Solving the problem of using dairy waste in Russia

T Pilipenko¹, E Belokurova¹, I Pankina¹ and A Shlykova¹

¹Peter the Great St. Petersburg Polytechnic University, 29, Polytechnicheskaya str., St. Petersburg, 195251, Russia

Corresponding authors: pilipenko_tv@spbstu.ru, belokurova_es@spbstu.ru, pankina_ia@spbstu.ru, shantonina@inbox.ru

Abstract. The present work is devoted to the problem of whey utilization, which is a by-product in the production of cheese and curd. We carried out analysis of modern Russian and foreign inventions aimed at waste-free milk treatment. We propose a modern waste-free method for curd production, which ensures the full use of the milk components. We carried out modeling of curd production process. The curd production process was presented as a combination of the most important technological operations – ultrafiltration whey treatment, mixing, thermocoagulation and clot treatment. We developed a structure of information flows, which totally characterizes waste-free technology of curd production. Alongside with that we proposed a structure of information flows accepted for mathematical modeling of the process. We propose models for formation of mathematical expectation of protein content in curd depending on the process factors, for which we used the regression equations. In this case, it turned out to be expedient to use linear dependencies. This can be explained by the fact that theory, research methods and calculation of linear models are developed deeper than others and require less computation. The question of applicability of such a model was resolved on the basis of checking its adequacy. The task of calculating the parameters of the model was solved on the basis of experimental data processing, which are the results of a passive experiment on study the waste-free curd production. Mathematical processing of experimental data allowed us to derive a regression equation and establish a correlation between the factors of curd production process and its protein content.

1. Introduction

During production of most types of dairy products (curd, cheese, casein) whey is formed, which can account for up to 75-85% of the raw material - milk. Currently, in Russia, most of the whey, unfortunately, is either not used at all and is discharged into sewage, or is not used rationally - as a raw material for production of feed for farm animals [1, 2].

It should be noted that a significant amount of useful substances of milk passes into the whey. The degree of transition of proteins into whey is 24.3%. Milk sugar (96.0%) is almost completely transferred to whey, as well as 22.5% of casein and 95% of whey proteins. Whey is saturated with lacto albumins and lactoglobulins - from 1.0 to 1.1%, which is important for adequate nutrition of a man of today [3, 4].

A scientific team from the Department of Food Sciences, School of Food Industry, University of Campinas (Brazil) found that whey protein is a potential and versatile ingredient at the development of a new and natural component of food. It can work as a texture modifier, thickener, carrier, gelling agent, surfactant component and foaming agent among other related functions and bioactivity. Nanocomposites containing whey proteins, for example, have been used by them as effective systems...
for encapsulating active food and drug components, increasing their solubility, transport, dispersibility, and bioavailability [5].

In the countries of the European Union, the discharge of whey into sewage is strictly prohibited, since it is known that when producing 10 tons of cheese or curd per day, the discharge of organic matter is equal to discharge of organic matter from 3000 people. In such countries where the technical base of cheese production is highly developed (France, Holland, USA), more than 90% of whey is processed. In the European Union, industrial processing of cheese whey for food products is 60%, and for feed and technical equipment it is 40%. In the USA, cheese whey processing is carried out into a wide range of products: 40% for dry whey; 30% for lactose; 10% for whey protein concentrate and dry demineralized whey; dry whey with hydrolyzed lactose; feed is only 3% and other technical products are 2%. Thus, in the USA for food purposes 95% of whey obtained in the production of cheese is used [6-8].

In Russia in 2011, 2,040 thousand tons of cheese whey were obtained, and only 779.2 thousand tons were processed by industry, which amounted to only 38.2%. Over the next 7 years, the percentage of whey processing decreased. The volumes of non-returnable waste (not processed whey) are constantly growing, as according to Art. 5 of the Tax Code of the Russian Federation, they are not taxed [9].

At the same time, Russian scientists are developing scientific foundations, methods and techniques for using whey in the production of various food products, including that for healthy nutrition [10, 11].

Membrane technology has revolutionized the production of dairy products. With the development of new technologies in membrane processes, it becomes possible to increase the use of whey in food production. Thanks to the introduction of membrane technologies, the full use of all milk substances occurs and the environmental friendliness of cheese and curd production is improved, preventing environmental pollution [12].

Nelson B.K, Barbano D.M developed a multi-stage MF process that removes a high percentage of whey proteins from skimmed milk, while creating a retentate with low concentrations of soluble minerals, non-protein nitrogen (NPN) and lactose [13].

The main developments both in Russia and abroad are aimed at increasing the efficiency of using dairy raw materials through introduction of new technologies based on development of membrane technology. Thus, the use of whey in production of food products, fodder and technical products will completely dispose such waste from the production of cheese and curd, which causes significant harm to the environment, polluting it with biological waste. However, it should be noted that in our country the volume of production of new types of milk protein products with WPC-UV (whey protein concentrate, obtained by ultrafiltration) is very insignificant [14-16].

2. Material and methods

In this work a waste-free method for curd production is proposed, which ensures the full use of the milk constituents. Herewith the organoleptic characteristics of the end product are improved, and the production process time is reduced. Coagulation is carried out by introducing of 10% ultrafiltration whey concentrate (WPC-UV) with an acidity of 250 °T and solids content of 18-20% in pasteurized milk with a temperature of 90-95 °C [17-19].

WPC-UV is obtained as follows: the whey from the previous batch of curd is pasteurized and subjected to ultrafiltration. The protein concentrate is pasteurized at a temperature of 72-74 °C with 20 s exposure time. For a more complete coagulation and compaction of the clot, the mixture is kept for 35-40 minutes. The prepared curd is of soft, spreadable consistence. The moisture content in the end product is 64%, the fat content is 10%, the acidity is 68 °T. Ultrafiltrate after pasteurization and introduction of flavoring components and aromatizing agents can be used for the production of refreshing drinks.

For a more reliable assessment of the process of curd waste-free production, we carried out a simulation of the technological process of curd production. As a basis for it we used an already existing model of a similar chemical-technological process. For the model being developed the curd production process was presented as a set of technological operators: ultrafiltration processing of whey -1, mixing - 2, thermocoagulation and processing of clot - 3. (Figure 1)
The purposeful functioning of the thermocoagulation tank is ensured by both interconnection of technological operators with each other through technological flows of clot and whey masses, and by interaction with external technological operators through technological flows of milk (A₁), whey (A₂), WPC-UV (A₃), filtrate A₄ and end product (A₆).

During the operation process, each technological operator converts physical parameters of the input process flows into the physical parameters of the output process flows in accordance with a given direction of technological connections of the curd production process.

The properties of each process flow can be characterized by a certain set of information variables. The process flow of milk A₁ supplied to the container for thermocoagulation (VDP) is characterized by flow rate $F_M$, fat content $Zh_M$, protein content $B_M$, acidity $K_M$, temperature $t_M$. The process flow WPC-UV (A₃), also supplied to VDP, is characterized by consumption $F_K$, fat content $Zh_K$, acidity $K_K$, protein content $B_K$, and temperature $t_K$.

The intermediate flow of clot and whey (A₅) is characterized by the physicochemical composition and properties of clot and whey (Q clot, Q W). The flow of end product (A₆) is characterized by flow rate $F_T$, fat content $Zh_T$, moisture content $V_T$, protein content $B_T$, physicochemical and organoleptic properties $Q_T$ and temperature $t_T$.

Output process flows of intermediate product (whey A₂) are characterized by flow rate $F_S$, fat content $Zh_S$, protein content $B_S$, temperature $t_S$. To maintain the temperature mode of the process, cooling water flows A₉, A₁₀, characterized by the flow rates $F_9$, $F_10$ and temperature $t_v$ are fed to the process operators.

### 3. Results and discussion

The obtained conclusions concerning relations between various stages of crud production process as well as complexity and multifactor nature of simultaneously occurring phenomena, justify the possibility of representing such objects as a single link of directional action for their mathematical description. The structure of information flows, which fully characterizes the waste-free method of curd production according to its protein content, is presented in Figure 2 (a).

We present each information variable that corresponds to a certain process which affects the protein content in the curd as an external input information flow. Then one can consider the waste-free crud production process as an information operator which transforms the input information flows into the output information flow - the protein content in crud.

When optimizing the waste-free crud production process, one should take into account only technological factors which provide better performance. In addition, when selecting process factors, one should consider only those that have a clear metrological meaning and meet the requirements for factors and its combination. All this allows excluding from further consideration some technological and other factors [20, 21]. The structure of information flows adopted for mathematical modeling of the process is shown in Figure 2 (b).
Due to the complexity and multifactorial nature of crud production for a healthy nutrition, it is not possible to obtain an analytical relationship between the process factors and protein content in crud. Therefore, to simulate this dependence, it is advisable to use experimental statistical methods. The validity of this approach is justified in a number of works devoted to modeling of technological processes [22, 23].

In this case, after selection of main group of factors, which determine the formation of protein content in the curd during the process stages, it is necessary to choose the form of relations between factors and the protein content. For this relationship, the main process factors are non-random values. The influence of unaccounted factors may cause discrepancies between the calculated values of the protein content in curd and the actual ones.

Therefore, the protein content should be considered as a random variable. In this case it is advisable to model the formation of mathematical expectation of the protein content in crud, depending on the process factors, for which the regression equations are used. In this case, it is advisable to turn to a linear relationship. This is due to the fact that the theory, methods of research and calculation of linear models

**Figure 2.** Parametric diagrams of crud production process:

a) Fully characterizing the crud production process,

b) Adopted for mathematical modeling of the process.
are developed deeper than others and require less computation. The question of the applicability of such a model is decided on the basis of checking its adequacy.

The empirical model describes the process only in the intervals of change of factors which will be considered during the experiment. The levels of factors characterizing the raw materials were in the following ranges: milk fat content from 2.7% to 3.0%, milk acidity from 14 to 19 °T, protein content from 2.8% to 3.0%, dry matter content from 10.0% to 11.7%; protein content WPC-UV from 16.4% to 20.4%, acidity WPC-UV from 247.9 to 325.4 °T. During the processing cycle of a homogeneous batch of raw materials, the levels of these factors can be considered constant, while the factors ZH, SB, BK, during the continuous technological process of curd production are uncontrollable. The level of factor BK has an impact on the crud production. With its increase, the quality of the end product deteriorates, and organoleptic indicators (consistency) also deteriorate. In this regard, the factor FK is taken constant and is 10% by weight of milk. This value was obtained experimentally. To stabilize the protein content in the end product, it is most convenient to use the change in acidity level of the UV concentrate (Kk).

In view of the aforesaid, the equation for this process of production of cheese will be written in the form:

$$B_T = B_0 + B_1 ZH + B_2 SB + B_3 BK + B_4 K + B_5 S$$

(1)

For convenience of subsequent mathematical processing the factors ZH, SB, BK, K, S were assigned code marks X1, X2, X3, X4, X5, respectively. Then equation 1 can be rewritten in the following form:

$$Y = B_0 + B_1 X_1 + B_2 X_2 + B_3 X_3 + B_4 X_4 + B_5 X_5$$

(2)

The task of calculating the model parameters was solved on the basis of processing the experimental data, which are the results of a passive experiment to study the waste-free crud production process. In an experimental study, the actually possible ranges of factor changes included in equation 2 were considered. This fact makes it possible to use the results of modeling in real production conditions. As a result, a linear model was obtained in the following form:

$$Y = 27.19 - 3.71X_1 + 0.54X_2 - 0.29X_3 + 0.01X_4 + 2.62X_5$$

(3)

Adequacy testing is an integral part of modeling, since the possibility of applying the obtained mathematical models in practice is determined by the required accuracy of describing the dependencies between protein content and process factors.

As a criterion of proximity of protein content in curd calculated from equation 3 and its experimental (real) values, i.e. the model adequacy, the coefficient of multiple correlation $P$ and Student's criterion $t$ can be used.

The following values were obtained: $P=0.773$; $t=5.15$ (at $P_{min}=0.75; t_{min}=3.1$). The given data testifies adequacy of the obtained mathematical model of a waste-free crud production process. In addition, checking the model adequacy was also carried out using the F-test. The hypothesis of the model adequacy is accepted if the calculated value of the F criterion is less than the $F_{tabl}$ value. In our case, $R_{crit}=1.484$, and $F_{tabl}=3.33$, with a significance level $q=5\%$ and the number of freedom degrees equal to 5. Thus, the obtained regression equation is adequate at a five percent level of significance.

4. Conclusions

The obtained results allow us to draw the following conclusions:

1. Basing on theoretical studies, we proposed modeling of the formation of the mathematical expectation of the protein content in curd, produced using waste-free technology.

2. We experimentally established technological factors which provide obtaining a product with high protein content. Mathematical processing of experimental data allowed us to derive a regression equation and establish a correlation between the factors of crud production process and its protein content.

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