MODELING OF DEEP-FRYING CULINARY PRODUCTS

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Abstract: The article presents an approximate physical-mathematical model that describes the process of frying deep-fried food products, and makes it possible to determine the duration of the frying process by temperature in the center of the product.
Keywords: frying, deep-frying, heat transfer, evaporation, product readiness.

1. INTRODUCTION

Frying is an important high-specific processes, which is widely used in food factories for thermal processing of foods [1]. Technological nature of the basic process of frying is to bring food to a state of cooking readiness by heating it at a temperature that causes the formation of specific crust surface on the product. The temperature of crust under normal heating ranges from 105^0 C to 135^0 C. At the food factories the following basic processes of frying are used [2]:

• basic (traditional) - frying pan on an open surface or deck with a small amount of fat (5...10% of the mass of product), which is used as an intermediate heat carrier, or without it;

• frying in fat (deep-frying) - no direct contact with the heating surface; the rational ratio between fat and the product immersed is 4:1.

During the deep-frying of foods, the productgets plunged in the fat which has been preheated to $140…180^0$ C. Fat in this case serves as the medium which transfers heat and provides even heating and crust formation on the entire surface of the product, regardless of the form.

There are two ways of frying in oil - immersion and floating [1]. During immersion the product doesn't not come to the surface, and fries in the volume of fat. During the floating products get submerged for 30...50 seconds in the fat, then come to the surface and deep-fries while floating in free state. Because only one side gets fried, the products must be turned to another side or stirred. The first method is more rational, because it provides even frying of products from all sides, reducing the cost of fat. Among the disadvantages of deep-frying we can count the change of physical-chemical parameters of fat, and consequently, lower product quality caused by uneven temperature fields of heaters [3].

2. RECENT INVESTIGATIONS

It is known that frying of food is a complex heat transfer process which is determined by different ways of heat supply to the surface of the product, peculiarities of the internal heat transfer, and unevenness of temperature field.

When the traditional method of frying is used, the heat from the heated surface is passed through a thin layer of boiling oil, heats the inner layers of the product and dissipates into the environment through the free surface. The authors in [4] have obtained an approximate physical-mathematical model of heat treatment of food products based on the basic method of frying. The obtained ratios make it possible to solve several problems related to the research of heat transfer during food preparation carried out by the basic method.

When the second method – deep-frying – is used, the product is completely immersed in boiling fat. Due to the heat transfer coefficient, the water boiling section arises almost immediately, which gradually spreads from the surface to the center. It can be assumed that almost all the heat supplied to the product is spent on evaporation, and its temperature does not change with time. On the surface of the product the temperature is determined by heat exchange processes, and in the inner layers, it is equal to the boiling point of water under these conditions. The process of deep-frying is finished when the boiling section reaches the center of the product. Upon further deep-frying, the temperature of the product will gradually reach the oil temperature.

This work [3] produces the general solution for the boundary value problem for boundary conditions of the third kind, in order to determine the full duration of the combined method of frying potatoes. But the equation can be used for bar-shaped food of the regular form under the regular mode. However, these assumptions and rather complicated look of the formulas obtained significantly limit the scope of applicability of these equations.

The aim of this work is to obtain the model of deep-frying process, which is free from these flaws.

3. RESULTS OF RESERCH

Based on the above described physical model we can create a mathematical model of the kinetics of the deep-frying process. Let us assume that there is a body of arbitrary shape with constant thermal properties. Then in this case the general energy balance equation for heat and mass process is as follows:

$$cm\frac{dT}{d\tau} = j \cdot S - r_w \frac{dm_w}{d\tau}\,, \tag{1}$$

where j - density of heat flow through the surface of the product, W/m^2;;

r_w - specific heat of vaporization, J/ kg;

m - mass of product, kg;

m_w - mass of water evaporated, kg;

S – surface area of product, m^2,

τ – the current time, s.

According to substantiated physical model, temperature does not change in the course of time, so in one-dimensional approximation the equation (1) takes the following form:

$$\lambda\frac{dT}{dr}S = -r_w \frac{dm_w}{d\tau}\,, \tag{2}$$

Mass of water that evaporates in an infinitely thin layer of product is equal to:

$$dm_w = w \cdot \rho \cdot dV\,, \tag{3}$$

where λ - thermal conductivity of the product, W/m K;
w - product moisture, kg/kg;
ρ - product density, kg/m^3.

Taking into consideration that $dr=dV/S$ is the current coordinate, and $v=dr/d\tau$ is the speed of evaporation zone's promotion, let's rewrite (2) as a differential equation relative to the current coordinates.

$$\lambda \frac{dT}{dr} = -r_w w \rho v\,, \tag{4}$$

If we make an assumption that the speed of evaporation zone's promotion v doesn't depend on the coordinates, the solution of the last equation is as follows

$$T = -\frac{r_w w \rho v}{\lambda} r + C\,, \tag{5}$$

where the constant C is determined by the boundary conditions on the product surface where there is a convectional heat transfer

$$-\lambda \frac{dT}{dr}\bigg|_{r=R_V} = \alpha\left(T_\infty - T(R_V)\right), \tag{6}$$

where α - heat transfer coefficient from boiling oil to the surface of the product. W/(m^2 K)
$R_V=V/S$ - characteristic size of the product, the ratio of its volume to the surface area,
T_∞ - oil temperature, K.

By placing (5) under boundary condition (6), we find the constant C

$$C = \left(\frac{1}{\alpha} + \frac{R_V}{\lambda}\right) r_w w \rho v + T_\infty\,. \tag{7}$$

Taking into consideration the fact that for any current coordinate the temperature of evaporation zone is equal to the temperature of boiling water, as well as for the expression of speed of evaporation zone's promotion, the equation (5) takes the following form:

$$T_k = r_w w \rho \left(\frac{1}{\alpha} + \frac{R_V}{\lambda} - \frac{r}{\lambda}\right)\frac{dr}{d\tau} + T_\infty\,, \tag{8}$$

where T_k - - boiling point of water, K.

The solution of this differential equation is as follows

$$\tau = -\frac{r_w w \rho}{T_\infty - T_k}\left(\frac{r}{\alpha} + \frac{R_V r}{\lambda} - \frac{r^2}{2\lambda}\right) + C_1\,, \tag{9}$$

The constant C_1 is determined by the condition of the evaporation zone's lay in the initial time часу $r=R_V$ $\tau=0$

$$C_1 = \frac{r_w w \rho}{T_\infty - T_k}\left(\frac{r}{\alpha} + \frac{R_V r}{\lambda} - \frac{r^2}{2\lambda}\right), \tag{10}$$

By placing the value of C_1 under (9),the formula describing evaporation zone's lay in the product in the course of time looks as follows:

$$\tau = \frac{r_w w \rho R_V{}^2}{2\lambda(T_\infty - T_k)}\left(1 - \frac{r}{R_V}\right)\left(1 + \frac{2\lambda}{\alpha R_V} - \frac{r}{R_V}\right), \tag{11}$$

The duration of the deep-frying process is, as indicated above, determined by the time which it takes the evaporation zone in order to reach the product's center (r = 0). Therefore, from (11) we have as follows:

$$\tau_{гот} = \frac{r_w w \rho R_V{}^2}{2\lambda(T_\infty - T_k)}\left(1 + \frac{2\lambda}{\alpha R_V}\right), \tag{12}$$

4. CONCLUSION

The obtained ratios can solve several problems related to the investigation of heat transfer during the process of deep-frying of culinary and pastry products. In particular, it makes it possible to calculate the change of the frying duration for the new culinary recipes as well as the compound of new kinds of oil.

Further application of the proposed model of food frying process will make it possible to optimize the process parameters for the selected task. Experimental verification of the obtained model is the future prospect.

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