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DYNAMIC MODELING OF THE WHEY SEPARATION PROCESS FROM BRYNDZA

Safarov Jasur Esirgapovich
prof., Tashkent State Technical University,
Sultanova Shakhnoza Abduvahitovna
prof., Deputy Mayor of Tashkent city
Ergasheva Zulfiya Kakhramanovna
Senior Lecturer, *Tashkent State Technical University*

Annotation. The article presents the results of research of mathematical modelling of bryndza production process using ultrasound.
Keywords: process; differential equation; differential equation; mathematical modelling; experiment; speed; automation; whey;

Introduction. In recent decades, there has been a sustained interest in the food industry to improve the efficiency and quality of production processes, especially in dairy processing [1,2]. Brynza, as one of the common soft cheeses, is a valuable product with high nutritional and biological value. However, in order to obtain cheese with specified physical and chemical properties, it is necessary to precisely control all stages of its production, especially the stage of whey separation from the protein clot [2,3,4].

In this regard, special attention is paid to innovative technologies that allow to intensify the process of whey separation. One of such promising technologies is the use of ***ultrasound influence***. Application of ultrasound allows to accelerate the process of syneresis due to cavitation phenomena, temperature increase at the micro level, destruction of weak bonds in the gel structure of the clot and activation of mass transfer. In this case, the frequency and power of the ultrasonic signal play a decisive role in determining the effectiveness of the impact [4,5].

In modern scientific literature there are some examples of modelling of filtration, drying and ultrasonic treatment processes in food technology. However, there are practically no complex dynamic models describing the process of whey separation from bryndza taking into account all key factors. Especially relevant is the task of building a ***differential model*** suitable for implementation in a software environment such as ***MATLAB/Simulink***, which will allow to use it not only in scientific but also in applied purposes - for forecasting, optimisation and automation of production [3,6].

The present work includes both theoretical justification and mathematical formulation of the problem and numerical implementation of the model with analysis of the results. In the future, it can be used to develop a digital twin of a production device for bryndza production [4,5,6].

The processes of liquid phase separation from coagulated or structured materials such as curd or bryndza can be described using various mathematical models [5,6]. The main approaches include:

- *diffusion models* based on Fick's equation to describe mass transfer;
- *capillary models* that take into account surface tension forces and capillary pressures;
- *hydrodynamic models* based on Darcy's law describing the filtration of liquid through porous media;
- *empirical and semi-empirical dependencies* derived from experimental data.

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The main equations of the model are:

$$\frac{dC}{dT} = -k_r C + \frac{Q_{in}}{V}(C_{in} - C) \quad (1)$$

Where C-concentration *of* dissolved substances in the volume ; Vk_r -removal coefficient of substance from the membrane surface; Q_{in} -flow rate and concentration of the incoming stream.

This is a standard implementation of a 1st order differential equation where: the state variable $-C$; the derivative $-\frac{dC}{dT}$ is given by the sum of two expressions.

Only basic Simulink blocks (Integrator, Sum, Gain, Constant) are used.

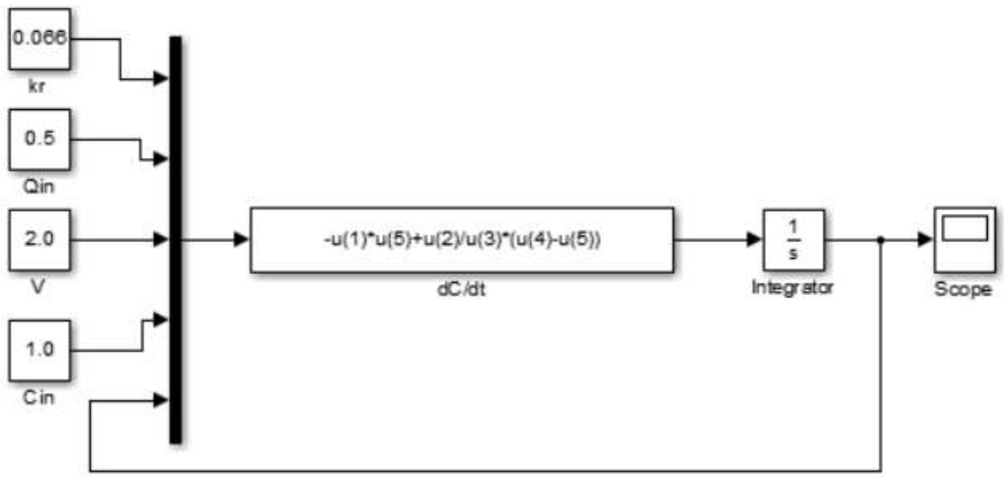

Fig. 1. Structural diagram of realisation of the differential equation of concentration in MATLAB/Simulink environment

The fluid flow through the membrane is described by Darcy's law:

$$J(t) = \frac{\Delta P - \Delta\pi}{\mu R_{tot}} \quad (2)$$

Where $J(t)$ -flow (flux) of liquid in time; ΔP -pressure gradient; $\Delta\pi$ -osmotic pressure; μ -viscosity of liquid; R_{tot} -summed flow resistance depending on membrane fouling [7,8].

The process of clot mass reduction due to moisture release can be expressed using a first order differential equation:

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$$\frac{dm(t)}{dt} = -k(f,T,S) \cdot (m(t) - m_\infty)$$

(3)

Where *m(t)*-mass of the clot at time *t*; m_∞ -residual mass (at complete separation of moisture); k-coefficient depending on the ultrasound frequency *f*, temperature *T* and salt content *S*.

The solution of the equation is an exponential function:

$$m(t) = m_\infty + (m_0 - m_\infty) \cdot e^{-kt}$$

(4)

This approach allows to easily interpret the experimental data, determine the rate of drying and predict the moment when a given moisture level is reached.

Theoretical foundations of filtration and ultrasound dynamics.

This section aims to outline the physical, chemical and mathematical foundations underlying the processes involved in the separation of whey from bryndza, especially under ultrasonic conditions.

Mathematical problem

The modelling problem is reduced to the solution of Eq:

$$\frac{dm(t)}{dt} = -k(f,T,S) \cdot (m(t) - m_\infty), \quad m(0) = m_0$$

(5)

Where k-coefficient depending on the ultrasound parameters.

Additionally, it is necessary to build a regression model of the dependence of *k* on frequency:

$$k(f) = a_0 + a_1 f + a_2 f^2$$

(6)

Where the coefficients a_1 are selected on the basis of experimental data by least squares method.

Analysing the combined plot of *T(t)* and *ϕ(t)* allows:

Determine the optimum operating temperature;

Identify the inflection point at which the separation rate decreases sharply;

Calculate the efficiency of the process in terms of energy to separated moisture ratio.

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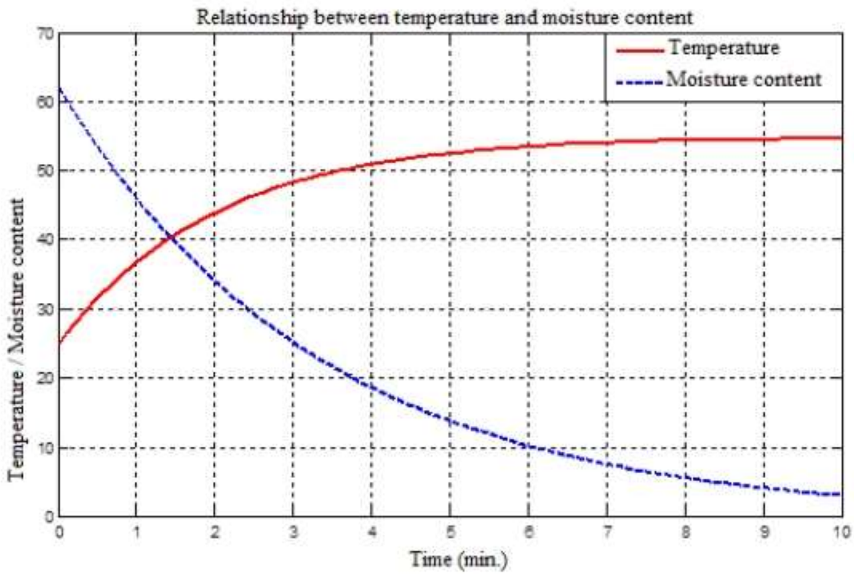

Figure 2. Conclusions from the graphical analysis

The process of whey separation from bryndza under the influence of ultrasound can be described as thermoacoustic desorption [4,5,6].

The most effective zone is the area where the temperature reaches 45-55 °C and the ultrasound intensity is 20-35 kHz.

Correctly selected parameters allow reducing the duration of treatment by 2-3 times compared to traditional methods.

Conclusion. Thus, this mathematical modelling and computer simulation can serve as a reliable basis for the design, optimisation and implementation of ultrasonic technology in the production of bryndza.

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