Innovative Solutions in Processing of Milk Whey on the Base of Ecological and Economic Principles

I V Buyanova¹,a, S M Lupinskaia²,b, I A Smirnova³, I A Maseeva⁴,c
¹Kemerovo State University, Lenigradsky ave., 40v/97, Kemerovo, Russia
²Kemerovo State University, Moskovsky ave., 29/33; Kemerovo, Russia
³Kemerovo State University, Oktyabrsky ave., 61b/189 Kemerovo, Russia
⁴Kemerovo State University, Lenina ave., 148/41, Kemerovo, Russia

E-mail: aibuyanova_@mail.ru, blupinskaia@mail.ru, cmazeevaia@yandex.ru

Abstract. Development and introduction of innovative processing technologies on the base of secondary raw materials is a burning issue for modernization of dairy industry in the Russian Federation. Milk whey processing for production of concentrates is among of the most reasonable and promising trends. A unique technique of whey dewatering (dehydration) by the method of vacuum thermo-radiation is reported. IR-rays and infrared drying of products are considered up to date and efficient techniques in processing of food raw materials. Kinetics of vacuum dewatering is investigated; it facilitates control of the process time till the required concentration of dry substances is obtained. The study data revealed a specific feature of water removal. IR-rays have a wave length of irradiation, which influences solely on water in the product, penetrating to a depth of 7 mm, and it isn’t absorbed by product and microstructures, therefore, drying is possible at quite low temperatures, in the range 40 to 60 ºС, moreover, practically all vitamins, biologically active substances, beneficial micro-flora remain intact in the product, its color, taste and aroma are similar to the natural ones. Alteration of chemical composition in milk whey (protein, lactose, mineral substances) is reported in the process of concentration. Appropriate conditions of thermo-radiation vacuum dewatering of milk whey are determined: temperature of heating in the vacuum chamber – 80 ºС, thickness of the layer – 10 mm, residual pressure in the chamber – 2-3 kPa. The developed method of milk whey concentration was used for production of concentrated whey drinks enriched in biologically active substances from wild-growing raw materials. Technologically, production of whey-based drinks requires a preliminary extraction of biologically active components from dry wild-growing raw materials conducted with the help of ultra-filtrate (permeate) of caseous whey or by protein-free (clarified) caseous whey. Technological process, recipe, physical and chemical properties, and sensory characteristics of “Vitaminny” drink are given. Infrared vacuum dewatering increased concentrations of biologically active substances in “Vitaminny concentrated” drink almost by 2-4 times. Technological solutions reported in the paper for concentration of milk whey by IR vacuum dewatering and processing of whey used as an extraction agent of biologically active wild-growing raw materials can facilitate solution of ecological problems in dairy industry, improve economic efficiency, reduce the cost price of products and optimize the structure of milk raw materials, and create a great variety of manufactured products.

1. Introduction

In the 21st century dairy industry in Russia faces problems of agrarian business and searches for their solution, namely, competitive dairy production facilities in market conditions, waste-free production with deep and full milk processing; ecology-orientated science, engineering, technologies, and industry. Branch research institutes attempt to find a complex solution of these issues. For instance, deficit of raw
materials can be eliminated to a considerable degree via processing and using regular wastes of dairy industry. The reasonable use of milk components is a significant factor for the increase of production volumes in domestic dairy industry. Introduction into a technological processing cycle of defatted milk, butter milk, milk whey furthers structural optimization of milk raw materials, and broadens the range of manufactured products [1, 2, 3].

Milk whey and its components are valuable raw materials to be processed. Approximately 6 % of dry substances are in its chemical composition; that is 50 % of their concentration in milk; therefore, a widespread drain of whey into sewerage equals to annual losses of 1.5 Mio tons of milk. Milk whey recourses in our country exceed 5 Mio tons every year. International Dairy Foods Association has estimated that almost 50 % of whey produced worldwide (140 Mio tons) are drained into sewerage lines. In Russia it amounts even to 80 %; and only 20 % milk whey are processed in Russia [4].

For example, 1000 kg of milk whey drained into the sewerage lead to environmental problems, polluting water basins like 100 m³ of household sewage. In most countries of the world whey drain is forbidden and criminally liable [5].

The problem in whey processing, as State Research Institution All-Russian R&D Establishment of Dairy Industry claims, is lacking treatment facilities in almost 30 % of dairy companies. The shortage of financial funds is the main reason for insufficient renewal and upgrade of basic technological equipment (maximum 3-4 % per year), production assets keep aging. To date, the share of basic technological equipment meeting standards in effect does not exceed 12 %.

Therefore, development and introduction of innovative technologies for processing of secondary raw materials is one of challenges dairy industry in the Russian Federation is facing these days. Unlike Russia deep processing of whey is accepted in Europe, since economic potential of enterprises is higher, technology is well-functioning and stimulated by laws and regulations prohibiting whey draining [6, 7, 8].

Various processing technologies are necessary for different volumes of milk whey. The use of whey in manufacturing of protein concentrates, milk sugar, drinks, concentrated and dry products, hydrolyzates of whey proteins, lactulose is in focus of many Russian researchers [8, 9, 10].

Low percent by mass of dry substances in milk whey (around 6 %), weak resistance when raw keeping for 24 hours at temperatures of 4-8 °C and maximum 72 hours after pasteurization make difficult its rational use.

Production of concentrates from milk whey is a prospective trend in its processing. Concentration is considered a main method to prolong a shelf life of food products. Concentration makes it possible to reduce the volume of whey by 6 to 10 times, reduce costs of transportation, and prolong a shelf life.

The rate of physical and chemical, biochemical, microbiological processes is slowed down in a concentrated product and whey concentrates, being products with a long shelf life, can contribute to damping of seasonable fluctuations in manufacturing of dairy products, because a reserve is manufactured for the off-season period. Prolonging shelf life of valuable raw materials, it is possible to supply whey-based dairy products to the consumer market without any delays. Therefore, processing of secondary raw materials and production of concentrates are considered promising directions in the reasonable use of raw materials and efficient economic activity of the company in conditions of increasing volumes of manufactured products of raw materials available.

2. Results and Discussion

The reported study was conducted using a unique dewatering (dehydration) technique on the base of the most promising and efficient method of vacuum thermo-radiation, since it enables manufacturing of a high quality product at low power consumption [11, 12]. IR-rays and infrared drying of food products are the most up to date and efficient processing techniques [13, 14].

In our country this technology is far from being broadly used, although it is quite wide-spread in the world. Dehydration on the base of infrared irradiation in vacuum was surprisingly neglected; therefore, synthesizing of concentrates from milk whey was investigated by thermo-radiation evaporation of water.
The selected objects or research, their composition and quality, were assessed before experiments (caseous and cheese whey, juice-containing whey drink “Aktual”).

In the process of research concentration was carried out till the percent by mass of dry substances was 40 %, it was checked according to losses in mass of the object, taking into account the input percent by mass of dry substances. The parameters are layer thickness 10 mm, heating power 400, 600 W, temperature of heating 60 and 90 °С, constant residual pressure 2-3 kPa.

Kinetics of infrared vacuum dewatering of whey was investigated; it facilitates control of the process time in order to obtain necessary concentration of dry substances (Figure 1).

![Figure 1. Vacuum dewatering thermographs of whey at a heating power of 600 W.](image)

The data on changing temperature in the chamber, on the surface and in the center of the object are plotted in Figure 1. Dynamics was quite the same, without sharp differences within the process in the range of set heating power. The difference in temperature of surface and central layers was registered 1-2 °С at the beginning of evaporation and at the end.

A temperature of a ready-made concentrate was around 20-22 °С, so concentration was carried out in a partial load mode providing maximal stability of product properties. Heating up of the object till the stable temperature took approximately 15 minutes.

The findings pointed at specifics of water removal. IR-rays have a wave length of irradiation, which influences solely on water in the product. Infrared irradiation penetrates up to a depth of 7 mm and it isn’t absorbed by product and microstructures, therefore, drying is possible at quite low temperatures in the range 40 to 60 °C, moreover, practically all vitamins, biologically active substances, beneficial micro-flora remain intact in the product, its color, taste and aroma are similar to the natural product [11,13]. According to the results, concentration time at 80 °С in the process chamber is shorter in comparison with a mode of heating at 60 °C. Comparing two temperatures of heating, a temperature of 80 °С is more appropriate, since it provides maximal concentration of dry substances for a short period of processing. As a result of increasing heating temperature the time is almost double-shortened.

Alteration of chemical composition in milk whey is shown in Figure 2.
On the base of the data above a conclusion was made that water is removed in a regular way within the entire dehydration process and irrespectively to the temperature of heating. The temperature of the object in experiments was kept stable. The process differed in time. It was revealed that the temperature increase from 60 to 80 °C shortens the process. Dewatering involves two simultaneous processes: heat transfer for liquid evaporation and mass transfer in the product and from its surface. The internal movement is caused by the gradient of concentration. The data on moisture state laid the ground for selection of appropriate parameters for thermo-radiation vacuum dewatering of whey: heating temperature in the vacuum chamber – 80 °C, thickness of the layer – 10 mm, residual pressure in the chamber – 2-3 kPa.

Physical and chemical characteristics of the samples vs. final concentration of dry substances are given in Table 1.

Table 1. Physical and chemical characteristics of whey concentrate.

| Whey concentrates with percent by mass of dry substances, % | Percent by mass of fat, % | Percent by mass of protein, % | Titratable acidity, °T | Active acidity, pH | Concentration degree |
|------------------------------------------------------------|--------------------------|-------------------------------|------------------------|-------------------|--------------------|
| 13                                                         | 0.70                     | 4.4                           | 150                    | 4.6               | 1.75               |
| 26                                                         | 1.60                     | 6.0                           | 260                    | 4.9               | 4.00               |
| 30                                                         | 1.84                     | 7.5                           | 380                    | 5.2               | 4.61               |

Alteration depended upon the period of concentration. For instance, color of whey ranged from light green to light yellow. Taste and aroma were sour; then a sweetish taste was identified, and finally the taste was pronouncedly sweet.

The concentration of dry substances was higher provided that evaporation lasted longer. Evaporation rate of the whey concentrates $K = 4.6$. Therefore, all milk whey components increase in quantity, as a consequence, acidity rises. Visual control of samples of whey concentrates demonstrated that denaturation of whey proteins doesn’t take place. The increase of dry substances up to 30 % hardly causes modification of native properties of the object, and whey components demonstrate no structural modifications.

The findings of studies laid a ground for the development of concentrate-based production technology of whey drinks, the concentrates are synthesized by vacuum-radiation concentration of raw materials.
As for the present day and future prospects of dairy industry, the market of innovative products will expand not only due to new consumers but also because of growing demand for this group of products. Experts of information agency “INFOLine” disclosed mainstems, which dominate the world market of dairy products these days. The experts came to a conclusion that a main trend on the global market of dairy products is manufacturing of nutritional dairy products (products enriched in vitamin and mineral complexes for kids and adults; products enriched in protein and vitamins for people with active life style) [1, 2, 10].

As a result, some strategic pathways can be suggested in the development of enterprises in dairy industry: introduction of new dairy products on the market, including whey-based products with improved taste characteristics and enriched in natural additives for a healthy diet; modified products with plant raw materials instead of some milk components; products with protective factors; products with new consumer properties; dairy products with a prolonged shelf life and improved taste characteristics; products and drinks for a diabetic diet, consumption of which fills the gap in protein, minerals and vitamins, that is particularly important for the elderly.

Therefore, an innovative decision in processing of milk whey is manufacturing of preventive whey drinks using local wild-growing raw materials.

Siberian wild-growing raw materials are distinguished by broad-ranging biologically active substances, first of all, by the combination of nutritive and pharmacologically active components. Biologically active substances in wild-growing plants can hardly be synthesized artificially; therefore, they are well-digested and have a preventive and frequently a therapeutic effect [15, 16]. At the same time, wild-growing plants are found on the soils free of fertilizers and pesticides; consequently, they are more ecologically-friendly sources of biologically active substances than traditionally used plants [17].

The use of local raw materials in food manufacturing has a positive effect on economic efficiency of food industry, decreases the cost price of products and improves the diet of population by means of natural biologically active substances.

Technologically, production of whey-based drinks requires preliminary extraction of biologically active components from dry wild-growing raw materials conducted with the help of ultra-filtrate (permeate) of caseous whey or by protein-free (clarified) caseous whey. A new whey drink is called “Vitaminny”. Such raw materials as clarified caseous milk whey or ultra-filtrate, dry wild-growing plants, granulated sugar, sweeteners are used in production of whey drinks.

The production process of “Vitaminny” drink involves the following stages: preparation and filtration of milk whey ultra-filtrate and its quality assessment, preparation of dry components, heating up of the ultra-filtrate and extraction, cooling, centrifugation (or separation), introduction of sugar syrup and lemon acid, cooling down, canning, labeling and storage (Figure 3).

Acceptance of ultra-filtrate of caseous whey, dry plant raw materials, and granulated sugar is quantity-based, while their quality is assessed according to regulations in effect for a particular raw material. Plant raw materials (stinging nettle leaves and rosehip fruits) and 1/3 sugar syrup required in the recipe are placed into a heated up to 85±5 °C ultra-filtrate of caseous whey; extraction is carried out for half an hour with periodical mixing. The mixture is cooled down to 65-75 °C and centrifuged or separated.
Sugar syrup and lemon acid are added to the extract obtained. Instead of sugar syrup a sweeter can be used according to the recipe. The extract is acidified with 50% water solution of lemon acid to 70-75 °C; that is to give to the drink a more pronounced sour taste. A ready-to-drink product is cooled down by a cooling unit up to 6-8 °C and packed into 0.2 or 0.5 dm³ plastic bags. That is the final stage of the technological process. The recipes for the whey drink “Vitaminny” are given in Table 2.

**Table 2.** Recipes of “Vitaminny” drink, 1000 kg of the product, losses are not considered

| Component                        | Quantity, kg |
|----------------------------------|--------------|
| Ultra-filtrate                   | 880.0        |
| Stinging nettle leaves (dry)     | 8.0          |
| Rosehip fruits (dry)             | 16.0         |
| Granulated sugar                 | 75.0         |
| Sweetener                        | -            |
| Sweetener                        | -            |
| Lemon acid (powder)              | 1.0          |
| Water                            | 20.0         |
| Total:                           | 1000.0       |

Physical and chemical, and sensory characteristics of “Vitaminny” whey drink are to meet the standards given in Table 3.
Table 3. Physical and chemical, and sensory characteristics of “Vitaminny” drink.

| Characteristic                       | “Vitaminny” drink | sugar | sweetener |
|--------------------------------------|-------------------|-------|----------|
| Active acidity, pH                   | 4.40-4.45         |       | 4.40-4.45|
| Titratable acidity, °T               | 70-75             |       |          |
| Density, kg/m³, minimum              | 1036              | 1024  |          |
| Percent by mass of dry substances, %, minimum | 11.55             | 5.60  |          |
| Percent by mass of protein, %        | 0.1-0.2           |       |          |
| Percent by mass of fat, %            | -                 |       |          |
| Percent by mass of lactose, %        | 4.0               |       |          |
| Percent by mass of sucrose, %, minimum | 7.5               | -     |          |
| Phosphatase                          | Not present       |       |          |
| Temperature, °C, maximum             | 8                 |       |          |
| Appearance and consistency           | Homogenous liquid, no sediments and flakes |       |          |
| Flavor and aroma                     | Soft sour-sweet refreshing taste with pronounced flavor and aroma of rosehip |       |          |
| Color                                | Brown to dark brown |       |          |

The final whey product can be stored for maximum 3 days. The amount of important micronutrients in whey drinks is acceptable for their entire shelf life.

To produce drinks with a prolonged shelf life and higher concentration of biologically active substances we studied a possibility to concentrate produced extracts using the method of IR vacuum dewatering. Since dehydration in the technique above is carried out at low temperatures, preservation and concentration (approximately two-four times) of almost all vitamins and biologically active substances are achieved.

Table 4 provides comparison of vitamin content in raw products and final whey drinks with wild-growing raw materials.

Table 4. Vitamin content in raw materials and final whey drinks with wild-growing raw materials.

| Parameter                              | Ultrafiltrate | “Vitaminny” drink | “Vitaminny concentrated” drink, 30% dry substances |
|----------------------------------------|---------------|-------------------|---------------------------------------------------|
| Polyphenol compounds, mg/100 g         | -             | 235.4             | 700.0                                             |
| Tanning and coloring agents, mg/100 g  | -             | 16.3              | 50.0                                              |
| Vitamins, mg/100 g:                    |               |                   |                                                   |
| Thiamine (B₁)                          | 0.03          | 0.07              | 0.20                                              |
| Riboflavin (B₂)                        | 0.11          | 0.12              | 0.50                                              |
| Antiscorbutic (C)                      | 0.045         | 9.550             | 27.500                                            |
| Tocopherol (E)                         | 0.050         | 0.160             | 0.500                                             |
| Pyridoxine (B₆)                        | 0.090         | 0.072             | 0.200                                             |
| Cobalamin (B₁₂), μg/ kg                | 2.60          | 1.80              | 5.80                                              |
| β-carotene, mg/100 g                   | 0.007         | 1.200             | 2.800                                             |
| Chlorophylls, mg/100 g                 | -             | 1.8               | 4.2                                               |

The storage term of “Vitaminny concentrated” drink with percent by mass of dry substances 30% cannot exceed 3 months. The studies conducted report on high sensory characteristics of the concentrated whey drink; it contains a complex of biologically active substances, the shortage of which
is determined in present-day human diets [18]. Pilot batches of the concentrated whey drink were produced, tested and rated for taste in Department of Milk and Dairy Technology of Federal State Budgetary Educational Institution of Higher Education “Kemerovo State University”.

3. Conclusions

To sum up, technological solutions described above to concentrate milk whey by IR vacuum dewatering and processing of milk whey used as an extraction agent of biologically active substances from wild-growing raw materials are relevant for solution of environmental problems, which a dairy company might face, they further economic efficiency of the company, contribute to the reduction of cost price of products, as a consequence, a diet of population can be enriched by necessary natural biologically active substances.

Implementation of above solutions requires a system-based analysis of present-day conditions in dairy industry, taking into consideration international standards in production, processing, consumption and development trends; invention of reasonable, resource-saving technologies with deep, full and complex processing of basic and side raw materials; development of rational technological processes and equipment for entire processing of basic, raw materials and wastes aimed at minimization of all kinds or resources, including raw materials, material recourses, power etc., as well as at minimization of their losses.

References

[1] Novikova, N.A. Trends in the development of dairy industry in Russia [in Russian] // Agro-Food Economy, 2017. №3. P. 17-20.

[2] Kharitonov, V.D., Lisenkova, L.L., Lisitsyn, D.N. The main directions of development in dairy industry and greening issues [in Russian] // Milk processing, 2010. №10. Pp. 15-17.

[3] Malykha, EF, Kataev, Yu.V. Actual problems of the organizations of dairy industry of Russia [in Russian] // Science without borders, 2017. №9 (14). P. 5-9.

[4] Kuznetsov, N., Iurkova, M., Shibaykin, V., Novikova, N., Sadovnikova, E. // Economic Chronicle–XXI, 2016. – V. 158. №3-4. P. 26-30.

[5] Novikova, N., Shihanova, J., Alaykina, L. Conceptualization of the corporatization of capital // Theoretical and Practical Issues of the Modern Innovation Society Science editor: A. Burkov. San Francisco, California, USA, 2013. P. 123-124.

[6] Russian whey has a great future [in Russian] [Electronic resource]: Dairy market news every day. Access mode: http://www.dairynews.ru/news/uRossijskojSyvorotki_bolshojebudushheje.html.

[7] Trends in the global dairy market in 2017 [in Russian] [Electronic resource]: Dairy market news every day. – Access mode: http://www.dairynews.ru/news/trendy–mirovogo–molochnogo–rynka–v–2017–godu.html.

[8] Whey in Russia: processing problems and market prospects [in Russian] [Electronic resource]: Industrial markets research: Biotechnologies. – Access mode: http://www.abercade.ru/research/analysis/5148.html.

[9] Khramtsov, A.G. Innovative priorities of the use of whey on the principles of non–waste technology logistics [in Russian] / A.G. Khramtsov, I.A. Evdokimov, P.G. Nesterenko // Dairy industry. – 2008. – №11. – Pp. 28–31.

[10] Evdokimov, I.A., Volodin, D.N., Misyura, V.A., Zolotorev, M.S., Shramko, M.I. Functional fermented milk desserts based on acid whey [in Russian] // Foods and Raw Materials, Vol. 3, No. 2, 2015.

[11] Buyanova, I.V. Scientific substantiation of modes of concentration of raw milk [in Russian] / I.V. Buyanova, M.V. Kurnosova, N.V. Bardokina // Dairy industry, 2015. – №12. – Pp. 22–24.

[12] Buyanova, I.V. Technological basis of vacuum concentration of whey [in Russian] / I.V. Buyanova, M.V. Kotlyarova // Dairy industry, 2017. – №7. – Pp. 27–30.
[13] Pannov, P., Pannov, A., Tansakul, M. Chinnan // Journal of food science. – V. 72. – 2007. – №1. – P. E42–E47.

[14] Drying food. Infrared drying [in Russian] [Electronic resource] / 2009–2011. – Access mode: http://www.prosushka.ru.

[15] Dali, V.A. Biologically active substances of plants as a factor of detoxification of the body [in Russian] / V.A Dali, V.G. Makarov // Nutrition. – 2003. – №5. – P. 49–56.

[16] Kodentsova, V.M. Foods enriched with vitamins and minerals: their role in providing the body with nutrients [in Russian] / V.M. Kodentsova, O.A. Vrzhezinskaya // Nutrition Issues. – 2008. – №4. – Pp. 16–22.

[17] Egorova, E.Yu. Wild–growing raw materials for food supplements [in Russian] / E.Yu. Egorova, M.N. Shkolnikova [in Russian] // Food industry. – 2008. – №4. – P. 50–51.

[18] Tutelyan V.A. Biologically active substances of plant origin. Phenolic acids: prevalence, food sources, bioavailability [in Russian] / V.A. Tutelyan, N.V. Lashnieva // Nutrition Issues. – 2008. №1. P. 4–19.