat samples frozen at -18, -20, -22 and -24 and with 20, 30, 40 mm thickness, the thawing times found experimentally at 10 and 22 °C thawing temperatures are presented in Table 1. As mentioned previously, the thawing at 10 °C was in a cold room while the 22 °C thawing process was in a regular lab envirronment having no air circulation, neglecting natural convection. Relative Humidity was approximately 38 % in the area of the 10 °C temperature while it was 50 % in the 22 °C thawing temperature vicinity. In order to demonstrate the influence of the meat thickness and different thawing temperatures, the thawing times are graphed in Figure

4 and 5. As can be seen in the figures, different thawing slopes were attained for the meat samples, of the same thickness at 10 and 22 °C thawing temperatures. Additionally, as shown in Table 1, different freezing temperatures of the meat samples did not have any effect on the thawing times. However, the literature (Fennoma and Powrie, 1964; Cemeroğlu, 1986; Gökalp, 1989) suggested that lower freezing temperatures cause small, smooth and uniform ice carystals in the tissue while higher freezing temperatures results in frozen food products with larger and more dispersed ice crystals. However, in this experiment, the freezing temperatures did not have any effect on thawing times obtained probably because there were not large differences between the various freezing temperatures.

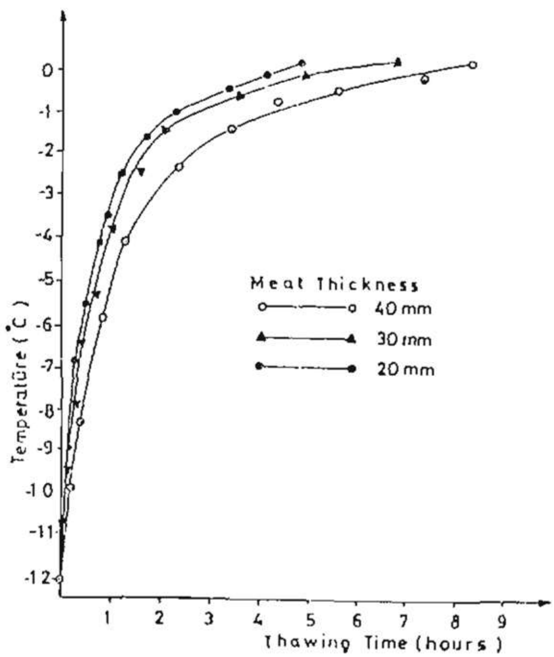

Figure 4. Thawing curve of the meat samples of different thickness, thawed at 10 °C environment.

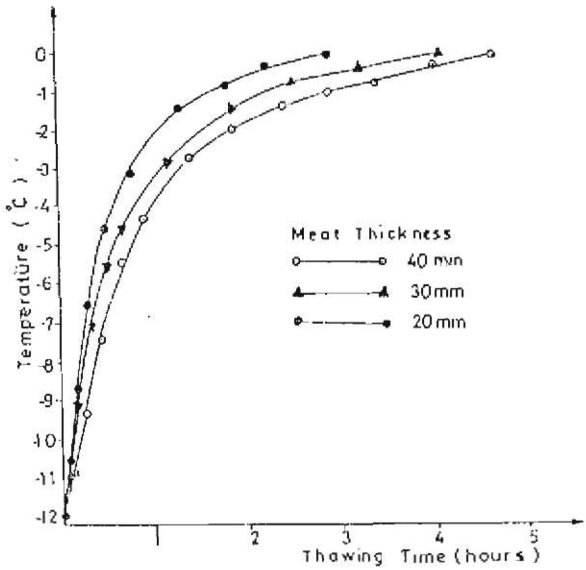

Figure 5. Thawing curve of the meat samples of different thickness, thawed at 22 °
environment.

Thawing Times Calculated by Mathematical Equations

The comparison of results of the thawing times calculated with mathematic models and observed experimentally are presented in Table 2. Calculated thawin times, resulted by using the equations, were found to be shorter than th experimentally determined times in this experiment. For the thick meat cut experimentally determined times were closer to the values obtained using th mathematical models and differences between experimental and mathematical mode were noticeable reduced. This fact can be observed in Table 2 where almost all of th mathematical prediction equation results for the thawing times were in reasonabl agreement with the results of the experiment when the meat slab thickness increase from 20 to 30 mm. Especially, at 10 °C thawing temperature with 30 mm mea thickness, all of the model aquations, except Plank's (1941) equation (Pham, 1984 resulted in a 90 % or higher agreement with the experimental measurements fo thawing times. However, at 40 mm meat thickness and 10 and 22 °C thawin temperatures, the equations suggested by Cleland and Earle (1982) and Cleland et a (1986a) resulted in thawing times with 10 % or less inaccuracy (that is, they we

Table 1. Experimental Conditions For Thawing and Thawing Times Determined Experimentally.

Expmt* #	T_f (°C)	L (mm)	T_T (°C)	T_i (°C)	h (W/m^2 °C)	M_a (%)	t_{DC} (hour)	Average t_{DC} (hr)	SD
1	-18	20	22	-12	15.58	74.48	2.86		
2	-20	20	22	-12	15.58	76.86	2.91		
3	-22	20	22	-12	15.58	75.96	2.80	2.870	0.0523
4	-24	20	22	-12	15.58	76.93	2.91		
5	-18	20	10	-12	15.09	75.53	4.90		
6	-20	20	10	-12	15.09	77.10	4.73		
7	-22	20	10	-12	15.09	75.03	4.70	4.807	0.1075
8	-24	20	10	-12	15.09	77.42	4.90		
9	-18	30	22	-12	15.58	76.83	4.16		
10	-20	30	22	-12	15.58	76.13	4.35		
11	-22	30	22	-12	15.58	76.28	3.76	4.057	0.2543
12	-24	30	22	-12	15.58	77.21	3.96		
13	-18	30	10	-12	15.09	76.27	6.83		
14	-20	30	10	-12	15.09	76.60	6.78		
15	-22	30	10	-12	15.09	75.11	6.46	6.692	0.1639
16	-24	30	10	-12	15.09	77.09	6.70		
17	-18	40	22	-12	15.58	74.93	4.66		
18	-20	40	22	-12	15.58	75.94	4.71		
19	-22	40	22	-12	15.58	76.18	-	4.593	0.1607
20	-24	40	22	-12	15.58	76.49	4.41		
21	-18	40	10	-12	15.09	75.30	8.36		
22	-20	40	10	-12	15.09	75.18	7.90		
23	-22	40	10	-12	15.09	76.71	8.03	8.087	0.1945
24	-24	40	10	-12	15.09	75.10	8.06		

* Experiment number SD : Standard Deviation

T_f : Freezing temperature (°C).

L : Thickness of the meat slab (mm).

T_T : Thawing environment air temperature (°C).

T_i : Initial temperature of thawed meat samples (°C).

h : Surface heat transfer coefficient (W/m^2°C).

M_a : Percentage of water in the meat, Mass fraction of water (dimensionless).

t_{DC} : Experimental thawing times (hours).

better for thicker meat samples). At the 20 and 30 mm meat thickness and at both thawing temperatures especially at 10 °C, Pham's (1986) mathematical prediction equation resulted in the best relationship with the experimentally determined thawing times.

Under these experimental conditions, the equations suggested by Cleland and Earle (1982) and Cleland et al. (1986a) can be recommended when the meat thickness is large (40 mm) and when the meat is thawed at 10 and 22 °C thawing temperatures, while the equation developed by Pham (1986) can be suggested in order to predict the thawing times of the less thick (20 mm) cuts of meats whick were thawed at 10 °C thawing temperature. For the thawing of 30 mm thick meat samples at 10 and 22 °C, all the experimented equations resulted in similar results and no noticeable variation was determined among them.

Table 2. Percentage differences between experimental thawing times and thawing times calculated by mathematical equations for the different meat samples.

Exp* #	L (mm)	T_T (°C)	Average (t_{DC}hr)	t (hr)	Deviat.** (%)	t_{CE} (hr)	Deviat.** (%)	t_{CC} (hr)	Deviat.** (%)	t_P (hr)	Deviat.** (%)
1-4	20	22	2.870	2.27	-20.90	2.00	-30.31	2.20	-23.34	2.32	-19.16
5-8	20	10	4.807	4.27	-11.17	3.83	-20.32	3.84	-20.11	4.20	-12.62
9-12	30	22	4.057	3.64	-10.27	3.22	-20.63	3.50	-13.73	3.76	-7.32
13-16	30	10	6.692	7.54	12.67	6.07	-9.29	6.10	-8.84	6.71	0.26
17-20	40	22	4.593	5.27	14.73	4.58	-0.28	4.93	7.33	5.40	17.57
21-24	40	10	8.087	10.66	31.81	8.57	5.97	8.58	6.09	9.48	17.22

* Experiment number.
** Deviation from experimental results.

L : Thickness of the meat slab (mm).
T_T : Thawing environment temperature (°C).
T_{DC} : Experimentally thawing times (hours).
T_{PL} : Thawing times calculated by using Plank (1941) model.
t_{CE} : Thawing times calculated by using Cleland and Earle (1982) model.
t_{CC} : Thawing times calculated by using Cleland et al. (1986a) model.
t_p : Thawing times calculated by using Pham (1986) model.

CONCLUSIONS

The results of the thawing experiment analysis indicated that meat cut thicknesses and thawing temeratures have and significant effect on thawing times.

There were no significant differences determined between the thawing times of the meat samples which were originally frozen at the different freezing temperatures (-18, -20, -22 and -24 °C).

The results indicated that almost all model prediction equations employed for estimating of thawing times in this experiment presented satisfactory results for the 30 mm thick frozen samples. However, the mathematical prediction equation prepared by

Cleland and Earle (1982) and Cleland et al. (1986a) were slightly better for the 40 mm thick samples at both 10 and 22 °C thawing temperatures, while Pham's (1986) mathematical prediction model gave somewhat better results for the 20 mm thick samples at 10 °C thawing temperature.

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REFERENCES

Anonymous, 1976. *Handbook of Chemistry and Physics*. CRC Press, Cleveland, Ohio, (57th. Ed.).

Bakal, A and Hayakawa, K.I., 1973. Heat Transfer During Freezing and Thawing Foods. *Adv. Food Res.*, 20, 217.

Bonacino, C., Comini, G., Fasona, A. and Primicerio, M., 1974. On the Estimation of Thermophysical Properties in Non-linear Heat Conduction Problems. *Int. J. Heat Mass Transfer*, 17, 861.

Cemeroğlu, B., 1986. *Fruit and Vegetable Processing Technology*. Institute of Food Technology (Turkish), No : 6, p. 517, Ankara, Turkey.

Cleland, A.C. and Earle, R.L., 1982. Freezing Times Prediction for Foods - A Simplified procedure. *Int. J. Refrig.*, 5, 134.

Cleland, D.J., Cleland, A.C., Earle, R.L. and Byrne, S.J., 1984. Prediction of Freezing Rates, Thawing or Cooling in Solids of Arbitrary Shape Using the Finite Element Method. *Int. J. Refrig.* 7, 6.

Cleland, D.J., Cleland, A.C., Earle, R.L. and Byrne, S. J., 1986a. Prediction of Thawing Times for Foods of Simple Shape. *Int. J. Refrig.*, 9, 220.

Cleland, D.J., Cleland, A.C. and Earle, R.L., 1986b. Prediction of Freezing and Thawing Times for Foods-a Review. *Int. J. Refrig.*, 9, 182.

De Michelis, A. and Calvelo, A., 1982. Freezing Time Prediction for Brick and Cylindrical-Shaped Foods. *J. Food Sci.*, 48, 909.

Fennoma, O. and Powrie, W.D., 1964. Fundamentals of Low Temperature Food Pereservation. *Adv. Food Res.*, 13, 219.

Gökalp, H.Y., 1986. Turkish Style Fermented Sausage (Soudjouk) Manufactured by Adding Different Starter Cultures and Using Different Ripening Temperatures. Ripening Period, Some Chemical Analysis, pH Vaues, Weight Loss, Color Values and Organoleptic Evaluations. *Fleischwirtsch.*, 66, 573.

Gökalp, H.Y., 1989. *Meat and Fishery Product Technology*. Atatürk Uni., Agricultural College, Food Science and Technology Dept., p. 150, Erzurum, Turkey.

Hung, Y.C. and Thompson, D.R., 1983. Freezing Time Prediction for Slab Shape Foodstuffs by Improved Analytical Method. *J. Food Sci.*, 48, 555.

Ilıcalı, C., (1989). A Simplified Analytical Model for Thawing Time Calculation in Foods. *J. Food Sci.*, 54, 1031.

James, S.J. and Creed, P.G., 1981. Predicting Thawing Time Of Frozen Boneless Beef Blocks. *Die Fleischerei.*, 9, 7.

Kakaç, S., 1982. *Introduction to Heat Transfer. I. Heat Transfer*. M.E.T.U. Engineering School, No : 52, 2nd. Ed., p. 315, Ankara, Turkey.

Mannapperuma, J.D. and Singh, R.P., 1989. A Computer-Aided Method for the Prediction of Properties and Freezing/Thawing Times of Foods. *J. Food Engin.*, 9, 275.

Mascheroni, R.H. and Calvelo, A., 1982. A Simplified model for Freezing time Calculations in Foods. *J. Food Sci.*, 47, 1201.

Nonino, C. and Hayakawa, K. I., 1986. Thawing Time of Frozen Food of a Rectangular of Finitely Cylindrical Shape. *J. Food Sci.*, 51, 116.

Ockerman, H.W., 1976. *Quality Control of Post Mortem Muscle Tissue*. Vol. 1, p. 230. The Ohio State University, Columbus, Oh., USA.

Pham, Q.T., 1984. An Extension to Plank's Equation for Predicting Freezing Time of Foodstuffs of Simple Shapes. *Int. J. Refrig.*, 7, 377.

Pham, Q.T., 1986. Simplified Equation for Predicting the Freezing Time of Foodstuffs. *J. Food Technol.*, 21, 209.

Schwarztberg, H.G., 1978. Effective Heat Capacities for the Freezing and Thawing of Food. *J. Food Sci.*, 41, 152.

Succar, J., 1977. Air Thawing of Beef Quarters. *J. Food Agric.*, 20, 1109.

Suziki, K. and Singh, R.P., 1985. A Computer-Aided Calculation of Temperature History During Thawing of Foods. *Trans. ASAE.*, 28, 1330.

Talmon, V. and Davis, H.T., 1981. Analysis of Propagation of Freezing and Thawing Fronts. *J. Food Sci.*, 46, 1478.