

THE BEHAVIOR PREDICTION OF RAW MATERIAL SYSTEMS IN THE TECHNOLOGY OF WHEY BEVERAGES

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Abstract: The relevance of researches is due to the need to develop the technology of whey-based beverages with high viscosity. The paper presents the criteria for choosing a method of milk whey processing; a list of existing technologies as classification scheme is included. An alternative ingredient of plant origin - orange fiber Citri-Fi has been proposed to regulate the consistency of the beverage. Due to the special processing it has functional and technological properties - the ability to bind moisture up to 13 mass particles for 1 weight fraction of the fiber. Using mathematical modeling, the optimal conditions of including dietary fiber in the milk whey have been determined in order to predict the behavior of raw material systems in the production of beverages with high viscosity in the technological cycle. Samples of dietary fiber were studied using an ultraviolet microscope with the optical system of fluorescent illuminator. Indices of dynamic viscosity of hydrated whey plant mixtures were determined by Geppler viscometer. The visualization of the transformation of dry Citri-Fi while swelling in whey was shown, allowing you to observe a multiple increase in the volume of tubular fibers. The mechanism of water-retaining process is confirmed by the preservation of the fiber structure and a significant increase in the volume of the fragment of dietary fiber due to the absorption of the whey. The conditions for the preparation and application of orange dietary fiber in the milk whey to obtain beverages with high viscosity were studied. Optimum conditions for preparation and application of whey plant mixture in the bulk of whey are the amount of Citri-Fi - 4–5%, the stirring time - 10–15 min, the swelling temperature - 30–35°C. The rational amount of whey mixture is 10–12.5%, provided that the temperature - 50–60°C, the stirring time - 8–10 min. The rational parameters and technological scheme of whey beverages with high viscosity have been developed.

Keywords: Dry and hydrated samples of Citri-Fi, whey plant mixtures, mathematical models, viscosity characteristics, beverages with high viscosity

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INTRODUCTION

Beverage industry is one of the efficient ways of using milk whey, which is accessible form for the correction of human nutritional status by enriching physiological functional ingredients with a favorable effect on the metabolism and immunity. All non-alcoholic drinks, including whey, are refreshing products in the daily diet of people. Nutritional value of whey beverages is linked to ensuring the water balance of the body and the energy [1-3].

Criteria for selection of whey as a basis for beverages formulated in published data are the following [4, 5]:

- minimal pre-treatment with the existing equipment and the possibility of correction of technological processes;
- the properties and composition of whey, its relative availability and low cost, safety;
- seasonal peaks of coincidence of the beverage consumption and production of whey at dairy processing plants;
- ecological necessity of solving the problem of whey disposal;
- the possibility of combining with herbal ingredients at the organoleptic level and ensuring their technological properties.

The composition of whey predetermines its use for production of various beverages, including fermented

ones. Beverages based on native whey have high value due to the preservation of all milk components. There are several classifications of whey beverages; one of the variants is shown in Fig. 1 [6, 7].

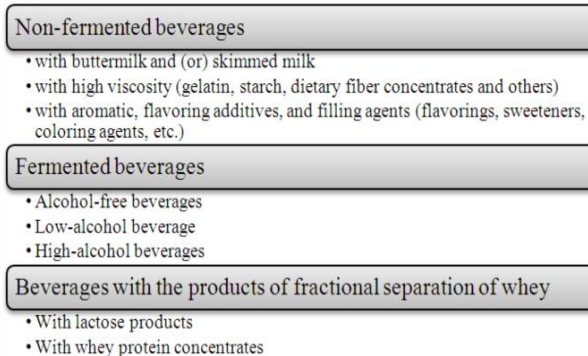


Fig.1. Classification of milk whey beverages.

There are a great number of technology solutions for complex processing of whey, including the production of beverages, however their implementation in the industrial process is insufficient [8-10]. This is due to the problem of ensuring production processes with modern expensive equipment, the lack of stringent en-

environmental requirements, sanitary control and economic motivation, low awareness of both producers and consumers about the nutritional and prophylactic properties of whey and products based on it, and the possibility of biotransformation in the carbohydrate and nitrogen derivatives (lactulose, ethanol, lactic acid and others).

The addition of gelatin, starch, pectin, xanthan and guar gum, agar, carrageenan, protein concentrate and others of different quantities into milk whey provides whey products with different structured viscoelastic characteristics including high viscosity beverages [11].

Problems that require scientific evidence in the development of technologies of whey beverages with high viscosity are the selection of available plant ingredient; the regulation of the guaranteed content of the plant component; the rationalization of the production process.

Alternatively, the ingredients of plant origin for the regulation of the consistency of beverages may be dry citrus concentrates (Citri-Fi) – the series of improved natural dietary fibers. According to the manufacturer, the introduction of the latter in the recipe composition of dairy products has a positive effect not only on their biological value, but also on the technological properties. Orange fibers possess textural and antioxidant properties [12, 13]. Their addition in the recipe composition would stabilize the viscosity characteristics, enrich whey beverages with dietary fibers, emphasize the fullness of taste and expand the product range.

The above information about the properties and the previous investigations of Citri-Fi – the determination of their solubility ($70.0 \pm 2.1\%$), and water-binding capacity (in water ($96.0 \pm 2.88\%$), in whey – ($95.0 \pm 2.85\%$)), were used to study the conditions of preparation and application of plant whey mixtures into the main volume of whey to produce beverages with high viscosity. For rational mixing and obtaining homogeneous beverage it is advisable to introduce pre-treatment with the testifying of this process [14, 15].

The aim of the paper is to develop whey beverages with high viscosity taking into account the possibility of predicting the behavior of raw material systems in the technological cycle.

OBJECTS AND METHODS OF RESEARCH

The object of research is orange fibers “Citri-Fi 200”, the manufacturer - Fiberstar Inc., USA (The conclusion of the state sanitary-epidemiological examination № 05.03.02-03/50735 of 14.08.2009); whey plant mixtures, the beverage with high viscosity.

“Citri-Fi 200” is the citrus dietary fiber derived from cell tissue of dried orange pulp by the mechanical processing without the use of chemicals. The organoleptic indices of orange fibers are the powder of light cream color with a neutral taste and smell with a shelf life of 36 months at a temperature neither lower than 0°C nor higher than 32°C , relative humidity - 30-60%. According to the manufacturers, “Citri-Fi 200” is capable of absorbing from 8 to 13 mass particles of water for 1 mass fraction of the fiber, the pH is 4.0-5.0. Nutritional value of 100 g is 224 kcal. Physicochemical and microbiological indices of orange fibers “Citri-Fi 200” are shown in Table 1.

Table 1. Indices of “Citri-Fi 200”

Physicochemical indices		Microbiological indices	
Total fat, %	1.08	Amount of bacteria, COE/g	$<10^5$
Total carbohydrates, %	82.55	Yeast, mold in 1 g	<500
The total amount of fiber, %:	75.3	Coliform bacillus in 1 g	<10
- Soluble	39.6		
- Insoluble	35.7		
Sugar, %	5.38	Salmonella, in 1 g	negatively
Proteins, %	7.38	E. coli, COE/g	<10
Ash, %	2.46		

Samples of dietary fibers Citri-Fi were investigated by the ultraviolet microscope (Axioskop 40, Carl Zeiss, Germany) equipped with the optical system of the fluorescent illuminator and the universal condenser working in the zoom range from 1 to 100 with the ability of rapid change of the filters.

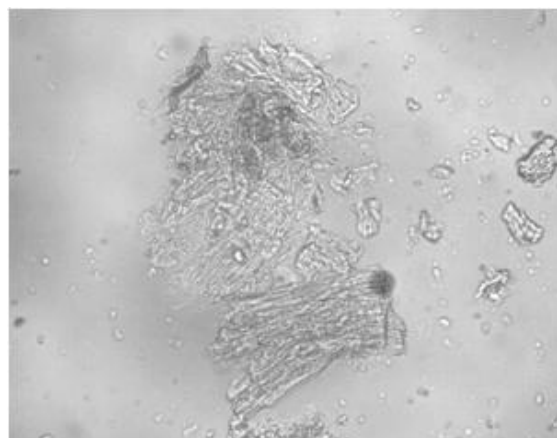


Fig.2. Visualization of Citri-Fi using autofluorescence.

While using autofluorescence a microphoto of “Citri-Fi 200” was obtained, visualizing an opened and dissolved structure of fiber cells links of which are able to bind a significant amount of fluid and keep it during the production process and product storage. It proves water - binding properties as it was claimed by the manufacturer.

The dynamic viscosity was selected as the main criterion of the efficient formation of viscous characteristics of whey plant mixtures and beverages.

With the application of mathematical package MathCad 15 three-dimensional regression models were constructed that adequately described the change of the dynamic viscosity of whey mixtures with Citri-Fi which were included in the main volume of whey to get beverages with a given consistency.

At the first stage for optimization and rationalization of the conditions for obtaining the homogeneous beverage with high viscosity model whey plant mixtures with different amounts of Citri-Fi (1–11%) were prepared. In native milk whey with the above indices heated to a temperature (30 ± 2) $^{\circ}\text{C}$ citrus fiber in various amounts was added and subjected to swelling from 5 to

15 minutes and different temperatures from 20 to 40°C. In hydrated whey plant mixtures the index of dynamic viscosity was determined using the viscometer Geppler BH-2. It was calculated by the formula:

$$\eta = K \cdot \rho - \rho_0 \cdot \tau, \quad (1)$$

where η is the dynamic viscosity (poise); τ is the time of the ball movement; ρ is the density of the ball material, kg/m^3 ; ρ_0 is the density of the test product, g/cm^3 ; K is the ball constant ($\text{cP} \cdot \text{cm}^3/\text{g} \cdot \text{sec}$).

To convert units of dynamic viscosity in the SI system the following ratio was used: 1 poise = $1 \cdot 10^{-3}$ Pa•sec.

RESULTS AND DISCUSSION

Researches were conducted in two stages: at the first stage the mixtures with optimal proportion of Citri-Fi and whey with respect to viscosity characteristics were simulated. At the second - mixtures in a certain amount were added to the bulk and adjusted to quality parameters by mixing.

Multifactor mathematical models were obtained that adequately described the change of dynamic viscosity in whey plant mixtures with Citri-Fi while changing three independent factors. The coded form of the equation describing the model is the following:

$$Y_1 = 2.545 + 0.0172 C_1 + 0.0092 C_2 + 0.0505 C_3, \quad (2)$$

where Y_1 is the dynamic viscosity of whey plant mixtures with Citri-Fi, 10^{-3} Pa•sec; C_1 is the amount of dietary fiber in the whey plant mixture, %; C_2 is the mixing time, min; C_3 is the swelling temperature, °C.

The adequacy of the models was tested by the determination coefficient $R^2 Y_1 = 95\%$, testifying to the high quality characteristic of the connection of the system coefficients, as well as the examination was done by using the F-test (F-Fisher criterion) and the t-distribution to assess the reliability of the correlation coefficients.

For a complex study and optimization of the component composition of whey plant mixtures three-dimensional regression models were constructed that adequately described the change of dynamic viscosity at the pair-wise change of two independent parameters ("the amount of Citri-Fi in whey plant mixture / the duration of mixing", "the amount of Citri -Fi in whey plant mixture / the swelling temperature"). For these models, the adequacy was tested by the method of root-mean-square deviation of calculated data from the experimental ones, which is less than unity.

Response surface and lines of constant values for the dynamic viscosity of whey plant mixtures with variable parameters of the swelling temperature, the duration of mixing and the amount of dietary fibers are shown in Fig. 3-4.

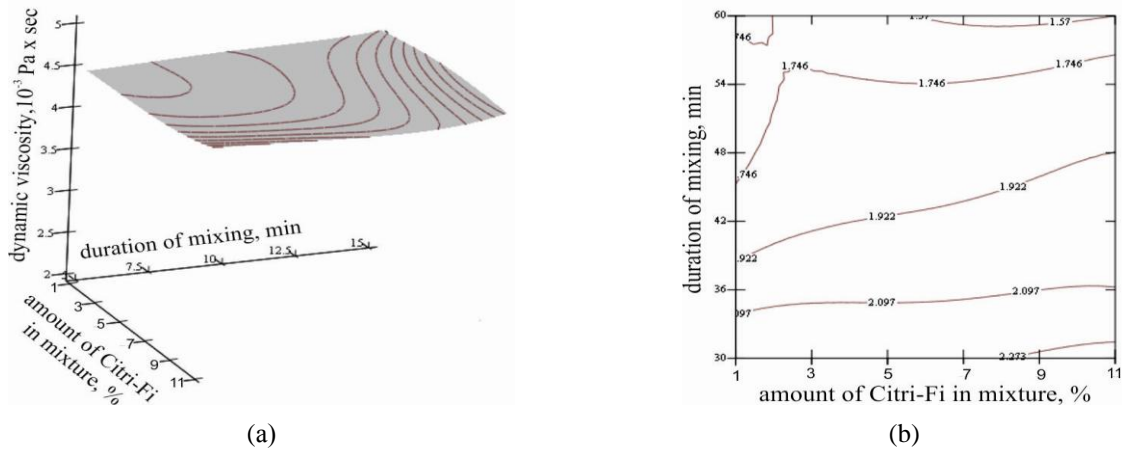


Fig. 3. Response surface (a) and lines of constant values (b) of a dynamic viscosity index in whey plant mixture with Citri-Fi depending on the amount of dietary fibers (C_1 , %) and the duration of mixing (C_2 , min).

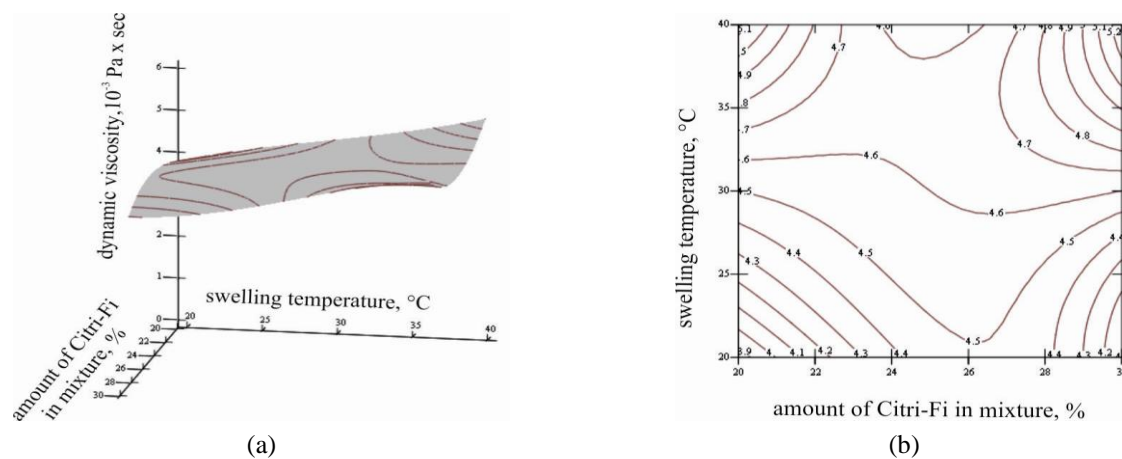


Fig. 4. Response surface (a) and lines of constant values (b) of a dynamic viscosity index in whey plant mixture depending on MF (C_1 , %) and the swelling temperature (C_3 , °C).

As shown in Fig. 3-4 the analysis of mathematical models and their graphical interpretation give the reason to consider that the amount of Citri-Fi, the duration of mixing and temperature significantly influence the swelling index of the dynamic viscosity of whey plant mixtures. The optimum range of values of the basic characteristics (dynamic viscosity index) is greatly narrowed in the area of mixing - 10–15 min and the swelling temperature of 30–35°C.

Linear increase in the values of variable parameters (C_1 , C_2 , C_3) leads to the growth of the dynamic viscosity index. Quadratic effects indicate the presence of areas of the extrema of the response function: the maximum for the input parameters. When adding Citri-Fi more than 7%, there is a rapid increase in viscosity – the apparatus problems are possible when incorporated in the bulk of the whey.

The comparison of response surface of output parameters and their lines of constant values allowed to set the optimal parameters of the process of increasing the viscosity of whey plant mixtures with the best index of the dynamic viscosity: the number of Citri-Fi - 4–5%, the duration of mixing - 10–15 min, the swelling temperature - 30–35°C.

To visualize the changes taking place with dry Citri-Fi while swelling in the whey the coloring agent Acridine Orange was used, which made it possible to observe how the tubular fibers are increased in volume by several times when adsorbing moisture. Some parts are deformed due to changes in soluble fiber (Fig. 5).

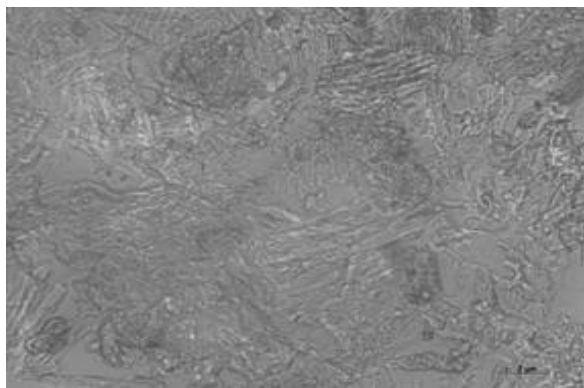


Fig. 5. Orange dietary fiber Citri-Fi.

It was found that orange fibers having a form of plates with a strong monolithic tubular structure like high-polymer complexes are damaged in some places due to mechanical processing (the cells were disclosed). Moreover, orange fiber in a non-hydrated state is characterized by a multilayer structure having the damaged walls of fiber with microcracks. This structure defines a high specific surface area of the carbohydrate matrix, and accordingly, increased moisture-absorbing capability. It is confirmed by the image of the hydrated sample Citri-Fi. There is a preservation of the fibrous structure and a sharp

increase in fragment volume due to the absorption of whey as it was mentioned above.

The next stage of research is to determine the optimal amount of whey plant mixture for adding in the main volume of whey to obtain a beverage with high viscosity. The control beverage is a viscous drink with stabilizer that resembles a liquid jelly (such organoleptic feature corresponds to the index with a dynamic viscosity up to $(2.55 \pm 0.13) \cdot 10^{-3} \text{ Pa}\cdot\text{sec}$). For obtaining the model beverage with high viscosity pretreated whey plant mixture in an amount of 5–15% with a particular amount of dietary fiber was added to milk whey. The mixing temperature was varied from 30 to 60°C, followed by mechanical processing of the obtained mixture for 6–10 min and then it was subjected to pasteurization at a temperature of $(78 \pm 2)^\circ\text{C}$ with a maturation of 2–3 min.

To study the effect of three variables of the process (the amount of whey-plant mixture, the mixing time and the temperature for introducing the mixture into the bulk of whey) to the index of the dynamic viscosity the approach to modeling mentioned above was applied once more. In encoded form the equation for the beverage with whey plant mixture is the following:

$$Y_1 = 2.8262857 - 0.00061 C_1 + 0.0095 C_2 - 0.021267 C_3, \quad (3)$$

where Y_1 is the dynamic viscosity of the beverage with whey plant mixture, $10^{-3} \text{ Pa}\cdot\text{sec}$; C_1 is the whey plant mixture, %; C_2 is the mixing time, min; C_3 is the temperature introducing into the whey, °C.

For a complex study of the influence of process conditions and optimization of the beverage composition with high viscosity when using the MathCad 15 three-dimensional regression models were constructed that adequately described the change of the dynamic viscosity of the beverage at the pair-wise change of two independent parameters ("the whey plant mixture / the mixing time within a total whey volume" and "the whey plant mixture / the temperature of introducing into the whey").

The obtained regression equations enable to predict the behavior of all systems throughout the technological process. Response surface and lines of constant values of the dynamic viscosity for the beverage with Citri-Fi with variable parameters – the temperature, the duration of mixing and the amount of whey plant mixture are shown in Fig. 6-7.

According to the analysis of the response surface shown in Figures 6-7, it was found that the optimum amount of whey plant mixture is 10–12.5%, with the introduction of the following modes in the bulk of whey: the temperature - 50–60°C, the stirring time - 8–10 min. Under these conditions, the dynamic viscosity index is $(2.64-2.68) \cdot 10^{-3} \text{ Pa}\cdot\text{sec}$.

Based on the results of the research the technology of whey beverage with high viscosity was developed. Parametric production scheme is shown in Fig. 8.

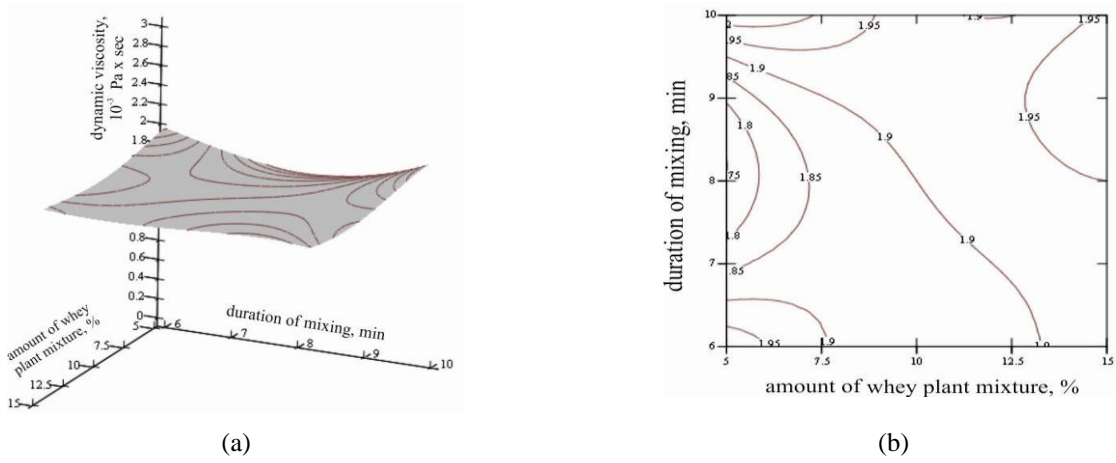


Fig. 6. Response surface (a) and lines of constant values (b) of a dynamic viscosity index of whey beverages depending on the amount of mixture with Citri-Fi (C_1 , %) and the duration of mixing (C_2 , min).

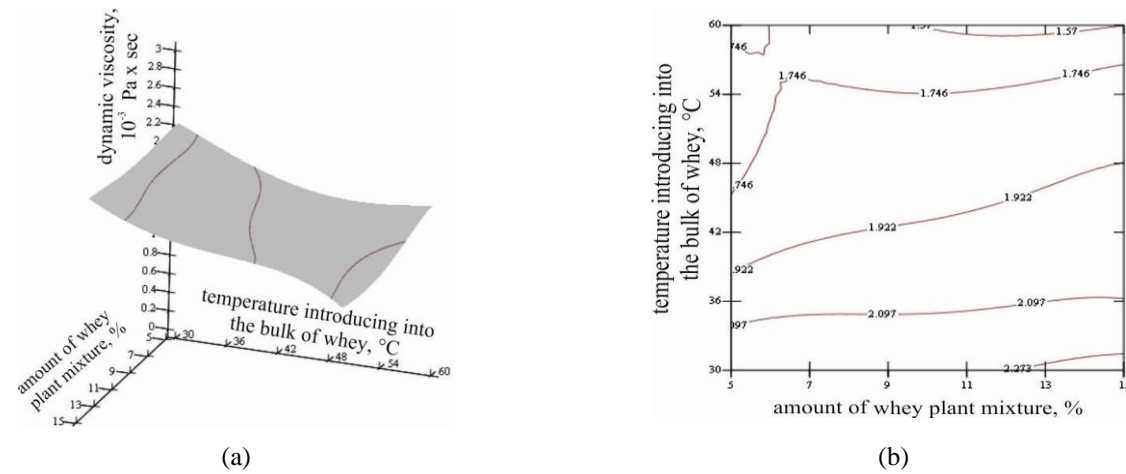


Fig. 7. Response surface (a) and lines of constant values (b) of a dynamic viscosity index of whey beverages depending on the amount of mixture with Citri-Fi (C_1 , %), and the temperature introducing into the bulk of whey (C_3 , °C)

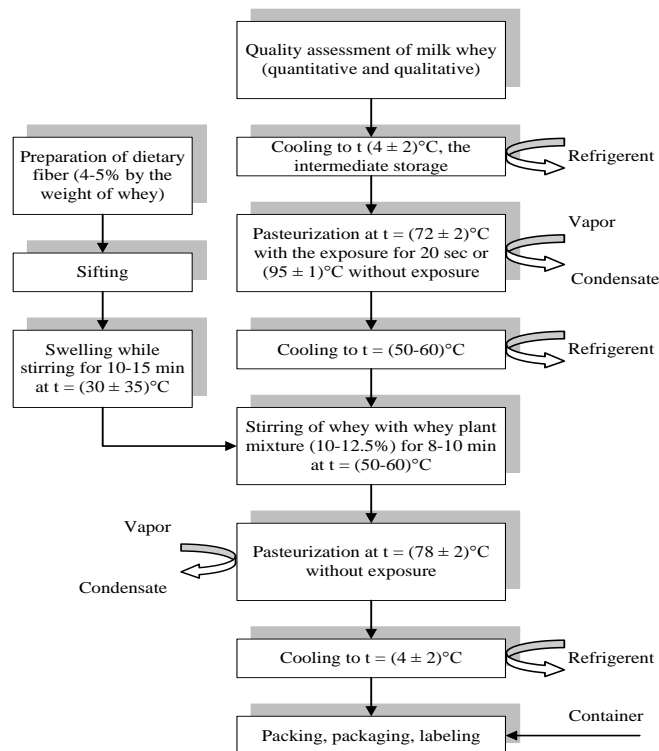


Fig. 8. Parametric production scheme of whey beverage with high viscosity.

CONCLUSIONS

The model is proposed to predict the behavior of raw material systems in the technological cycle to obtain whey beverages with high viscosity. The optimum parameters of the process of improving the viscosity in whey plant mixtures were determined. They are the amount of Citri-Fi - 4–5%, the stirring time - 10–15 min, the temperature of the swelling - 30–35°C. Also, a rational amount of whey plant mixture (10–12.5%) was found. The following modes

of introducing this mixture into the bulk of whey are the temperature - 50–60°C, the stirring time - 8–10 min.

The paper shows the visualization of dry and hydrated orange fiber samples that are characterized by the presence of complex polyangular associates linked in a solid fibrous structure having a large number of fragments of orange dietary fiber. Also the parametric production scheme of whey beverages with high viscosity was proposed.

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