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RESEARCH ARTICLE

COOLING AND FREEZING TIME OF BEEF BASED THERMAL AND PHYSICAL PROPERTIES AS FUNCTION OF MOISTURE CONTENT

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ABSTRACT

One of the most important value that determine the quality of beef at refrigeration treatment is duration of cooling and freezing process which should be determined in advance. Mean while duration depends upon more than one factor such as initial moisture content of beef, dimention, temperature and velocity of cooling air. The objective of this paper is to study the effect of mentioned above factors on duration of one stage freezing process. This study has been based on various analyies of calculation results using a mathematical model. A computer program was developed to simulate the appropriate equations that calculate the cooling and freezing time at different conditions of moisture content of beef, temperature and velocity of cooling air. Expression the thermal and physical properties of beef as a function of its moisture content, the calculation method of refrigeration treatment duration have been given. The flow chart of the computer program has been represented. The results obtained indicate that duration of one stage freezing process could be decreased from 21 hours to 19 hours as a result of decreasing in temperature of cooling air from -25C° to -30C° at the same conditions of cooling air velocity of 4m/s, initial moisture content of beef about 0.75, beef initial temperature of 35C°, final temperature of center beef of -8C° and beef thickness of 0.20 m. In addition to that, it was found that increasing of cooling air velocity from 4 to 5m/s will cause more decreasing in duration of one stage freezing process from 19 hours to 16.5 hours at the same conditions.

INTRODUCTION

To retain the quality of beef, freezing should be accomplished quickly. In addition to that rapidly frozen foods have much longer storage life. So quickly freezing of foods for long-term storage is attaining greater importance. One of the products that preserved by quick freezing is beef. quickly freezing of beef could be realized by one stage freezing method immediately after butchering using forced cooling air as secondary refrigerant with temperature range of –20 C° to -40c° and velocity not less than 3m/s. during the process of one stage freezing, the product temperature drops down fast to the freezing temperature. Thereafter the latent heat of the water content in the products has to be removed and during this process, the temperature does not fall. As the major portion of the water content in the product has been frozed, the remaining water will have a high concentration of salts, and so it can freeze only at a much lower temperature. Once this stage is reached, the temperature falls down further to the required level. For quick freezing it is important to obtain good heat transfer coefficient on the surface of the foods (beef) which depends upon the size of beef and the conditions of cooling air such as temperature and velocity.

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In order to increase the efficiency of one stage freezing process, its duration should be under study for the given conditions. This can be achieved either by experiment or by computer- based simulation. The latter saves time and maney.

Calculation method

Taking into account that the moisture content of food products is between 0.50 and 0.96, the thermal and physical properties of any food products could be expressed as a function of moisture content (Kauhochvely , 1985) as follows: Specific heat of food products (in this case it is beef) is defined as:

C_{P2} = 2093.4+4186.8 ($W_p - W_h$) for cooling process where ($t_p > t_{cr}$) (1)

C_{P1} = 1465.4+1482.7 ($W_p - W_h$) for freezing process where ($t_p < t_{cr}$) (2)

Conductivity of food products (beef) is expressed as

K_{P2} = 0.29 + 0.604 ($W_p - W_h$) for cooling process where ($t_{pf} > t_{cr}$) (3)

K_{P1} = 0.58 + 1.917 ($W_p - W_h$) for freezing process where ($t_{pf} < t_{cr}$) (4)

Density of food products (beef) is calculated as

$\rho_p = 1005 + 208.3\,(W_p - W_h)$ for ($t_{pf} > t_{cr}$) and ($t_{pf} < t_{cr}$) (5)

where:

W_p - initial moisture content of food product (beef), %.
W_h - the least moisture content of food products =50%.
t_{pf} - finality temperature of food product (beef).
t_{cr} - crystallizing temperature of food products (beef) is considered to be -1.45c^o for all food products (Kauhochvely, 1985). Once the thermal and physical properties of beef are determined then the dimensionless numbers may be expressed as follows:

Biot number is calculated as:

$Bi_2 = h_{crv} R_p / K_{P2}$ (6)

Where:

R_p designates a characteristic dmension of beef piece which could be defined as:
$R_p = L/2$ where L is the diameter or thickness of beef piece.
h_{crv} - is the heat transfer coefficient which considers the heat transfer by convection radiation and vaporization of moisture which could be expressed as follows:

$h_{crv} = h_c + h_r + h_v$ (7)

where:
h_r - heat transfer coefficient for radiation is considered, (h_r=1w/(m^2 c^o)).
h_v - heat transfer coefficient for vaporization is considered, (h_v = 0.5 w/(m^2 c^o)).
h_c - Heat transfer coefficient for convection is defined as:
$h_c = Nu\, K_a / L$ (8)

where:

K_a - conductivity of air may be expressed as a function of cooling air temperature as:
$K_a = (2.4362 + t_a\, 0.0079)\, 10^{-2}$ (9)

Nu - nusselt number could be determined using the following correlation suggested for forced convection heat transfer from the product (meet):

$Nu = 0.17\, Re^{0.7}$ (10)

Where:
Re - reynolds number expressed as:

$Re = V_a L / \gamma_a$ (11)

Where:
V_a - velocity of cooling air
γ_a - kinematic viscosity of air is given at cooling air temperature (t_a) as:

$\gamma_a = (13.3844 + t_a\, 0.0857)\, 10^{-6}$ (12)

The correlation suggested for Fourier number is given as [2]:

$Fo_2 = 0.56\, [(Bi_2 + 3)/(3\, Bi_2)\, \ln((t_{pi} - t_a)/(t_{cr} - t_a)) + Fo^o]$ (13)

Where
t_{pi} - initial temperature of beef
t_a - temperature of cooling air
Fo^o is fourier number that characterizes duration at which the center temperature of beef piece stays constant.

$Fo^o = (1/12) + (1/(3\, Bi_2))\, (2/(3\, Bi_2^2))\, \ln(1 + (0.5\, Bi_2))$ (14)

Fourier number is expressed as:

$Fo_2 = (\tau_c\, a_{p2}) / R_p^2$ (15)

where
a_{p2} is thermal diffusivity of beef defined as:
$a_{p2} = K_{P2} / (C_{P2}\, \rho_p)$ (16)

Equations (1,3,5) are used to determine the thermal and physical properties of beef for cooling process. Once these are found then fourier number is determined according to equation (6), and (13). Then cooling time of beef (duration) τ_{ch} in hours is found from Eq. (15),as follows:

Cooling time of beef (from initial temperature to crystallizing temperature of beef) in seconds is found from the equation below.

$\tau_c = (Fo_2\, R_p^2) / a_{p2}$ (17)

Thus, cooling time in hours will be as follow:

$\tau_{ch} = (Fo_2\, R_p^2) / (a_{p2}\, 60\, 60)$ (18)

Since the cooling time in seconds has been determined, then heat flow rate rejected from beef during the cooling process could be be determined using the following formula:

$Q_{OC} = (G_p\, C_{P2} / 1000\, (t_{pi} - t_{pf})) / \tau_c$ (19)

Where
G_p is mass of beef, kg

To predict the duration of one stage refrigeration treatment of beef (time of cooling and freezing processes in hours), the following empirical correlation (Malovoy , 1986) is used:

$\tau_{cf\,h} = [((0.027/\ h_{crv})\ (C_{P2}/1000)\ \rho_p L((t_{pi} - t_a)/(t_{cr} - t_a))^{1.5} + (0.025/h_{crv}) + C_w^2\ \rho_p L/(C_{P1}\ 1000)((t_{cr} - t_a)/(t_{pf} - t_a))^{1.09})\ 1000]/(3600)$ (20)

where:

C_w - total specific heat which involves the latent heat of crystallization could be determined as follows:
$C_w = (C_{P1}/1000) + 335.2\ W_p\,(W_{L2} - W_{L1})$ (21)

where:
($W_{L2} - W_{L1}$) - Th difference in percentage of freezed water in product due to the changing in temperature of one centigrade.

$W_{L2} = (1 - (0.27\,((1 - W_p)/W_p)))\,(1 - (t_{cr}/-4))$ (22)
$W_{L1} = (1 - (0.27\,((1 - W_p)/W_p)))\,(1 - (t_{cr}/-3))$

Once duration of one stage refrigeration treatment of beef (time of cooling and freezing process as one stage) is determined, then the heat flow rate from beef is defined as:

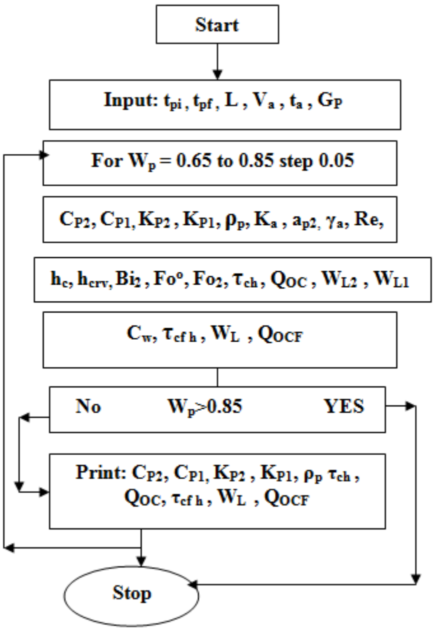
$Q_{OCF} = [G_P\,(C_{P2}/1000)\,(t_{pi} - t_{cr}) + 335.2\, W_p W_L + (C_{P1}/1000)\,(t_{cr} - t_{pf})] / (\tau_{cf\,h}\, 3600)$ (23)

Where:
W_L - the proportion of freezed water in product (meet) at the given final temperature (t_{pf}) which is expressed as:

$W_L = (1 - (0.27\,((1 - W_p)/W_p)))\,(1 - (t_{cr}/t_{pf}))$ (24)

Simulation procedure

Based on the given calculation method, a computer program have been created and the following flow chart illustrates the steps of this program.



RESULTS AND DISCUSSION

The simulation model presented in this study is based on (-1.45c°) crystallizing temperature of food products, (35c°) initial temperature of food production (beef), (-8c°) finality temperature of product (beef) center,(4 m/s) velocity of cooling air.

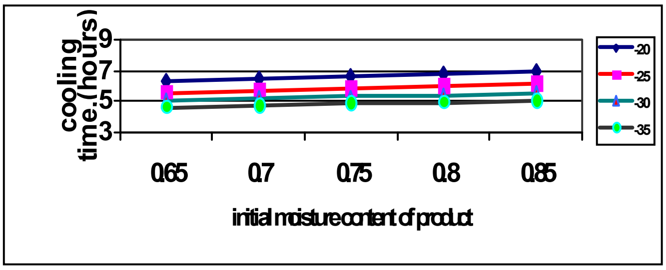


Fig 1.Time of cooling as a function of moisture content and cooling air temperature

Using the developed model , and giving different cooling air temperature and moisture content of food product (beef), the time of cooling(τ_{ch}) required to decrease the temperature of product from 35c° to -1.45c°, the duration of one stage freezing ($\tau_{cf\,h}$) have been under study and illustrated in figure (1) and (2) respectively. The effect of cooling air velocity on duration of one stage freezing ($\tau_{cf\,h}$) at the condition of moisture content of 0.75 is defined and illustrated in figure (3).

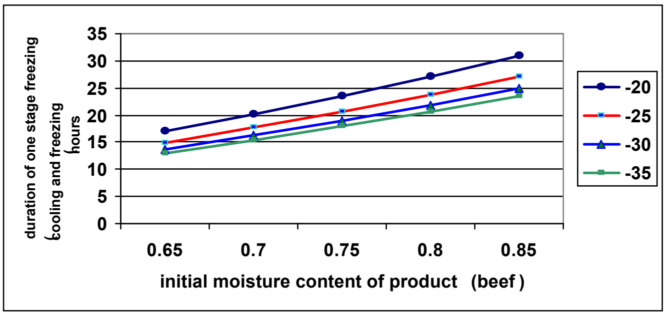


Fig 2. Duration of one stage freezing as a function of moisture content of product (beef) and cooling air temperature

In addition to that the effect of moisture content and temperature of beef center on the proportion of freezed water (W_L) has been determined and shown in figure (4). Taking in to account that moisture content of food products has a great bearing upon their thermal and physical properties (Holman, 2002) accordingly they have been calculated as a function of moisture content and shown in table (1). The effects of temperature and velocity of cooling air, dimention of beef on the heat transfer coefficient and duration of one stage freezing

Table 1. Thermal and physical properties of food products (beef) as a function of moisture content.

W_p	Cooling process ($t_{pf} > t_{cr}$)				Freezing process ($t_{pf} < t_{cr}$)			
	C_{P2}	K_{P2}	ρ_p	a_{p2}	C_{P1}	K_{P1}	ρ_p	a_{p1}
0.65	2721	0.38	1036	$1.35 * 10^{-7}$	1687	0.87	1036	$4.96*10^{-7}$
0.70	2930	0.41	1047	$1.34 * 10^{-7}$	1762	0.96	1047	$5.22*10^{-7}$
0.75	3140	0.44	1057	$1.33 * 10^{-7}$	1836	1.06	1057	$5.46*10^{-7}$
0.80	3349	0.47	1067	$1.32 * 10^{-7}$	1910	1.15	1067	$5.66*10^{-7}$
0.85	3559	0.50	1077	$1.31 * 10^{-7}$	1984	1.25	1077	$5.85*10^{-7}$

Table 2. The effect of beef thickness or diamerer and cooling air velocity and its temperature on the heat flow coefficient and duration of one stage freezing.

	t_{pi}=35c°, Nu	t_{pf}= - 8c°, h_{crv} w/m2c°	W_p= 0.75, $\tau_{cf\,h}$, hours
L=0.2m, V_a= 4m/s	423	48.92	20.67
L=0.1m, V_a= 4m/s	268	59.88	8.44
L=0.1m, V_a =8m/s	423	96.36	5.25
L=0.1m, V_a =8m/s, t_a= -35c°	447	98.22	4.5

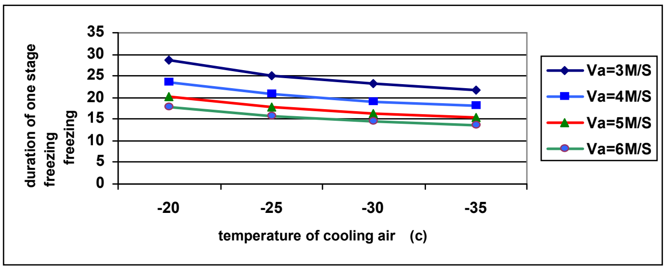


Fig 3. The effect of cooling air velocity on the duration of one stage freezing

are defined and and illustrated in table(2). As well the effect of beef diameter or thickness (L) and heat transfer coefficient on duration of one stage freezing process was under study and

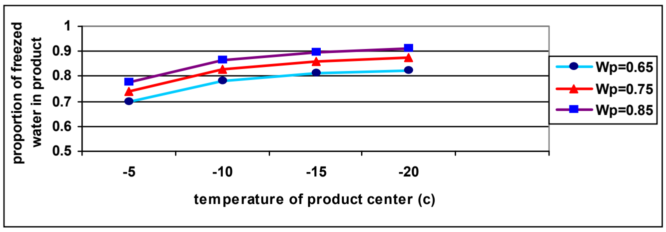


Fig 4. The effect of moisture content and temperature of beef center on the proportion of freezed water

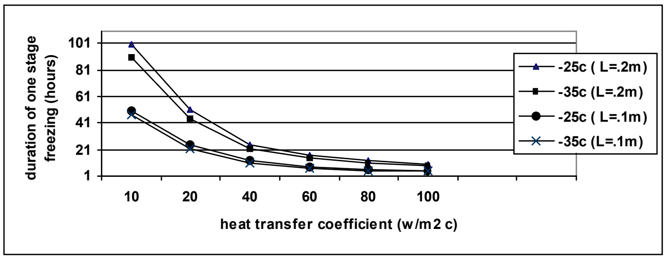


Fig 5. Duration of one stage freezing as a function of heat transfer coefficient (hcrv) and diameter of beef (L) at different conditions of cooling air temperature

demonstrated in figure (5). It is clearly demonstrated that duration of cooling process and duration of one stage freezing could be reduced about (22%) by decreasing the cooling air temperature from -20c^o to -35c^o as shown in Fig (1) and (2). Taking in to account that velocity of cooling air is acceptible at the range of (3 to 6 m/s) for one stage feezing, it is possible to get (23%) more reduction in duration of one stage freezing process by increasing the velocity of cooling air from 4 to 6 m/s as demonstrated in fig (3). From figure (4) it is seem that intensity of moisture crystallization in beef is very high at the beginning of freezing process. The proportion of freezed moisture is 0.02 (1/c^o) at the range of center beef temperature of (-5c^o to -10c^o), Meanwhile it is 0.004 (1/c^o) at the range of (-15c^o to -20c^o). In addition to that it is seem that the initial moisture content effects the intensity of moisture freezing, where the product with high initial moisture content connected with high intensity of freezing specially at the beginning of one stage freezing process (Hruby,1990). Reduction the diameter or thickness of beef from 0.2 to 0.1m causes reduction in duration of one stage feezing of (50%) as demonstrated in fig 5. as well, increasing in heat transfer coefficient from 10 to 100 (W/m2 c^o) causes more decreasing in duration of one stage freezing of (89%) . the initial moisture content of food product seems to have some influence on the thermal diffusivity of product as shown in tab1.The greater moisture content the lower thermal diffusivity of product at ($t_p > t_{cr}$) and reverse at ($t_p < t_{cr}$).

Conclusion

The outcome of this study suggests the following conclusion:

1. The thermal and physical properties of any food products could be dermined as a function of their moisture content instead of structure as a whole. this method will be greatly useful for simulation procedure and engineering calculation at refrigerated treatment of food products.
2. The developed model and simulation method is flexible, hence the can be used as diagnostic tool to investigate the one stage freezing process of beef at different dimensions of beef, temperature and velocity of cooling air. Such investigations increase the efficiency of one stage freezing by selection the optimum values of heat transfer coefficient according to the temperature and velocity of cooling air, as well as dimension of beef where duration could be the least.
3. It was found that 88% of reduction in duration of one stage freezing of beef could be achieved as a result of increasing in heat transfer coefficient from 10 to 60 w/m2c.
4. Duration of one stage freezing is reduced about 78% (from 20.67 to 8.44 hours) as a result of increasing in heat transfer coefficient of 50% (from 48.9 to 98.2 w/m2c). This effect could be achieved by increasing the cooling air velocity from 4 to 8m/s, decreasing the cooling air temperature from -25c to -35c^o and reduction the thickness or diameter of beef from 0.2 to 0.1m. Where 11% of 50% increasing in heat transfer coefficient, (59% of 78% reduction in duration of one stage freezing process) are due to reduction in thickness or diameter of beef (from 0.2 to 0.1m). 37% of 50% increasing in heat transfer coefficient, (15% of 78% reduction in duration of one stage freezing process) are due to increasing in cooling air velocity (from 4 to 8m/s) and 2% of 50% increasing in heat transfer coefficient, (4% of 78% reduction in duration of one stage freezing process) are due to decreasing in cooling air temperature (from –25c^o to –35c^o).

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