Study of processing and concentration of the meat industry biotechnological raw materials

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Abstract. The application of cold in the processes of slaughter animals blood and its components processing is considered to become more and more prospective nowadays. Therefore, a special role is given to the low-temperature concentration by blood plasma freezing, which ensures preserving the entire complex of biochemical compounds in solution to the maximum extent. The process of cattle blood plasma concentration in a continuous screw crystallizer was studied in the work. It was revealed that the maximum amount of ice is frozen out of the blood plasma at the boiling point of the refrigerant equal to minus 25...24 °C, the rotational speed of the crystallizer screw of 0.06 s^{-1}. It was found out that an increase in the initial content of soluble compounds in the initial blood plasma contributes to an increase in the content of dry matter in the concentrated plasma. Analysis of the process of blood plasma and frozen ice centrifugal separation proved that the optimal dry matter content in a solution of molten ice equal to 0.182 % corresponds to a dry matter content in freeze-concentrated blood plasma equal to 22.34 % and a separation factor equal to 515.25.

1 Introduction

One of the ways of blood plasma technological application is its use in liquid stabilized form (as well as after cooling and freezing) with a relatively low protein content and preserved native functional - and technological properties.

In this case, blood plasma proteins are characterized by a high level of water-binding capacity and emulsification, which is due to the presence of water-soluble proteins in it capable of forming a gel when heated [1].

Blood plasma consists of water and dry matter, which comprises organic and inorganic compounds. Organic substances of blood plasma include proteins albumin, globulins, fibrinogen, prothrombin and others, amino acids, urea, glucose, neutral fats, enzymes, mineral hormones and other substances.

These properties combination allows the widespread use of blood plasma not only as a component balancing the general chemical composition of finished products, but also as a functional additive in the production of emulsified meat products with a high final moisture content, such as cooked sausages, frankfurters, minced semi-finished products, canned minced meat, ham products. In addition, the use of blood plasma as a medium for the hydration of protein preparations proved itself from the best side. Blood plasma is indispensable in the manufacture of protein-fat emulsions, binders, multicomponent protein systems with a given composition and functional - and technological properties, structured protein preparations.

Denaturation- and coagulation sedimentation provides a combination of thermotropic structuring, flocculation (sedimentation) and blood plasma proteins concentration. This makes it possible to obtain preparations with a relatively high concentration of protein and extraordinary functional - and technological properties, which ensures their use in recipes for semi-smoked, smoked - baked, liverwurst sausages, canned pâté and semi-finished products with a limited final moisture content and high fat absorption capacity.

However, it should be noted that the use of these types of blood plasma preparations in the domestic meat production is very limited.

Blood plasma structuring by recalcification significantly expands the possibilities of its technological application. The conversion of blood plasma and multicomponent systems based on it into a gel form makes it possible to obtain structural matrices that imitate natural biological objects in appearance, composition and properties, creates preconditions for functional and technological properties regulation, ensures the involvement of low-grade raw materials in the production process, makes it possible to approach solving the problem of developing new types of food products from new positions. The complex use of blood plasma and protein preparations (soy isolates, sodium caseinate, etc.) is especially effective.

Structured forms of blood plasma are used in the production of cooked sausages, chopped semi-finished products, cased ham, semi-smoked and liverwurst sausages, pates, canned mince, textured fillers for recipes, meat products analogs.

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Concentration of blood plasma by drying, ultrafiltration and freezing methods can significantly increase the protein content in it. The concentrates obtained by these methods are successfully applied in the production of meat products along with liquid blood plasma. In this case, blood plasma proteins, as a rule, are characterized by a high level of water-binding capacity and emulsification, which is due to the presence of water-soluble proteins in it that can form gels when heated [2, 3].

Cattle blood plasma tolerates low temperatures and freezing well enough, while proteins do not undergo denaturation, retain their properties and biological activity. When obtaining concentrated blood plasma by the freezing method, it is important that the liquid phase (water) is mainly in the crystalline state, and the protein phase is in the dissolved state.

2 Materials and methods

Concentration of cattle blood plasma by freezing with a screw crystallizer, shown in figure 1, was studied in the work.

The screw crystallizer, equipped with the necessary measuring and control appliances and instruments, contains a fixed cylindrical body 10, equipped with a heat exchange jacket 5, a system for supplying the heat exchange jacket with cold and a drive 1. The heat exchange jacket 5 is equipped with a nozzle 7 for supplying a liquid boiling refrigerant and a nozzle 9 that provides a drain of the spent refrigerant vapor. The latter circulates in the space formed by the heat exchange jacket 5 and the crystallizer cylindrical body 10 with spiral winding 6. To increase the heat- and power characteristics of the screw crystallixer, all of its heat exchange surfaces are equipped with thermal insulation.

The screw 4 continuously rotates inside the crystallizer body 10 in bearing supports 2, by means of the drive 1. It cleans the inner surface of the crystallizer body 10 from the frozen ice and moves the mixture of concentrated product and ice crystals to the branch pipe 8 for removal from the crystallizer. Blood plasma to be concentrated is continuously supplied to the crystallizer through the branch pipe 8.

The counterflow of the concentrated product supplied through the branch pipe 3 and the refrigerant circulating in the heat exchange jacket 5 is organized in the crystallizer for concentration by freezing.

The temperature of the initial liquid was controlled during the process. The values of the boiling points of the refrigerant in the crystallizer heat-exchange jacket, the screw rotation frequency and the initial dry substances content in the initial blood plasma were varied during the study of the concentration process by freezing moisture from the blood plasma [4, 5].

Determination of the content of dry substances in the original and concentrated blood plasma was carried out by refractometric method.

To carry out the experiment, the crystallizer was brought to a predetermined operating mode by its cooling to the required temperature. After that, the drive 1 of the screw 4 was switched on, and the supply of whey to the crystallizer was carried out. A mixture of concentrated blood plasma and ice crystals leaving the screw crystallizer was continuously fed for separation in a centrifugal field.

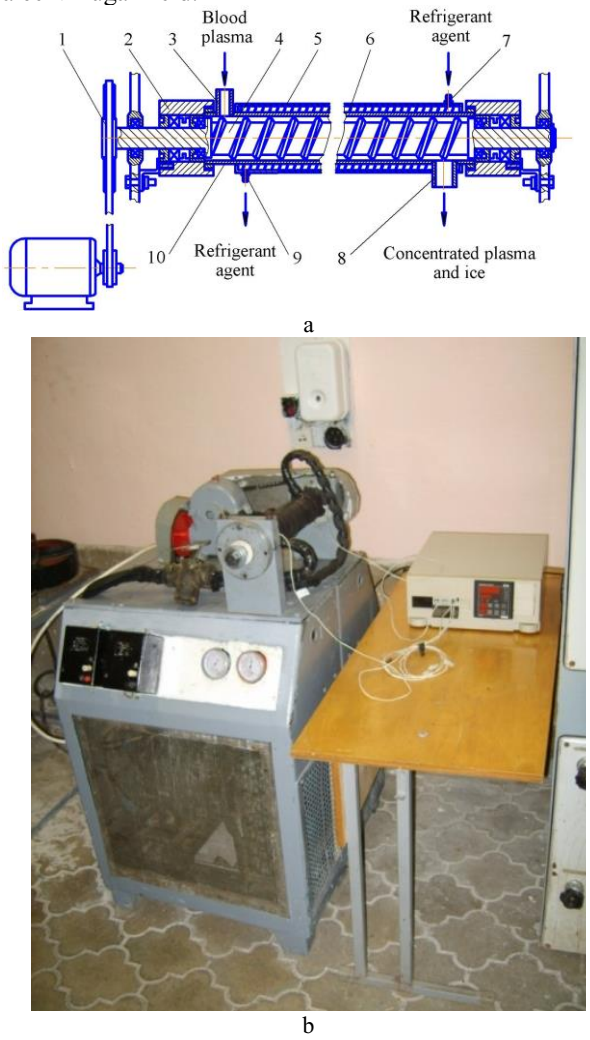

Fig. 1. Continuous screw crystallizer: a - scheme; b - general view: 1 - drive; 2 - bearing support; 3 - branch pipe for initial blood plasma supplying; 4 - screw; 5 - heat exchange jacket; 6 - spiral winding; 7 - nozzle for liquid boiling refrigerant supplying; 8 - branch pipe for removal of a mixture of concentrated blood plasma and frozen ice; 9 - nozzle for spent refrigerant vapors draining; 10 - crystallizer body.

The study of the centrifugation process of ice frozen from cattle plasma was carried out on the OS-6MC laboratory centrifuge equipped with a special rotor 200 mm in diameter, as well as devices for temperature recording, the rotor speed monitoring and regulating. The amount of dry matter in the initial and concentrated blood plasma was determined by the refractometric method.

Freezing of moisture from the plasma was carried out in a screw crystallizer before centrifugation. The resulting mixture of ice crystals and concentrated plasma was loaded in portions into the centrifuge rotor. The required rotor speed was set, and the separation of ice and concentrated plasma was carried out in a centrifugal field. At the end of the separation of the concentrated

plasma from the frozen ice, the centrifuge was stopped. Ice was removed from the rotor and melted. And the dry matter content was determined in it.

The screw crystallizer made it possible to obtain concentrated blood plasma with a final dry matter content of 14.0 to 24.0 %. The centrifugal separation process was investigated at a rotor speed from 950 to 2750 min^{-1}. This corresponds to the value of the separation factor *Fr* from 100 to 850.

3 Results and their discussion

A series of experiments was carried out to study the influence of various conditions on blood plasma concentration in the continuous screw crystallizer.

The dependences reflecting the change in the content of soluble substances in the concentrated blood plasma on the operating parameters of the screw crystallizer (fig. 2 - 4) were of special interest.

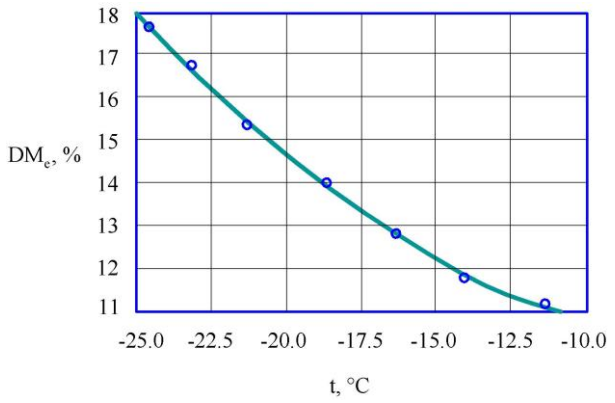

Fig. 2. Change in the final solids content in the concentrated blood plasma at a screw rotation speed n = 0.12 s^{-1}, and the initial solids content DM_s = 8.5 % of the refrigerant boiling point in the crystallizer t, °C.

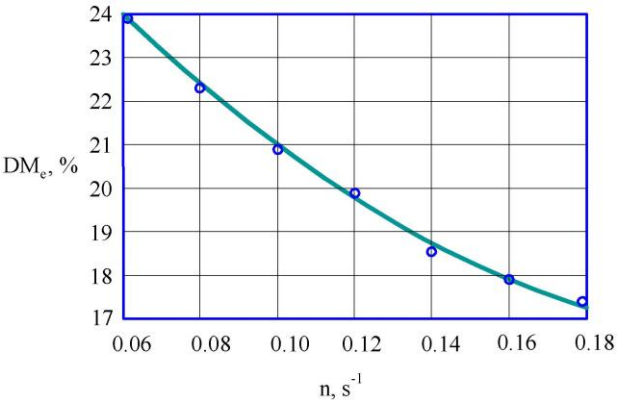

Fig. 3. Change in the final solids content in the concentrated blood plasma at the refrigerant boiling point in the crystallizer t= –22 °C, the initial solids content DM_s = 9.0 % on the screw rotation speed n, s^{-1}.

The analysis of the obtained graphical dependencies showed that the operating characteristics of the screw crystallizer for all values of the refrigerant boiling point in the heat exchange jacket of the crystallizer, the screw rotation speed and the initial content of dry substances in the plasma during concentration had a similar form [6-9].

With a decrease in the refrigerant average boiling point, the content of dry substances in the concentrated blood plasma increases monotonically. This causes an increase in energy consumption required to freeze moisture from the concentrated blood plasma. It is pointed out that the form of this dependence is close to linear.

Analysis of the graph reflecting the change in dry substances content in the concentrated blood plasma depending on the rotation speed of the crystallizer screw revealed that the indicated dependence is nonlinear, the dry matter content in the concentrated liquid increases with a decrease in the rotational speed of the crystallizer screw [10, 11].

In addition, an increase in the initial dry matter content in the initial blood plasma from 8.0 to 9.2 % leads to an almost linear increase in the dry matter content in the concentrated blood plasma.

The results of the studies proved that the temperature of the crystallizer wall and the rotational speed of the screw have the greatest effect on the value of the final dry matter content in the concentrated blood plasma, while the initial dry matter content in the initial blood plasma has the least effect on it [12].

The efficiency of suspension separation into ice crystals and concentrate, as well as the performance of separation plants, depend mainly on the size of the ice crystals formed and the viscosity of the concentrate. An increase in the viscosity of the concentrate in suspension, due to an increase in concentration in the process of moisture removal, leads to an increase in the loss of soluble substances with the ice removed.

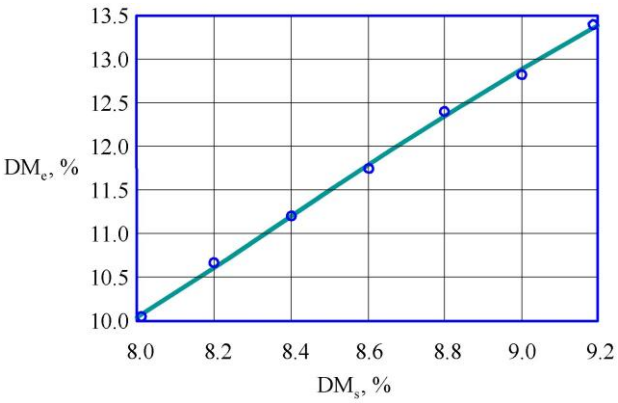

Fig. 4. Change in the final solids content in concentrated blood plasma at the refrigerant boiling point in the crystallizer t = –18 °C, screw rotation speed n = 0.1, s^{-1} from the initial solids content DM_s, %.

The solution retention by ice is due to the possible forms of links between the liquid and solid phases. Quantitatively, the retention of the liquid phase by ice is assessed by one of two indicators: the retention capacity for the solution K_s or the volumetric saturation of the layer with the liquid phase m. The first one is determined by the equation

$$K_s = G_s / G_i, \quad (1)$$

where G_s, G_i are retained solution and ice mass per unit volume of the layer, kg.

The K_s value is convenient for calculating freeze separation plants. It can be easily determined by measuring the solution concentration in the ice layer and after its melting by the equation

$$K_s = \xi_s / (\xi_0 - \xi_s), \quad (2)$$

where ξ_0, ξ_s are concentration of non-aqueous components in a solution in a porous ice layer and in this layer's melt.

It is more reasonable to use the value of the volumetric saturation of the layer by the liquid phase in calculations from the point of view of the theory of capillary capture of liquid by a porous layer:

$$m = V_s / (V_1 \varepsilon_V), \quad (3)$$

where V_1, V_s are the volumes of the porous layer and the liquid retained by it m^3, respectively; ε_V is the ice layer volumetric porosity.

The quantities m and K_s are related to each other by the dependence

$$m = K_s \rho_i (1 - \varepsilon_V) / (\rho_s \varepsilon_V), \quad (4)$$

where ρ_i, ρ_s are density of ice and solution, kg/m^3, respectively.

Centrifugation is one of the most common ways to separate frozen ice from a concentrated solution. Centrifugation is one of the main processes of food technology, and a large number of theoretical and experimental works are devoted to its study.

It is known that the ice residual saturation with a solution can be reduced by a factor of 6...7 in comparison with the gravitational removal of the solution during centrifugation. At the same time, an increase in the separation factor *Fr*, reflecting the ratio of centrifugal force to gravity, more than 750...1000 changes the residual saturation of the layer insignificantly. This should be taken into account when choosing the operating modes of centrifuges.

Mathematical methods for the experiment planning were applied to study the separation factor influence and the final dry matter content of blood plasma on the dry matter content in molten ice after freezing and centrifugation.

In this case, x_1 is the content of dry matter in the concentrated blood plasma, % and x_2 is the separation factor of the centrifuge, which is the ratio of centrifugal force to gravity during separation, were chosen as the main factors. These factors are compatible and not correlated with each other. The final solids content in the molten ice Y was used as the evaluation criterion.

The regression equation that adequately describes the process of centrifugation of ice frozen from blood plasma was obtained as a result of statistical processing of experimental data:

$$Y = 0.1910 + 0.2334 X_1 - 0.1333 X_2 + \\ + 0.0793 X_1 X_2 + 0.0912 X_1^2 + 0.1287 X_2^2, \quad (5)$$

Where X_1, X_2 are coded values of the specified factors in accordance with the statistical plan.

The analysis of the obtained equation (5) showed that the content of dry substances in concentrated blood plasma has the greatest effect on the content of dry substances in a solution of molten ice. The splitting factor has the least impact, since the ratio of the coefficients facing the corresponding linear terms of the equation is 1.751.

The resulting equation makes it possible to calculate the final content of dry substances in a solution of ice frozen from blood plasma with a screw crystallizer under conditions of adiabatic centrifugation.

The optimization problem is formulated as follows: to find such centrifugation modes that would provide a minimum of the final content of dry substances in a solution of ice frozen from blood plasma in a wide range of input parameters.

Introducing the assumption that the obtained regression equation (5) describes a certain surface in multidimensional space, it is possible to find out what kind of bodies this surface belongs to by the canonical form coefficients. The center coordinates were found from the system of equations obtained as a result of the regression equation (5) differentiating with respect to X_1 and X, and the derivatives were equated to zero. Knowing the coordinates of the center according to equation (5), the corresponding values of the optimization parameter were determined and the canonical coefficients were calculated.

The analysis of the obtained canonical equations showed that the response surfaces are a two-lane hyperboloid.

Curves of equal values of the solids content in the solution of frozen ice, having the form of a nomogram, are shown in Fig. 5. The nomogram is used to determine the operating parameters of blood plasma centrifugation and is of practical interest.

The application of mathematical methods for optimizing technological processes made it possible to calculate the optimal values of the factors influencing the centrifugation process of ice frozen from blood plasma. The optimal solids content in the molten ice solution, equal to 0.182 %, corresponds to the solids content in the freeze-concentrated blood plasma equal to 22.34 % and the separation factor of 515.25. The suboptimal modes of centrifugation are as follows: the solids content in the concentrated blood plasma is 18.74...20.02 % and the separation factor is 485...628. At the same time, the solids content in the molten ice solution is in the range of 0.181...0.216 %.

The obtained dependence of the value of the solids content in the solution obtained by melting the frozen ice DM_i, % on the solids content in the concentrated blood plasma DM_e, % and the separation factor *Fr* are shown in figure 6.

The solids content in the solution obtained by frozen ice melting is seen to increase monotonically with an increase in the solids content in the concentrated blood plasma and a decrease in the separation factor value.

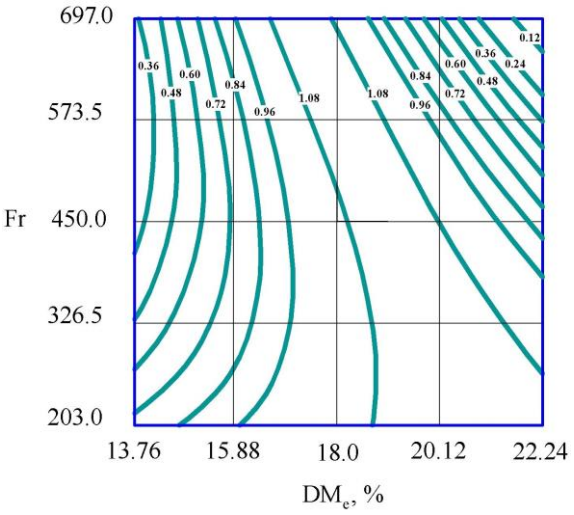

Fig. 5. Curves of equal values of the solids content in the frozen ice solution from the solids content in the concentrated blood plasma DM_e, % and the centrifuge separation factor *Fr*.

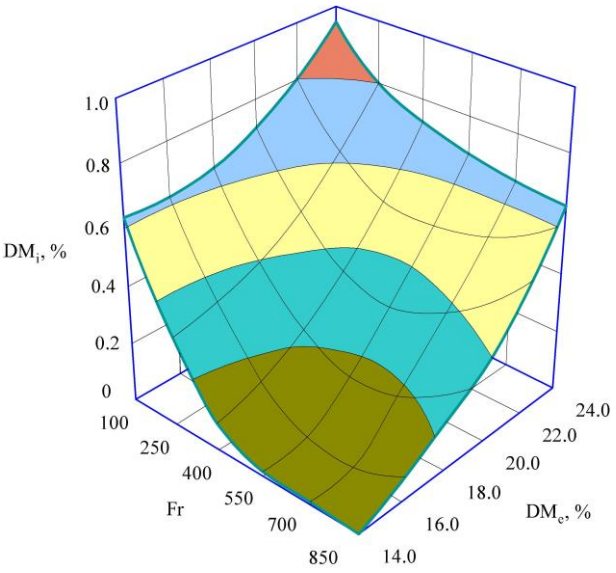

Fig. 6. Change in the solids content in the frozen ice solution depending on the solids content in the concentrated blood plasma DM_e, % and the centrifuge separation factor *Fr*.

When the solids content in the concentrated blood plasma is equal to 14.0 % and the separation factor is equal to 850, the solids content in the solution obtained by frozen ice melting is really low. This can be explained by insignificant ice melting and the crystal layer washing with the formed water due to errors that inevitably affect the conditions of adiabatic centrifugation at high rotor speeds.

4 Conclusions

Summarizing the results obtained in the blood plasma concentration, we can conclude that the process efficiency in the screw crystallizer depends on the temperature of the crystallizer wall. And the latter depends on the refrigerant temperature and the screw rotation speed [13].

The results of the studies performed to examine the nature of changes in soluble substances in concentrated blood plasma from changes in the moisture freezing modes can be useful in calculating the heat transfer process during concentration in freezing plants, in the development of technology and hardware design for the production of concentrated blood plasma.

The research results concerning the separation peculiarities of concentrated blood plasma and frozen ice make it possible to identify practical recommendations for the development of separation modes by concentrated liquids centrifugation during separation freezing and to predict the conditions for carrying out this process in the development of technology and hardware design for the production of concentrated media [13-15].

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