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The Processing Technology of Soy Protein Meat Analog Using Twin-Screw Extruder

– Heat Transfer Analysis of Cooling Die –

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Abstract: Soy protein meat analog was produced using a twin-screw extruder attached with a cooling die. Heat transfer analysis was performed for cooling dies with various die sizes at the four different moisture contents of feed during extrusion process. The experimental design consisted of two cooling die widths (30 and 60 mm), three cooling die lengths (100, 200, and 300 mm), four product moisture contents (71.2, 67.0, 61.6 and 55.8%), and water and water plus ethylene glycol as cooling material. When water was used as cooling medium, the values of equivalent overall heat transfer coefficient (U_e) for each die width of 30 and 60 mm were in the range of 187.0 – 341.4 and 358.5 – 191.6 W/m^2℃ depending on the size of die length. Convective heat transfer coefficients between cooling water and inside die wall of cooling channel (h_c) for both die widths of 30 and 60 mm were 588.5, 416.1, and 339.8 W/m^2℃ for each die length of 100, 200, and 300 mm. Convective heat transfer coefficients between product and inside die wall of product channel (h_p) for each die width of 30 and 60 mm were in the range of 434.6 – 888.1 W/m^2℃ and 460.7 – 1014.5 W/m^2℃ depending on the size of die length. When water plus ethylene glycol was used as cooling medium, the values of U_e were in the range of 143.9 – 319.6 W/m^2℃ and 177.8 – 332.7 W/m^2℃ for each die width of 30 and 60 mm depending on the size of die length.

Keywords: Heat Transfer, Meat Analog, Twin-Screw Extrusion, Cooling Die

Introduction

Extrusion cooking has been used for processing many kinds of food products such as ready-to-eat cereals, various snacks, confectionery products, texturized products from vegetable proteins, dry or semimoist pet foods, etc. Twin-screw extruders can effectively texturize and shape a wide range of ingredients in a continuous operation. In recent years, they have been used to produce fibrous soy protein meat analog under high moisture (>50%) extrusion conditions. A twin-screw extruder has many advantages for food extrusion due to its characteristics of the screw (Harper, 1989). Its greater conveying angle and self-wiping feature make it possible to handle various ingredients. It also eliminates or minimizes pressure and leakage flows by virtue of the direction of screw rotation, screw shape, screw configuration, and relative position of screw sections. These characteristics of the twin-screw extruder allow processing of high-moisture extrusion with improved texture and offer the possibility of taste modification (Noguchi, 1989).

Soy protein products such as meat analog could either be texturized by twin-screw extruders at high moisture conditions above 50% (Noguchi, 1989; Cheftel et al., 1992; Thiebaud et al., 1996; Lin et al., 2000; Lin et al., 2002) or by single-screw extruders at moisture conditions below 35%. Texturized protein products produced at low moisture contents by single-screw extruders have an expanded sponge-like structure. These products need to be rehydrated with water or flavored liquids. Their uses as a meat alternative are very limited due to the time required for preparation and the lack of fibrous, meat-like appearance. Extrusion cooking by a twin-screw extruder at high moisture levels prevents expansion of products, reduces viscous dissipation of energy and is capable of producing fibrous meat analog with improved texture.

Production of texturized soy protein products requires the selection and control of extrusion variables such as extruder barrel temperature, feed rate, screw speed, die cooling, etc., at suitable levels. Essentially three steps for soy protein texturization are: (1) melting of the protein constituents inside the extruder as a result of high shear and temperature; (2) steady pumping of the food melt from the extruder into

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the die; and (3) development of a laminar flow in the cooling die to initiate fiber formation (Cheftel et al., 1992).

Cooling die is a major component of extruder set-up, which is responsible for the final shape and texture of extruded products such as meat analog. It is attached at the extruder outlet with circulation of cooling medium in the die jacket. A long cooling die is often used at the end of the twin-screw extruder to control the product temperature and to facilitate the texturization or fiber formation of final products. An important role of cooling die is the dissipation of the thermal and mechanical energy accumulated in the food mix with increasing the viscosity and reducing fluidity of it, therefore maintaining necessary pressure and temperature before the die and preventing steam flash at the die outlet. Cooling of the protein dough inside the die allows the condensation of steam within the product and the formation of longitudinally oriented bubbles give the resulting product the typical layered characteristic of meat (Harper, 1981). The magnitude of heat transfer coefficient in the cooling die will influence the die design for the process scale-up. However, the study of heat transfer analysis for the cooling die has not been carried out. The objectives of this study were to estimate the equivalent overall heat transfer coefficient (U_e) and convective heat transfer coefficient for cooling die with various sizes of width and length.

Materials and Methods

1. Materials

Soy protein isolate (Pro Fam 974) was obtained from ADM (Decatur, IL, USA) and unmodified wheat starch (Midsol 50) and wheat gluten were purchased from Midwest Grain Products (Atchison, KS, USA). Soy protein isolate and wheat gluten were blended in 60:40 ratio with addition of wheat starch (5% of protein blend) using an 18.9 L Hobart Mixer (Model A-200-F, Hobart Corp., Troy, OH, USA) for 10 min to ensure the uniformity of the feed material.

2. Sample Preparation and Extrusion

A co-rotating, intermeshing, self-wiping twin-screw extruder (Model MPF 50/25, APV Baker, Grand Rapids, MI, USA) was used for producing meat analog. Only last 750 mm of total barrel length of 1,250 mm was used in this study so that the barrel length to diameter ratio (L/D) was 15:1. The feed rate of dry blend was fixed at approximately 8 kg/h for processes using water as die cooling medium. The screw speed was fixed at 125 rpm for all extrusion processes. Water was injected 0.108 m downstream from the center of the feed port to the extruder and adjusted to give the four levels of moisture content in the feed (71.2, 67.0, 61.6, and 55.8%). The barrel temperature was set at 26, 50, 100, 150 and 170℃ for each five zone.

3. Cooling Die

Cooling dies of various dimensions were fabricated with carbon steel (Figure 1) and attached at the transition block of the extruder end. The product channel of cooling die had 300, 200, and 100 mm length (L) with the section ($W \times H$) of 30 × 10 mm and 60 × 10 mm. Cooling die was composed of upper and lower parts, both had a flow channel for circulating cooling medium. Sectional dimension ($W \times H$) of flow channel for each upper and lower parts of cooling die was 60 × 10 mm with the same length as the product channel. In this study, water and water plus ethylene glycol (1:1 ratio) were used as cooling medium for die cooling. Initial setting temperatures of cooling fluid at cooling system (Model FP50, Julabo USA Inc., Allentown, PA, USA) were 5℃ for water and -10℃ for water plus ethylene glycol. Cooling medium cooled from cooling system was circulated in the die jacket of upper and lower parts of die in opposite direction to the flow of extrusion product. Cooling fluid passing through a PVC hose from cooling system was divided into two flow lines using an adapter for circulating cooling material into upper and lower parts of cooling die. Cooling medium being passed through upper and lower parts of cooling die was combined into one flow line and returned to the cooling system. Ports for inserting the temperature sensors were holed at the inlets and outlets of product channel and cooling fluid channels. Outside surface of cooling die was insulated with glass wool for preventing the heat exchange with environment.

4. Measurement of Temperature and Mass Flow Rate

Twin-screw extruder attached with a cooling die of a specified length and width was operated at a level of feed moisture content according to the experimental design. As operational conditions of extruder were stable and meat

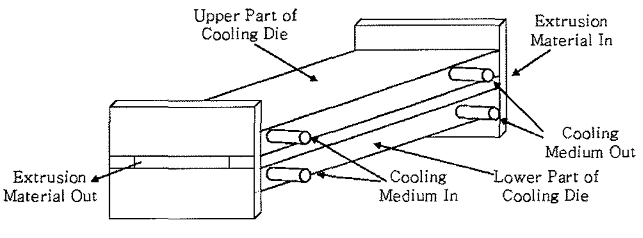

Fig. 1 Cooling die fabricated for extrusion of meat analog.

analog was formed at the steady mass flow rate, the die inlet and outlet temperatures of product and cooling medium were recorded continuously with a data logger and product was collected from the die outlet for one minute. Sample collections of product were carried out four times to obtain an average mass flow rate of product (m_1). After the temperature measurements and product collections were completed at a level of feed moisture content, water injection to extruder was adjusted to another level of moisture condition. As the extruder operation was stable for the meat analog formation, the experimental processes for temperature measurement and product collection were repeated. Operation of extruder was continued until obtaining the experimental data for all four levels of feed moisture conditions.

A data logger attached to an IBM compatible personal computer was used to record the inlet and outlet temperatures (T_{2i}, T_{3i}; T_{2o}, T_{3o}) of cooling medium for upper and lower parts of cooling die. Averaged inlet and outlet temperatures of cooling medium (T_{si}, T_{so}) for upper and lower parts of cooling die were used to calculate the overall heat transfer coefficient. Temperatures of extruded product were also measured by a data logger system at the center and near the bottom wall of each die inlet and outlet of the product channel. These measured temperatures were averaged and used as the die inlet and outlet temperatures of product (T_{1i}, T_{1o}).

Mass flow rate of cooling medium circulating in the die jacket was calculated by measuring the volume of returning cooling medium to cooling system from die outlet for 30 sec. A half amount of calculated value was considered as the mass flow rate of cooling medium ($m_2 = m_3$) circulating each upper and lower part of cooling die. The average mass flow rates of cooling medium for each part of cooling die were 131±5 kg/h and 106±5 kg/h for water and water plus ethylene glycol, respectively.

5. Thermal Properties

Specific heat of cooling water ($c_{p2} = c_{p3}$) was obtained at an average value of die inlet and outlet temperatures of water (Incropera and Dewitt, 2002). Specific heat of water plus ethylene glycol ($c_{p2} = c_{p3}$) was measured by the thermal properties analyzer (KD2, Decagon, USA) around the cooling medium temperature. Specific heat of product (c_{p1}) was calculated from an equation, which is applicable for temperatures above freezing for food as a function of composition as follows (Singh and Heldman, 2001):

$$c_p = 1.424X_c + 1.549X_p + 1.675X_f + 0.837X_a + 4.187X_w \quad (1)$$

where X_c, X_p, X_f, X_a, and X_w present mass fractions of food components with subscripts referring to carbohydrate, protein, fat, ash, and moisture, respectively.

6. Analysis of Overall Heat Transfer Coefficient

In the cooling die, the extrusion melt is in the central channel (channel no. 1) and cooling fluids are in the opposite direction of the two side channels (channels no. 2 and no. 3) as shown in Figure 2. The mass flow rates and specific heats in channels are denoted as m_1, m_2, m_3 and c_{p1}, c_{p2}, c_{p3}, respectively. The inlet and the outlet temperatures of fluid in each channel are denoted as T_{1i}, T_{2i}, T_{3i} and T_{1o}, T_{2o}, T_{3o}. The flow capacity rate, $C = mc_p$, for fluid of each channel no. 1, 2, and 3 is represented as $C_1 = m_1c_{p1}$, $C_2 = m_2c_{p2}$ and $C_3 = m_3c_{p3}$. The length of the cooling die is designated as L. The overall heat transfer coefficient and the transverse heat transfer rate between fluids in channel no. 1 and channel no. 2 are specified as U_{12} and Q_{12}, respectively. The overall heat transfer coefficient and the transverse heat transfer rate between fluids in channel no. 1 and channel no. 3 are specified as U_{13} and Q_{13}. These coefficients are based on reference surface areas, A_{12} and A_{13}, which can be represented by the multiplication of their corresponding reference perimeters, P_{12} and P_{13} (die width, W) with the die length, L.

The cooling die is considered as a special case of the triple channel heat exchanger with the same inlet temperature in channel no. 2 and 3, $T_{2i} = T_{3i}$ and the following relationship is established (Ko and Wedekind, 1996) as

$$\frac{U_{12}P_{12}}{C_2} = \frac{U_{13}P_{13}}{C_3} \quad (2)$$

For a three-channel split-flow heat transfer, the flows in channel no. 2 and 3 can be treated as the split shell flows. Thus, we can define the equivalent overall heat transfer coefficient, U_e, based on an equivalent parameter, P_e as follows:

$$U_eP_e = U_{12}P_{12} + U_{13}P_{13} \quad (3)$$

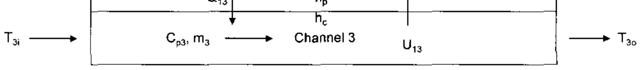

Fig. 2 Schematic representation of heat transfer channels for the cooling die.

The equivalent shell flow temperature, T_s, and the total flow capacity rate, C_s, of the split flow are defined as the following equations:

$$T_s = T_2 = T_3 \tag{4}$$

$$C_s = C_2 + C_3 \tag{5}$$

Based on the heat balance between the cold fluid with temperature T_s, in the split shell flows and the hot fluid with temperature T_1 in central channel, the total heat exchanger heat transfer rate can be expressed as follows:

$$Q = C_s(T_{so} - T_{si}) = C_1(T_{1i} - T_{1o}) \tag{6}$$

For the case of $C_s \neq C_1$, the LMTD (log mean temperature difference) formulation of the total heat transfer rate for the counter flow configuration is expressed as

$$Q = U_e P_e L \Delta T_m \tag{7}$$

where

$$\Delta T_m = \frac{[(T_{1o} - T_{si}) - (T_{1i} - T_{so})]}{\ln\left(\dfrac{T_{1o} - T_{si}}{T_{1i} - T_{so}}\right)} \tag{8}$$

Under the condition of $C_s \neq C_1$, the fluid temperatures T_{1o}, T_{so} at the flow outlets of a counter flow heat exchanger can be obtained by manipulating equations (6) and (7) as follows:

$$T_{1o} = T_{1i} - (T_{1i} - T_{si})\left\{\frac{1 - \exp\left[U_e P_e L\left(\dfrac{1}{C_s} - \dfrac{1}{C_1}\right)\right]}{1 - \dfrac{C_1}{C_s}\exp\left[U_e P_e L\left(\dfrac{1}{C_s} - \dfrac{1}{C_1}\right)\right]}\right\} \tag{9}$$

$$T_{so} = T_{si} + (T_{1i} - T_{si})\left\{\frac{1 - \exp\left[U_e P_e L\left(\dfrac{1}{C_s} - \dfrac{1}{C_1}\right)\right]}{\dfrac{C_s}{C_1}\exp\left[U_e P_e L\left(\dfrac{1}{C_s} - \dfrac{1}{C_1}\right)\right]}\right\} \tag{10}$$

The equivalent number of transfer units (NTU) which is identical to that for the classical two-channel heat exchanger can be expressed as

$$\mathrm{NTU} = \frac{U_e P_e L}{C_1} = \frac{(T_{1i} - T_{1o})}{\Delta T_m} \text{ if } C_1 < C_s \tag{11}$$

$$\mathrm{NTU} = \frac{U_e P_e L}{C_s} = \frac{(T_{so} - T_{si})}{\Delta T_m} \text{ if } C_1 > C_s \tag{12}$$

Therefore, if the inlet and outlet fluid temperatures of heat exchanger are known, the NTU can be determined from equation (11) or (12). Then, the equivalent overall heat transfer coefficient, U_e can be estimated.

7. Analysis of Convective Heat Transfer Coefficient

Convection heat transfer is occurred between cooling medium and inside wall of cooling channel and between product and inside wall of product channel. Calculation of convective heat transfer coefficients between water as cooling medium and inside wall of cooling channel (h_c) and between product and inside wall of product channel (h_p) were calculated as the following equations (Incropera and Dewitt, 2002):

$$N = h_c L / k_f = 0.664(Re)^{1/2}(Pr)^{1/3} \tag{13}$$

$$h_c = (N \times k_f)/L \tag{14}$$

$$h_p = \frac{1}{\dfrac{1}{U_e} - \dfrac{1}{h_c} - \dfrac{\Delta x}{k_s}} \tag{15}$$

The values of physical and thermal properties of water at 20℃ were used to calculate convective heat transfer coefficients (Pr = 7.0, viscosity = 1027.4 × 10^{-6} Ns/m^2, density = 998.2 kg/m^3, water thermal conductivity, k_f = 0.603 W/mK). Thermal conductivity of steel (k_s) used in equation (15) was 48.0 W/mK and the thickness of cooling die wall, Δx was 5 mm.

Results and Discussion

Table 1 presents the calculation results of the equivalent overall heat transfer coefficients (U_e) for cooling die, convective heat transfer coefficient between water as cooling medium and inside wall of cooling channel (h_c) and between product and inside wall of product channel (h_p) for cooling die of 100, 200, and 300 mm length with the widths of 30 and 60 mm achieved during extrusion process at the four different moisture contents of feed. Generally, mass flow rate of product affecting the value of U_e was decreased as the feed moisture content was decreased. It was caused by the decrease of water added to feed for lowering the moisture content. It would be expected that lower moisture condition has higher shear stress in the extruder barrel and the product channel of cooling die due to its higher viscosity (Cheftel et al., 1992). Temperature differences of cooling water at the die inlet and outlet (ΔT_c) were varied in the range of 1.6 - 2.8℃ and 2.1 - 3.2℃ for each die width of 30 and 60 mm. Temperature differences of product at the die inlet and outlet (ΔT_p) were varied in the range of 10.1 - 25.0℃ and 12.1 - 29.8℃ for each die width of 30 and 60 mm. These temperature differences at the die inlet and outlet for cooling water and product would be due to the operational conditions of extruder, moisture content of feeding material, mass flow rate of product, die width, etc. However, these temperature differences of the die inlet and outlet under various extrusion conditions were not expected to affect determining the values of U_e, h_c, and h_p, because the die inlet and outlet temperatures of cooling water and product were essentially influenced by the heat gain or loss between each other in the die channels.

The values of U_e for 30 mm die width were in the range of 313.7 - 341.4, 232.1 - 262.4, and 187.0 - 199.9 W/m^2℃ for each die length of 100, 200, and 300 mm. For the die width of 60 mm, the values of U_e were in the range of 330.8 - 358.5, 207.2 - 258.6, and 191.6 - 206.1 W/m^2℃ for each die length of 100, 200, and 300 mm. The values of U_e were increased with increasing the moisture content of feed in all of different die size. It was shown that larger length of die had smaller value of U_e compared with that of shorter die. These results present that the moisture content and die length affect significantly on the value of overall heat transfer coefficient. Convective heat transfer coefficients between cooling water and inside die wall of cooling channel (h_c) for both die widths of 30 and 60 mm were 588.5, 416.1, and 339.8 W/m^2℃ for each die length of 100, 200, and 300 mm. The value of h_c was decreased with increasing the die length for the die width of 30 and 60 mm. Convective heat transfer coefficients between product

Table 1 Heat transfer analysis obtained for cooling die using water as cooling medium

Die Width (mm)	Die Length (mm)	Moisture Content (%)	Product Mass Flow Rate (kg/s)	C_s (J/sK)	C_l (J/sK)	DT (℃) Cooling Medium	DT (℃) Product	ΔT_m (℃)	NTU	U_e (W/m^2℃)	h_c (W/m^2℃)	h_p (W/m^2℃)
						ΔT_c	ΔT_p					
30	100	71.2	0.0073	152.6	25.0	1.7	10.1	61.5	0.164	341.4	588.5	888.1
		67.0	0.0063	152.6	20.8	1.8	13.4	68.6	0.195	337.4	588.5	861.7
		61.6	0.0054	152.6	17.0	1.7	15.5	67.3	0.230	325.9	588.5	790.4
		55.8	0.0047	152.6	14.1	1.6	17.7	66.1	0.267	313.7	588.5	722.6
	200	71.2	0.0073	152.3	25.0	2.2	13.2	52.4	0.252	262.4	416.1	766.8
		67.0	0.0063	152.3	20.8	1.9	13.7	48.0	0.285	246.8	416.1	647.4
		61.6	0.0054	152.3	17.0	1.7	15.5	46.2	0.336	238.5	416.1	593.2
		55.8	0.0047	152.3	14.1	1.6	17.4	44.0	0.395	232.1	416.1	555.0
	300	71.2	0.0073	152.3	25.0	2.8	17.3	59.9	0.288	199.9	339.8	511.4
		67.0	0.0063	152.3	20.8	2.6	18.8	56.0	0.337	194.4	339.8	476.9
		61.6	0.0054	152.3	17.0	2.6	22.9	57.1	0.401	189.4	339.8	448.2
		55.8	0.0047	152.3	14.1	2.3	25.0	52.4	0.478	187.0	339.8	434.6
60	100	71.2	0.0073	152.6	25.0	2.1	12.1	74.5	0.163	358.5	588.5	1014.5
		67.0	0.0063	152.6	20.8	2.1	15.7	76.4	0.206	356.4	588.5	998.0
		61.6	0.0054	152.6	17.0	2.1	18.8	77.9	0.242	342.8	588.5	897.6
		55.8	0.0047	152.6	14.1	2.1	22.2	78.8	0.282	330.8	588.5	819.8
	200	71.2	0.0073	152.3	25.0	3.0	18.2	73.1	0.249	258.6	416.1	735.6
		67.0	0.0063	152.3	20.8	2.8	20.8	72.7	0.286	247.8	416.1	654.2
		61.6	0.0054	152.3	17.0	2.7	24.2	75.5	0.321	227.8	416.1	531.4
		55.8	0.0047	152.3	14.1	2.6	28.3	80.3	0.353	207.2	416.1	431.0
	300	71.2	0.0073	152.3	25.0	3.2	19.3	65.0	0.297	206.1	339.8	555.0
		67.0	0.0063	152.3	20.8	3.0	21.7	61.0	0.355	205.2	339.8	547.8
		61.6	0.0054	152.3	17.0	2.9	25.6	61.7	0.415	196.1	339.8	487.3
		55.8	0.0047	152.3	14.1	2.8	29.8	60.9	0.490	191.6	339.8	460.7

and inside die wall of product channel (h_p) for each die width of 30 and 60 mm were in the range of 434.6 - 888.1 W/m^2℃ and 460.7 - 1014.5 W/m^2℃ depending on the size of die length. The value of h_p was also decreased with increasing die length for the die widths of 30 and 60 mm.

Table 2 presents the calculation results of the equivalent overall heat transfer coefficients (U_e) for cooling die of 100, 200, and 300 mm length with the widths of 30 and 60 mm achieved during extrusion process at the four different moisture contents of feed, when water plus ethylene glycol was used as cooling medium. For the die width of 30 mm, the values of U_e were in the range of 306.4 - 319.6, 222.8 - 280.5, and 143.9 - 166.9 W/m^2℃ for each die length of 100, 200, and 300 mm. The values of U_e for the die width of 60 mm were in the range of 306.9 - 332.7, 200.2 - 244.4, and 177.8 - 200.7 W/m^2℃ for each die length of 100, 200, and 300 mm. The values of U_e were increased with increasing the moisture content of feed in all of different die size as the use of water as cooling medium, when water plus ethylene glycol was used as cooling medium. However, it is considered that the size of die width does not significantly affect the values of U_e.

Conclusions

During extrusion of soy protein meat analog, texturization takes place as a result of lamella flow in the cooling die, which dissipates the thermal and mechanical energy accumulated in the extrusion melt. The heat transfer analysis for

Table 2 Heat Transfer analysis obtained for cooling die using water plus ethylene glycol as cooling medium

Die Width (mm)	Die Length (mm)	Moisture Content (%)	Product Mass Flow Rate (kg/s)	C_s (J/sK)	C_l (J/sK)	ΔT (℃)		ΔT_m (℃)	NTU	U_e (W/m^2℃)
						Cooling Medium	Product			
						ΔT_c	ΔT_p			
30	100	71.2	0.0109	117.2	37.3	2.7	8.6	83.1	0.103	319.6
		67.0	0.0095	117.2	31.4	2.8	10.3	85.5	0.121	315.3
		61.6	0.0082	117.2	25.9	2.8	12.5	87.1	0.143	308.3
		55.8	0.0071	117.2	21.3	2.8	15.2	88.0	0.173	306.4
	200	71.2	0.0109	117.2	37.3	4.1	12.9	69.8	0.181	280.5
		67.0	0.0095	117.2	31.4	3.7	13.8	68.7	0.201	262.6
		61.6	0.0082	117.2	25.9	3.7	15.3	68.5	0.223	240.0
		55.8	0.0071	117.2	21.3	3.1	17.0	67.7	0.251	222.8
	300	71.2	0.0109	117.2	37.3	3.5	11.0	68.4	0.161	166.9
		67.0	0.0095	117.2	31.4	3.3	12.3	67.7	0.182	158.3
		61.6	0.0082	117.2	25.9	3.2	14.6	69.9	0.209	150.0
		55.8	0.0071	117.2	21.3	3.2	17.5	71.7	0.243	143.9
60	100	71.2	0.0109	117.2	37.3	3.0	9.4	87.8	0.107	332.7
		67.0	0.0095	117.2	31.4	3.0	11.0	89.1	0.124	323.3
		61.6	0.0082	117.2	25.9	2.9	12.9	88.4	0.146	314.8
		55.8	0.0071	117.2	21.3	2.8	13.5	90.4	0.150	306.9
	200	71.2	0.0109	117.2	37.3	3.9	12.1	77.0	0.157	244.4
		67.0	0.0095	117.2	31.4	3.6	13.4	74.1	0.181	237.0
		61.6	0.0082	117.2	25.9	3.3	14.7	73.7	0.200	215.6
		55.8	0.0071	117.2	21.3	3.0	16.6	73.5	0.226	200.2
	300	71.2	0.0109	117.2	37.3	4.3	13.5	69.4	0.194	200.7
		67.0	0.0095	117.2	31.4	3.7	13.8	65.7	0.210	182.9
		61.6	0.0082	117.2	25.9	3.6	16.2	65.0	0.250	178.8
		55.8	0.0071	117.2	21.3	3.6	19.6	65.2	0.301	177.8

cooling die in this study is valuable for the die design and the prediction of product temperature at the die outlet - both are important for the texturization process and the control of meat analog quality during process scale up. The moisture content and die length affect significantly on the value of equivalent overall heat transfer coefficient (U_e), and convective heat transfer coefficients between water as cooling medium and inside wall of cooling channel (h_c) and between product and inside wall of product channel (h_p) were decreased with increasing the die length. Similarly, the values of U_e were also increased with increasing the moisture content of feed in all of different die size, when water plus ethylene glycol was used as cooling medium.

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