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Development of Beer Filtration Processes Using Membrane Technologies

The Author's Abstract
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GENERAL DESCRIPTION OF WORK

Topicality of research. The process of stabilization of microbiological and physicochemical properties of drinks is of theoretical and practical interest for brewers, in connection with interest in longer terms of storage of the product. In the conditions of modern, tough competition, the ability of beer to last long enough became an indispensable condition for its successful implementation. In this brewery, a qualitative filter is usually helped and, as an addition to it, pasteurization. The necessary degree of transparency of beer is traditionally achieved through qualitative filtration. By filtration, in this case, we mean separation from the beer of suspended particles, yeast cells and microorganisms.

The requirements that are imposed on the quality of bottled beer make the necessary multi-stage processing of the product, while it is necessary to preserve all the available quality attributes and to exclude a decrease in quality in the future.

Although all the existing types of equipment in the complex fully meet the requirements for the filtration process, provide the required quality and long shelf life of beer, they have a number of significant disadvantages:

- the need for production costs for auxiliary filtering aids;
- complexity of construction and, accordingly, operation and repair;
- relatively high losses of beer;
- labor intensity in maintenance;
- susceptibility to high bacterial contamination and concentration of solids in filtered beer;
- the problematical nature of the utilization or preparation of diatomaceous earth for povtornogo application.

Also, the process of beer filtration does not ensure complete removal of yeast cells and bacteria that form opacities, therefore, to ensure biological stability, all remaining microorganisms are destroyed - a pasteurization process is carried out, which is associated with greater energy costs and entails a change in organoleptic showers

The tasks solved in the process of beer filtration are becoming increasingly diverse. If twenty years ago the main task was to clarify the unfiltered beverage, then today in the filtration department are stabilized and carbonized beer, here additives are added to it, correcting the parameters of the initial wort, and beer mixing is made [51,79,93]. In addition, in countries that are not covered by the German law on the purity of brewing (according to which only water, malt, hops and yeast can be used to make beer), various additives are introduced into the beverage during the filtration phase. Beer is a complex system, the composition of the components in which it changes over time (in the first instance, we are talking about complex polyphenolic and protein compounds). Whatever components we take out of the beer, it will inevitably have an influence on organoleptic. Fractions that remain in poorly filtered beer, practically do not affect the taste. But after a certain time, they lead to the emergence of undesirable reactions, detrimental to beer. According to many experts, it is the low microbiological discipline has made pasteurization so popular in domestic enterprises, especially carried out in bottles [74]. It provides an opportunity to eliminate all possible consequences of secondary exposure or contamination of beer at the last stage. But pasteurization distorts the taste of beer. Most foreign experts agree that membrane filtration has every chance to seriously press kieselguhr and reach the level of the main technology. But according to the same forecasts, this will be possible not earlier than in 10 years.

The use of membrane technology in the process of beer clarification will eliminate all the deficiencies presented and come to a new level in the process of stabilizing the properties of beverages

Aim and objectives of research. The aim of the thesis is to find the most rational energy and resource-saving technological processes and devices capable of providing
effective clarification of beer In accordance with the goal, the following tasks were accomplished

- determination of the basic properties of beer as a filter object,
- justification of the selection of membranes and study of their properties,
- study of the kinetics and hydrodynamics of the filtration process baromembrane method,
- development and analysis of the mathematical model of the filtering process suspension
through semipermeable partitions, the creation of engineering methods of calculation,
- study of methods for controlling concentration polarization and their implementation in
practice,
- development of innovative equipment and technology for effective beer clarification

Novelty of research. The dependence of the viscosity of the Hermanudi beer on the content of yeast cells was determined. The kinetics and hydrodynamics of the beer filtration process by the baromembrane method were studied. A mathematical model of the process of filtering a suspension in a tubular channel has been developed, which makes it possible to determine the membrane selectivity with high accuracy, depending on the technological parameters of the process, the dimensions and concentration of the dispersed phase.

Practical bearing of research. On the basis of a complex of studies conducted in laboratory and production conditions, the expediency of using a membrane device with tubular elements in the process of beer filtration is shown. Designs for membrane equipment with a lower level of concentration polarization for effective beer clarification are proposed. Technological recommendations on the use of the microfiltration process and the technological scheme of the beer clarification area based on the developed mathematical model An engineering technique for calculating the process of microfiltration of suspensions, taking into account the change in the concentration of the dispersed phase in time and along the length of the channel.

Approbation of work. The results of the research were reported and discussed in forums of various levels. The results are published in the form of printed material in scientific journals and in conference proceedings.

Published materials:

On the topic of the thesis, a dozen printed works were published in local and international peer-reviewed journals.

The thesis consists of 160 printed sheets. Which contains 61 figures, 12 tables and 131 names of applied literatures.

Work contents

In the introduction, the modern state of stabilizing the microbiological and physicochemical properties of beverages, in particular beer, is characterized, the relevance of the theme of the dissertation work, the scientific novelty and practical significance of the studies performed.

The first chapter systematizes the literature data on the current state of the technology and the technology of beer clarification, identifies the main possible ways of intensifying the technology and the direction of creating highly efficient membrane equipment. The product characteristics and the current state of its production are considered. The process of beer filtration and the factors influencing the filterability of beer, stabilization of beer, ways of beer filtration, modern equipment for beer clarification.

The membrane processes of separation of membrane materials and structures, membrane modules, the classification of membrane systems, the phenomena of concentration polarization, the instrumental design of membrane processing of liquid food media, the mathematical description of the microfiltration process are analyzed. Based on the analysis, the goal and tasks of the dissertation work are formulated, solving the problems

In the second chapter, for the scientific and practical analysis of the filtering process, data characterizing the properties of the selected product and methods for their determination are given. To assess the filterability of beer, the following methods

- determination of the content of microorganisms,
- measurement of pH value,
- cold-alcohol test (according to Hapon),
- membrane-filtration test (according to Esser)

According to the results of the conducted analyzes of unfiltered beer, the concentration of yeast cells was 5.36 million cells / ml, the pH was 4.38, the turbidity was 78 units of EBU-it was concluded that the filterability of beer was unsatisfactory.

The poor filterability of beer was not a negative factor for us, because if the results of the experiment are positive, then there should not be any problems with clarifying the beer with good filterability. Since in the filtration process the concentration suspension is constantly changing, the dependence of the viscosity of beer on the concentration of yeast cells was determined and constructed (Fig. 1), which is adequately described by Einstein's equation.

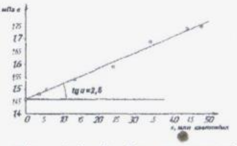

Fig. 1 Dependence of viscosity of beer on concentration yeast cells

When choosing the threshold for the retention of membranes, they were guided by the recommendations of literature sources and the characteristics of the product under study, namely the relative sizes of the beer particles. When the beer is clarified, the following substances are removed: mechanical impurity (1-60 μm), yeast (1-13 μm), bacteria (0,2- 5 μm) and part of colloidal particles (> 0.1 μm). In any case, one should also not forget that real pores are very different from idealized pores, and apart fromThe existence of a stationary or inactive layer of liquid pores membranes, te membrane selectivity will depend on the ratio of the radii of particles in the divided system and the pores in the membrane. Therefore, it was concluded that using membranes with threshold delay of less than 0.1 micron is inadvisable, since protein compounds and other substances forming physicochemical and organoleptic parameters of beer can be removed. Therefore, in the initial stage of the experiment, we used membranes with a pore size of 0.2 and 0.4 microns. membranes, first of all proceeded from the fact that it must have the maximum specific productivity with selectivity, which ensures that the quality of the permeate is satisfied. In addition, the membrane must have high chemical stability with respect to the solution to be separated and to the microbiological effect, high operating temperature. Investigating the market of membrane equipment and membranes, analyzing all the advantages and disadvantages presented, we chose tubular ceramic membranes of the CMFE type, which meet all the requirements. Further, the main physico-mechanical properties of membranes were studied: water permeability, allowable pressure, allowable pH range, porosity of the membrane depending on the pore size (Table 1).

Table 1.

Parameters of ceramic membrane filters

Threshold delay, µm	**0,2**	**0,4**	**1,2**	**3**	**5**	**7**
Water permeability at 20 ° C m^3/m^2-h	1	3,85	6,70	9,10	15	20
Permissible pressure, MPa	Guaranteed not less than 1					
Permissible range, pH	0 to 13 for a long time, More than 13 - for a short time					
Thickness of selective layer, mkm	10 to 45					
Porosity of the membrane,%	62	64	66	72	78	82

According to the obtained data, a scheme of the experimental installation was developed –

a "portioning" system with a complete recirculation mechanism.

To select membranes for microfiltration of such colloidal suspensions as beer, wine, grape juice and other fruit juices and to predict the effectiveness of industrial microfiltration, the filtrruence benefits on membranes were proposed. The results are presented mainly in the form of a constant, calculated on the basis of the volumes of permeate accumulated at different times.

In order to better define the applications of this kind of tests and the precautions to be taken when performing them, we also studied microfiltration at constant pressure on cellulose acetate membranes of colloidal suspensions of calibrated latexes.

Filtration at constant pressure is described by four laws of plugging:

Clear clogging $$k_b V = Q_0[1 - \exp(-k_b t)] \quad (2.1)$$

The intermediate case $$k_i V = \ln[1 + k_i Q_0 t] \quad (2.2)$$

The standard law $$k_s t = \frac{2t}{V} - \frac{2}{Q_0} \quad (2.3)$$

Filtration through the sediment layer $$k_c V = \frac{2t}{V} - \frac{2}{Q_0} \quad (2.4)$$

where: V is the volume of the permeate;

t-time;

k_b is the constant of the pure clogging law;

k_i is the constant of the intermediate filtering law;

k_c is the constant of the filtration law through the sediment layer;

k_s-constant of the standard filtering law;

Q_0 is the initial flowrate. Q

(conditionally and for microfiltration we use the term filtering).

Each of these equations is derived from the physical filter model. Thus, the law of pure clogging was obtained on the basis of the assumption that the fibrillar membrane consists of parallel pores, each particle reaching the membrane blocking the pore.

The intermediate law is derived on the assumption that the particle can be deposited on another particle, which leads to [illegible] increase in the probability of clogging the pores.

The standard law is obtained under the assumption that the pore volume decreases in proportion to the volume of the permeate as a result of the deposition of particles on their walls.

More familiar to experts, filtering through a layer of sludge is to increase the resistance of the filter baffle as a result of the accumulation of particles forming a layer of sediment.

In order to determine the most suitable equation for the experimental curve, we have developed a computer program that gives the constants k and Q_0 optimal for each model. Then we compared the values obtained for the optimal equation with the experimental data. If we consider the pairs of experimental values (ti, Vi) and (ti), the permeate volumes calculated from equations (2.1), (2.2), (2.3) and (2.4) for the optimal values k_b, k_i, k_s, k_c obtained from using a computer, you can calculate

$$\Delta = \sum_{i=1}^{N} (f(t_i \quad V_i))^2 \quad (2.5)$$

where: N is the number of experimental points; N

Vi- volume of permeate collected at time t_i.

Thus, the best of the models will be the one that will give the smallest value

$$e = \frac{\sqrt{\Delta}}{N} \quad (2.6)$$

which is the root-mean-square deviation of the considered mold for each experimental point.

The study was carried out on a third type plant. The amount of permeate as a function of time was recorded. Then the resulting curve was processed on a computer to determine the clogging model to which it best approaches.

In the third chapter, the description of the experimental setup (Figure 2) and the procedure for carrying out the experimental studies are described for the complete analysis and justification of the rational operating parameters of the process, the results of studies on the off-state and hydrodynamics of filtering the beer using barome-branck processes are described. The first stage

of the experimental studies was the determination of the permeability of membranes 0, 2 and 0.4 μm, which made it possible to make the removal of shrinkage of membranes, i.e. the membrane stability coefficient is equal to 1

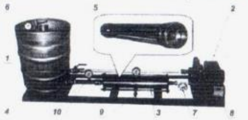

Fig. 2. Experimental setup: 1 - buffer tank, 2-centrifugal pump, 3-filtration unit, 4-frame, 5-membrane module, 6 - a manometer, 7 - a flowmeter, 8-starter, 9-outlet tube permeate, 10 - retort return nozzle

Further, the technological properties of 0.2 and 0.4 μm membranes were determined on the object under study - beer. The experiment was carried out for three hours, the resulting clarified beer was returned back to the container.

In each experiment, the working pressure was determined (Fig. 3) and the productivity (Fig. 4) of ceramic membranes according to unfiltered beer.

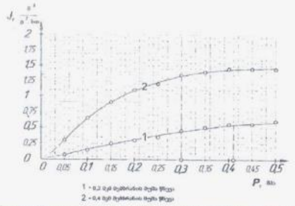

Fig. 3. Dependence of permeability membranes 0.2 and 0.4 μm from excess pressures

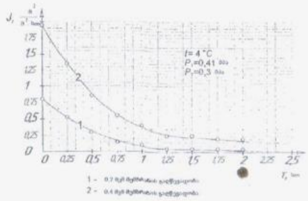

Fig. 4. Dependence of permeability membranes 0.2 and 0.4 μm in length filtering

To assess the quality of the filtrate obtained, such indicators as extractivity, volume fraction of alcohol, microorganism content, pH, turbidity were monitored. The results of filtered beer analyzes are shown in Table. 2.

Table 2

Results of filtered beer analysis on membranes 0.2 and 0.4 μm

Indicator name	Pore size, micron	
	0,2	**0,4**
The content of microorganisms, million cells / ml	not detected	not detected
pH	4,39	4,38
Turbidity, unit, EBU	0,37	0,47
Extractivity,%	10,55	11
Volume fraction of alcohol,%	4	4

According to the obtained data, the following conclusions were made: Filtering on membranes with a pore size of 0.2 and 0.4 μm, the extractivity of the beer and its chromaticity changed. Hence, a membrane of 0.4 μm was preferable, since it did not affect the quality of beer, completely removing bacteria and yeast particles. the permeability of the membrane was noticeably reduced over time and after two hours practically equaled zero. Thus, it was concluded that it is necessary to filter in several stages, that is, the variation in the retention threshold For preliminary The filtration was collected for subsequent filtration on a 0.4 μm membrane. As a result, the working pressure was determined for the membranes under study (7 µm - 0.100 MPa, 5 µm µm - 0.135 MPa, 3 µm - 0.190 MPa, 1.2 µm - 0.235 MPa) and the graphs of the permeability versus the filtering duration have been constructed (Fig. 5).

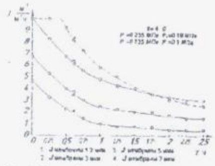

Fig. 5. Dependence of permeability membranes from the duration of filtration

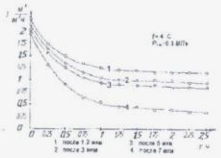

Fig. 6. Dependence of membrane permeability 0.4 µm of duration filtering after a preliminary clarification

The resulting permeate was evaluated for filterability (Table 3) and brightened on a 0.4 µm membrane. The permeability of the membrane with a pore diameter of 0.4 µm versus the duration of the microfiltration process is shown in Fig. 6.

Table 3

Microbiological and physico-chemical properties clarified beer

Indicator name	Pore size, µm			
	1,2	3	5	7
Content of microorganisms, mln. ml / ml	0,6	1,02	1,38	3,1
pH	4,38	4,38	4,38	4,38
Turbidity, unit EBU	0,77	1,22	1,27	1,64

As can be seen from the graphs obtained, the membrane permeability of 0.4 µm after pre-clarification on membranes 5, 3 and 1.2 µm increased almost fourfold, and after membrane 7 µm only in two times. In addition, filtration on a 7 µm membrane occurred with an obvious blocking of the pores, Therefore, its use was considered inexpedient. According to the analyzes, the filterability of the resulting beer is good for all membrane sizes of 5, 3 and 1.2 microns, therefore

For pre-clarification, a membrane with a higher capacity was selected, that is,

5 µm. The main problem in carrying out membrane processes is the reduction of permeability with In the course of time, mainly because of the formation of a gel layer with an increased concentration on the membrane surface. The main methods for reducing the concentration polarization can be include the following:

- the use of apparatus with narrow channels,
- temperature increase,
- pulsation of the solution,
- flow turbulence

The use of the first two methods is unacceptable, therefore, the influence of the tangential velocity over the surface of the membrane and the concentration of the dispersed phase on its permeability was investigated - Fig. 7.

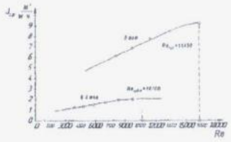

Fig. 7 Dependence of membrane permeability of the Reynolde number

As a result, the speed at which the gel layer was completely destroyed approximately 3.7 m / s. However, application of such a large speed leads to a sharp increase in the energy consumption for solution recovery and a significant increase in its temperature. Also, prolonged exposure to high velocities of the tangential flow can lead to inactivation of biologically active macromolecules.

To reduce the negative effect of concentration polarization in tubular membrane apparatuses, analogues of the authors (Rukhadze Sh.Sh., Starov VM), where the flow of a liquid is considered flat in the intermembrane channel under the influence of pulsating pressure, we have examined fluctuations in the fluidity in a tubular membrane channel caused by a periodic change pressure drop. Such oscillations can be carried out by alternating motion of the piston in one direction or the other.

Consider a long tube with a circular cross section. Let x be the coordinate in the direction of the tube axis, and r the radial distance from the middle of the pipe. It can be assumed that the phenomenon under consideration does not depend on the coordinate x, therefore, does not depend on x and the velocity component u in the direction of the tube axis. In this case, the remaining velocity components, and therefore the convective terms in the equation of motion for the direction coinciding with the axis of the tube, will disappear, and instead of the three Navier-Stokes equations, we obtain without any displacements exactly one equation

$$\frac{\partial u}{\partial t} = -\frac{1}{\rho}\frac{\partial p}{\partial x} - \nu\left(\frac{\partial^2 u}{\partial r^2} + \frac{1}{r}\frac{\partial u}{\partial r}\right) \tag{3.1}$$

with boundary condition

at r = R (i.e., on the walls of the pipe).

Let the pressure gradient caused by the movement of the piston vary according to the hormone law, therefore,

$$\frac{1}{\rho}\frac{\partial p}{\partial x} = K\cos nt \tag{3.2}$$

Where K is a constant. And in this case it is advisable to introduce a complex form for writing the equation (3.2); then we get

$$\frac{1}{\rho}\frac{\partial p}{\partial x} = Ke^{int} \tag{3.3}$$

Of course, only the real part of the complex quantity has a physical meaning. Further, we take for velocity u the following expression:

$$u(r,t) = f(r)e^{int}. \tag{3.4}$$

Substituting this expression into Eq. (3.1), we obtain for the amplitude distribution the differential equation

$$f''(r) + 1/r\, f'(r) - \frac{in}{\nu} f(r) = -\frac{K}{\nu}. \tag{3.5}$$

Solving this equation, we find the velocity distribution

$$u(r,t) = -\frac{K}{in}e^{int}\left[1 - \frac{J_0\left(r\sqrt{\frac{-in}{\nu}}\right)}{J_0\left(R\sqrt{\frac{-in}{\nu}}\right)}\right] \tag{3.6}$$

where there is a Bessel function of the first kind of zero order. Because of the linearity of equation (3.1), solutions (3.3) can be superimposed one on another. The investigation of solutions (3.3) in the general case, i.e. for any frequency n, is relatively dull due to the presence of Bessel functions with a complex argument. But the limiting cases of a very small and very large frequency are investigated quite simply.

If the dimensionless quantity $R\sqrt{n/\nu}$ is very small (very slow oscillations), then, expanding the Bessel functions in solution (3.3) into series and retaining only the first two terms in the latter, we obtain

$$u(r,t) = -\frac{K}{in}e^{int}\left[1 - \frac{1 - \frac{in}{4\nu}r^2}{1 - \frac{in}{4\nu}R^2}\right]. \tag{3.7}$$

or, going back to the material entry,

$$u(r,t) = \frac{K}{4\nu}e^{int}(R^2 - r^2) = \frac{K}{4\nu}(R^2 - r^2)\cos nt. \tag{3.8}$$

Consequently, with slow oscillations of pressure, the velocity oscillations take place in an identical phase with pressure oscillations, and the amplitude of velocity oscillations changes along the diameter of the tube in accordance with the parabolic law, i.e. in the same way as in a stationary flow.

If, however, the dimensionless quantity is very large (very rapid oscillations), then, by performing the asymptotic expansion of the Bessel function and bearing in mind that

$$J_0(z) \approx \sqrt{\frac{2}{\pi z}}e^{i(z - \pi/4)}, \tag{3.9}$$

we will get

$$u(r,t) = -\frac{iK}{n}e^{int}\left\{1 - \sqrt{\frac{R}{r}}\exp\left[-(1+i)\sqrt{\frac{n}{2\nu}}(R - r)\right]\right\}. \tag{3.10}$$

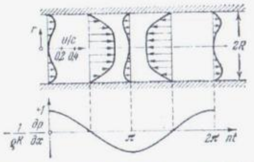

Fig. 8. Distribution of velocities with oscillating flow in the tube at various times of the oscillation period.

Gradient of pressure –

$$\frac{\partial p}{dx} - \rho K\cos(nt);\quad K = R\sqrt{n/\nu} = 5 = \frac{\pi R^2}{8\eta} = 3.125$$

or, going to the real record,

$$u(r,t) = \frac{K}{n}\left\{\sin nt - \sqrt{\frac{R}{r}}\exp\left(-\sqrt{\frac{n}{2\nu}}(R-r)\right)\sin\left[nt - \sqrt{\frac{n}{2\nu}}(R-r)\right]\right\}. \qquad (3.11)$$

For large values $R\sqrt{n/\nu}$, the second term in the curly brackets decreases rapidly with increasing distance from the wall, so only the first term, which does not depend on the distance from the wall, plays a role far from the wall. Consequently, the solution (3.11) has properties characteristic of the boundary layer. At a great distance from the wall, the oscillations of the liquid occur without friction and, moreover, in a phase shifted relative to the phase of the oscillating excitation force by half the period.

In Fig. 8 shows the velocity profiles of the oscillating flow in the tube at an average frequency $\left(R\sqrt{n/\nu} = 5\right)$ at different times of the oscillation period. From a comparison with the curve of the variation in the time of the pressure gradient plotted below, the advance phase of the flow in the middle of the tube is clearly visible in comparison with the layers close to the walls.

The time-average value of the square of the velocity for the case of fast oscillations, as is easily seen from (11), is

$$\overline{u^2(r)} = \frac{K^2}{2n^2}\left\{1 - 2\sqrt{\frac{R}{r}}\exp\left[-\sqrt{\frac{n}{2\nu}}(R-r)\right]\cos\left[\sqrt{\frac{n}{2\nu}}(R-r)\right] + \frac{R}{r}\exp\left[-2\sqrt{\frac{n}{2\nu}}(R-r)\right]\right\}. \qquad (3.12)$$

If the distance $y = R - r$ from the wall is small in comparison with the radius R of the tube, then the ratio R/r is approximately equal to unity. Then, by introducing a dimensionless distance from the wall

$$\eta = (R-r)\sqrt{\frac{n}{2\nu}} = y\sqrt{\frac{n}{2\nu}} \qquad (3.13)$$

We obtain from the preceding formula

$$\eta = (R-r)\sqrt{\frac{n}{2\nu}} = y\sqrt{\frac{n}{2\nu}}. \qquad (3.14)$$

The distribution of the time-averaged square of the velocity calculated from (3.14) is shown in Fig. 9. We see that the maximum of this average lies not at a great distance from the wall (ie not on the axis of the pipe), but near the wall, at a distance

$$\eta = y\sqrt{\frac{n}{2\nu}} = 2.28 \qquad (3.15)$$

y is the distance from the pipe wall; $\overline{u_0^2} = K^2/2n^2$ averaged over time, the square of the velocity from a small distance from the wall. (the so-called annihilation Richardson effect). This theoretical conclusion is in good agreement with the results of measurements by EG Richardson and E. Tyler.

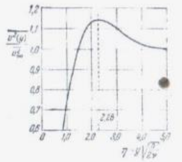

Fig.9. The distribution of the time-averaged velocity square for a periodic flow of a velocity square for a periodic flow in a pipe.

Therefore, one of the most promising areas is the use of pulsed regimes, since this method does not have the above disadvantages and is easily realized in practice.

In our case, a pulsating flow with the following characteristics

- frequency v = 0.025 Hz,
- duration of pulsation t2 - 3 s,
- duty ratio Q = 10%,
- amplitude APb = 0.25 MPa,
- flow velocity v, = 3 m / s

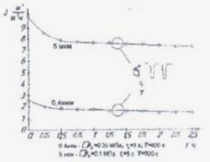

Fig.10 Dependence of membrane permeability 0.4 µm on the duration of filtering under pulsed conditions

The results of the experiment are shown in Fig. 10, from which it can be seen that the application of the impulse regime allowed to increase the productivity by an average of 96% and eliminate the formation of the gel layer. To determine the quality of the filtrate obtained, an organoleptic evaluation and prediction of the beer resistance was made (Table 4), which led to a conclusion about the high quality of the clarified beer obtained.

Table 4

Prediction of beer resistance

Turbidity, units EBS	**Colloid resistance, days**	
	Maximum	Minimum
1,63	90	40-55

The fourth chapter proposes a mathematical description of the process of microfiltration of a suspension in a tubular channel with the following assumptions:
1) the motion is steady; 2) the problem is axisymmetric; 3) the task is unidirectional; 4) the hydrodynamic structure is close to the kideal mixing in the transverse direction; 5) the hydrodynamic structure is close to the kideal displacement in the longitudinal direction

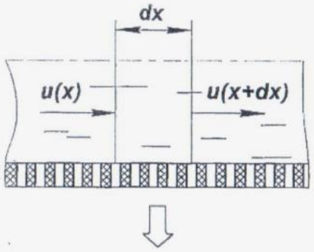

Fig. 11. The calculation scheme

The physical formulation of the problem makes it possible, according to accepted assumptions, to proceed to the stage of synthesizing a mathematical model. To this end, we select an elementary volume and write for it the differential equation of material balance

$$G(x + dx) - G(x) = -G_{\varphi}(x). \qquad (4.1)$$

$$u(x + dx) = u(x) + du / dx\, dx, \qquad (4.2)$$

with an obvious initial condition

$$u(0) = u_0.$$

After the mathematical transformations

$$u(x) = u_0 - \frac{2}{r}\int_0^x k(x,\tau)dx \qquad (4.3)$$

The material balance of particles in the suspension for an elementary volume in a differential form:

$$dN = dN^{+} - dN^{-} - dN^{0} \qquad (4.4)$$

where dN is the change in the number of particles in the elementary volume, dN^{+} is the number of particles entering the elementary volume, dN^{-} is the number of particles leaving the elementary volume, dN^{0} is the number of particles that settled or filtered through the porous wall.

After the mathematical transformations

$$\frac{\partial n(x,\tau)}{d\tau} = -\left(u_0 - \frac{2}{R}\bar{k}x\right)\frac{\partial n(x,\tau)}{\partial x} - \frac{2}{r}\left(\bar{k} - \bar{k}_0\right)n(x,\tau), \qquad (4.5)$$

with obvious boundary conditions n (x, 0) = 0; n (0, τ) = n_0.

Eventually

$$N(x,\Theta) = \left[\Theta - \frac{\ln(1 - Ax)^{-1}}{A}\right]\exp\left[\left(1 - \frac{A_0}{A}\right)\ln(1 - Ax)^{-1}\right] \qquad (4.6)$$

Where

$$A = 2\frac{\bar{k}}{r}\frac{h}{u_0}; A_0 = 2\frac{\bar{k}_0}{r}\frac{h}{u_0}.$$

Day of identification of the filtration coefficient k̄ Use the empirical law of filtering Darcy

$$\bar{k} = -c\,grad\,P. \qquad (4.7)$$

$c = (\mu r)^{-1}$ μ-viscosity of the fluid, r^0 is the specific resistance of the layer and membrane, m^{-2}.

If the flow rate of the filtrate through the membrane corresponds to a laminar regime, and the membrane itself together with the sediment on its surface are incompressible, then we can assume c = const, then

$$\bar{k} = \frac{\Delta P}{\mu(\tau_0 h_0 + R_n)}. \qquad (4.8)$$

To determine the migration rate coefficient, we use the Mednikov formula

$$k_a = \begin{cases} 7.25\cdot 10^{4} & \text{при } [illegible] \le 15.6 \\ [illegible] & \text{при } [illegible] > 15.6 \end{cases} \qquad (4.9)$$

The generalization of the solution (6) can be obtained by superposition of concentration fields. For a fraction with particle sizes from l to l + Δl, we write

$$\Delta n(l,x,\tau) = \Delta n_0(l) N(l,x,\tau) \qquad (4.10)$$

And introducing the dimensionless variables переменные

$$l = l/\bar{l};\ F_0(l) = \frac{\bar{l} f_0(l)}{n_0};\ F(l,X,\theta) = \frac{\bar{l} f(l,x,\tau)}{n_0}$$

Finally, we obtain the expression for the dimensionless density function , as a result, the relative mass concentration of impurities at the output of the filter

$$M_{max} = \frac{m(x_{max})}{m_0} = \int_0^{\infty} L^3 F(LX_{max})dt, \qquad (4.11)$$

Where $c_0 = k_v \rho \bar{l}^3 n_0$ is the mass concentration of particles at the inlet to the filter; k_v-coefficient of particle form.

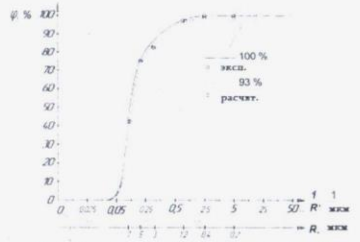

Fig. 12 Dependence of selectivity on pore size of membrane

As a result, an algorithm was developed (and later an engineering method) for calculating the selectivity depending on the technological parameters of the process, the size and concentration of the dispersed phase, taking into account the change in the concentration of the dispersed phase in time and along the channel length. Comparative analysis of the calculated and experimental data showed good convergence deviation of the calculated from experimental data did not exceed 17%. According to the obtained curves, a conclusion was made about the adequacy of the mathematical model.

In the fifth chapter, based on the results of the research, the original machine-instrumental design of the technological line of clarification of beer was developed (Fig. 13).

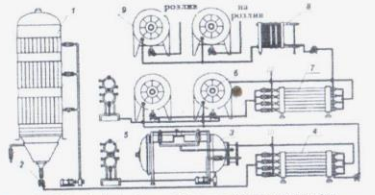

Fig. 13. Technological scheme of the area of beer clarification.
1-CKT, 2-centrifugal pump, 3, 4-membrane filter for pre-clarification of beer, 5-membrane apparatus for the recovery of beer from excess yeast, 6, 9 - buffer capacity, 7-membrane filter for the filtering of beer, 8- Plate cooler.

Based on the theoretical and experimental studies developed, the mathematical model was developed and proposed the biological stabilization of the beer and the original design of the membrane equipment for the process of clarification of beer, the distinguishing feature of which is resource and energy saving, the use of effective methods to control the concentration polarization, recycling of secondary resources, improving the quality of the finished product Fig. 14.15)

The following is an engineering procedure for calculating the process of microfiltration of beer in a tubular channel and the technical and economic indicators of the efficiency of introducing a clarification line using membrane systems. The cost estimate showed that when the beer is clarified using the microfiltration process, the total costs are four times less than in the case of filtering with kieselguhr filters.

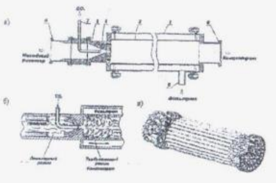

Fig. 14. Membrane apparatus for the filtration of gas-saturated food products: a) nrodolysy section of the membrane apparatus: 1-cylinder body, 2-membrane module, 3-injector, 4 feed pipe, 5-branch filtrate, 6- branch pipe, 7- pipeline C02, 14-injector for the supply of CO2;
b) the scheme of work; c) three-dimensional model

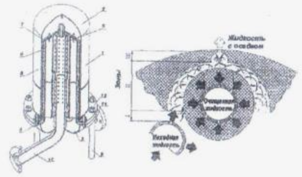

Fig. 15. Membrane apparatus with directed flows: three-dimensional model of membrane apparatus with directional flows: 1 - cylindrical shell, 2 - elliptic lid, 3 - elliptical bottom, 4 - filter holder, 5 - perforated distributor, b - filter elements, 7 - clamping plate, 8 - a profile element, 9 - supports, 10 - a branch pipe of input of a source liquid, 11 - outlet branch of the filtrate, 12 - flange; principle of operation: I - pressure zone, II - zone of speed conversion, III - zone of meeting of two flows.

MAIN CONCLUSIONS AND RESULTS

1. The physicochemical and microbiological properties of unfiltered beer have been studied, which have an effect on the process of beer filtration-the content of microorganisms is 5.68 million cells / ml, the value is 4.38, the turbidity is 78 units. EBU; the dependence of the viscosity of the beer "Germani" on the content of yeast cells in it was determined.

2. The choice of the membrane (tubular grade KMFE) and the configuration of the membrane system based on which the experimental setup was designed was justified.

3. The dependence of the amount of microscopic particles in vivo on their size was estimated, the structure of membrane properties was studied, which allowed to pre-plan the rational pore size and technological conditions of membrane operation

4. A computer program was developed to study the filterability of colloidal solutions

5. A mathematical model of fluid flow in a tubular membrane channel is developed under the influence of pulsating pressure.

6. The pattern of velocity distribution in a tubular membrane channel is established under the action of pulsating pressure.

7. The optimum frequency of pressure pulsation is established in the tubular membrane channel.

8. Kinetics and hydrodynamics of the filtering process were studied by the baromembrane method, the following sequence of filters

a) a filter with a pore size of 5 μm to ensure simultaneous coarse and fine filtration (Pp5 = 0.135 MPa, p = 76%, Jcp = 7.5 m^3 / m^2 h, v = 1.9 m / s, recirculation rate 3),

b) a sterilizing (filtering) filter with a pore size of 0.4 μm (Prab = 0.3 MPa, φ = 100%, Jcp = 1.7 m3 / m2h, v = 0.9 m / s, recirculation rate 5)

9. The physicochemical, microbiological and organoleptic parameters of the clarified beer "Germanyuli" have been studied, the stability of beer has been predicted, which made it possible to conclude about the high quality of the clarified beer obtained (TI 9184-103 2007, GOST R51174-98)

10. A mathematical model of the process of filtering a suspension in a tubular channel has been developed, which makes it possible to determine with high accuracy the selectivity of a membrane, depending on the technological parameters of the process, the dimensions and concentration of the dispersed

phase

11. Based on the developed mathematical model, the engineering procedure for calculating the process of microfiltration of suspensions has been improved, taking into account the change in the concentration of the dispersed phase in time and along the length of the channel.

12. The methods for controlling the concentration polarization are investigated, the use of a pulsed microfiltration regime to destroy the gel layer on the membrane surface is justified, rational parameters of the pulsed mode 0.4 μm -ΔP_b = 0.25 MPa,

τ_1=3 s, T=600 s, 5 мкм -ΔP_b = 0,1 MPa, τ_2=5 s, T=600 s

13. Designs of membrane equipment with a lower level of concentration polarization for effective clarification of beer have been developed.

14. Technological recommendations on the use of the microfiltration process and the technological scheme of the beer clarification section are proposed.

The main questions of the thesis are published in the following works:

1. Shota Rukhadze, Megi Afradonidze, Shalva Tsagareishvili. Grape wines and Biological stabilization of juices using electrolysis. Akaki Tsereteli State University "Moambe" 1 (11), 6 pp. 2018.
2. Afradonidze str. D., Rukhadze Sh. Sh., Martaleishvili n. V., Tsagareishvili Sh. D. "The study of colloidal filtration capability on computer computing. Akaki Tsereteli State University "Moambe" 2 (10), p.181-184. 2017.
3. REDUCTION OF CONCENTRATION POLARIZATION IN A TUBULAR MEMBRANE APPARATUS BY THE ACTION OF PULSATING PRESSURE. Collection of Works - International Scientific Conference Agricultural and Transport Machines: Development Prospects in Response to Modern Requirements of Standardization and Quality Management Kutaisi 2017.
4. Sh. Ruxadze, M. Apridonidze, A. Shotadze, Sh. Cagareishvili DEVICE FOR PROVIDING ECOLOGICAL SAFETY OF BALLAST WATERS AND PRODUCING INDUSTRIAL WATER AT THE DESTINATION SAEPORTS. Collection of Works - International Scientific Conference Agricultural and Transport Machines: Development Prospects in Response to Modern Requirements of Standardization and Quality Management Kutaisi 2017.
5. Sh. Ruxadze, M. Apridonidze, A. Shotadze, Sh. Cagareishvili ELCTRODEIONIZATION AND WATER USE PRACTICES. Collection of Works - International Scientific Conference FOOD QUALITY IMPROVEMENT PROBLEMS PROCEEDINGS. Tbilisi 2016.
6. O. Sesikashvili, D. Tsagareishvili, Sh. Tsagareishvili-Production of extradites of the porous microstructure of the nut flour filler. Collection of Works-International Scientific and Practical Conference „Innovative Aspects in Food and Hospitality Industry Equipment Development Under Present Conditions" Melitopol-Kyrylovka,Ukraine, 8–11 september 2015. pp.187-189
7. Tsagareishvili, O. Sesikashvili, Sh. Tsagareishvili -Thermoplastic extrusion process parameters affect the functional properties of extrudes. International Scientific and Practical Conference „Actual Problems and Modern Technologies of Food Products" Kutaisi, 2014, pp.398-400.
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9. D.Tsagareishvili, A. Tvalchrelidze, Sh. Tsagareishvili - Studies of Production Processes of Foods with Porous Structures by Thermoplastic Extrusion Method for the purpose of Designing Low-Productive Extruder. International Scientific-Practical Conference "Improvement of Food Production Technologies and Engineering" Conference Proceedings, Kutaisi, 2011, pp. 231-235