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Theoretical and experimental studies of the nanofiltration separation process under laminar flow conditions

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Abstract

The paper presents the nanofiltration process of mineral water from Borjomi, in particular, specifically from borehole No. 37, which is preceded by theoretical studies, as a result of which the speed range for implementing the laminar regime was determined for different heights of the working pressure cell.

Experimental studies of mineral water defluoridation-debarring have established that the liquid treated under laminar conditions of the nanofiltration process complies with the normative values of the “ZDK” for mineral waters.

Keywords: nanofiltration, laminar flow, Specific productivity.

Introduction (problem, relevance)

To ensure human health and food safety, it is necessary to comply with the standards of mineral waters, which is directly related to the development, creation and use of modern membrane systems of membrane equipment and technologies [1,2}. As is known, nanofiltration occupies an intermediate position in baromembrane processes between reverse osmosis and ultrafiltration. The reverse osmosis process provides almost complete demineralization of water, while nanofiltration serves for more selective purification. At the same time, it is equally effective in removing organic substances, bacteria and viruses.

We should also mention the advantages of nanofiltration technology: on the one hand, the possibility of partial desalination, and on the other hand, nanofiltration membranes can operate at lower pressures than conventional reverse osmosis membranes. {4,5,6,} As is known, under laminar flow conditions, an ordered movement of fluid is observed in layers, with particles moving along specific trajectories without chaotic motion and eddies. The creation of membrane nanosystem technology is preceded by a separate and complex discussion of scientific research, experimental, and design work to demonstrate the effectiveness of baromembrane processes.

For this purpose, the paper presents the results of both theoretical and experimental studies of the baromembrane nanofiltration process for laminar regime conditions. One of the most important issues in solving these issues is the creation of conditions that ensure the effective conduct of baromembrane processes through studies of the hydrodynamic and mass transfer processes of the flow in the filtration device.

To determine the hydraulic regime parameters, a theoretical calculation of the water flow parameters for the working node of the laboratory device was carried out using the Reynolds number Re = $\frac{v\,d}{\nu}$, where v is the velocity, d is the hydraulic diameter, and ν is the kinematic viscosity of the fluid.

The geometric dimensions of the pressure cell of the laboratory working unit are: width B=50mm=50×10^{-3}m; length l=540mm=540×10^{-3}m; heights:

h= 0.2mm=0.2 ×10^{-3}m ; h=0.35mm=0.35×10^{-3}m and h= 0.6mm=0.6 ×10^{-3}m. The kinematic viscosity coefficient of water at 20^{0}C is ν=1.004 mm^2/s = 1.004×10^{-6} m^2/s.

Table 1. presents the hydraulic characteristics for different heights of the working node under laminar regime conditions, Re number values for fluid velocities: 0.5 m/s; 1 m/s; 1.5 m/s; 1.97 m/s; 3.36 m/s; 5 m/s; 5.85 m/s.

Table 1. Results of the theoretical calculation

v(m/s)	0,5	1	1,5	1,97	3,36	5	5,85
h=0,2 mm F=B× $\boldsymbol{h} = \mathbf{50}$ **×0,2=10mm²=** $\mathbf{10 \times 10^{-6}} \boldsymbol{m^2}$; χ=2B+2h=100+0,4=100,4mm=100,4×10^{-3} R= $\frac{F}{\chi}\frac{10}{100,4}$ ≈0,09782mm=09782 ×10^{-3} m; d=4 × R =0,398406mm=0,398406×10^{-3}m; cn=5,85 m/s							
$v \times d$ (m^2/s)	0,1992 ×10^{-3}	0.3984 ×10^{-3}	0,5976 ×10^{-3}	0,7848 ×10^{-3}	1,3386 ×10^{-3}	1,992 ×10^{-3}	$\mathbf{2,3306}$ **×10^{-3}**
Re	198	396	595	781	1333	1984	**2321**
Q (m^3/s)	5 × 10^{-6}	10 × 10^{-6}	15 × 10^{-6}	19,7 × 10^{-6}	33,6× 10^{-6}	50× 10^{-6}	$\mathbf{58,5}$ × **10^{-6}**
h=0,35mm F=B× $\boldsymbol{h} = \mathbf{50}$ **×0,35=17,5m²**$\mathbf{17,5 \times 10^{-6}}\boldsymbol{m^2}$; χ=2B+2h=100+0,7=100,7mm=100,7×10^{-3}m;							

R= $\frac{F}{\chi}$=$\frac{17,5}{100,7}$ ≈0,17378 mm=0,17378310^{-3} m; d=4 × R =0,695134∂∂=0,695134×10^{-3} m; cn=3,36 m/s							
$v \times d$ (m/s)	0,3475 ×10^{-3}	0,6951 ×10^{-3}	1,0426 ×10^{-3}	1,3694 ×10^{-3}	**$\mathbf{2,3356}$ × 10^{-3}**	-	-
Re	381	762	1144	1583	**2326**	-	-
Q (m^3/s)	8,7 × 10^{-6}	17,5 × 10^{-6}	26,2 × 10^{-6}	34,47 × 10^{-6}	**$\mathbf{58,8}$ × 10^{-6}**	-	-
h=0,6mm **F=B× $\boldsymbol{h}$ = $\mathbf{50}$ ×0,6=30mm^2= $\mathbf{30}$ × $\mathbf{10^{-6}}\boldsymbol{m^2}$;** χ=2B+2h=100+1,2=101,2mm= 101,2 × 10^{-3} m; R= $\frac{F}{\chi}$=$\frac{30}{101,2}$ ≈0,296242mm=0,29442 ×10^{-3} d=4 × R =1,18577mm=1,18577×10^{-3} m; cn=1,97 m/s							
$v \times d$ (m^2/s)	0,5627 ×10^{-3}	1,125 ×10^{-3}	1,68752 ×10^{-3}	**$\mathbf{2,334}$ ×10^{-3}**	-	-	-
Re	569	1120	1680	**2325**	-	-	-
Q (m^3/s)	2,7 × 10^{-6}	5,4 × 10^{-6}	8,1 × 10^{-6}	**$\mathbf{11,20}$ × 10^{-6}**	-	-	-

According to Table 1, based on the theoretical calculation data, the critical values of the Reynolds number were determined for all three different heights in the pressure cell, which led to the appropriate velocity range for laminar flow: for the pressure cell h=0.2 mm, 0<v≤5.85 m/s; for h=0.35 mm, 0<v≤3.36 m/s and for =0.6 mm, 0<v≤1.97 m/s. In the case of all three heights, laminar flow is ensured for the velocity range 0.5 ≤ v<1.97 m/s.

Experiments were conducted on Borjomi water from well 37, the treatment fluid of which, along with other chemical elements, contains a large amount of fluorine and barium elements, which are hazardous to human health [7,8,9]

The experiments were conducted on the pressure cell of the working unit under different pressure conditions, where the transverse values of the laminar velocities were: 0.4 at - (0.53-0.50); 0.6 at - (0.52-0.48); 0.8 at - (0.50-0.46). Table 2 presents the results of the experiments.

Table 2. Performance values at different pressures for the laminar regime.

dP at	J_l l/($m^2 h$)
0,4	180
0,6	286
0,8	390

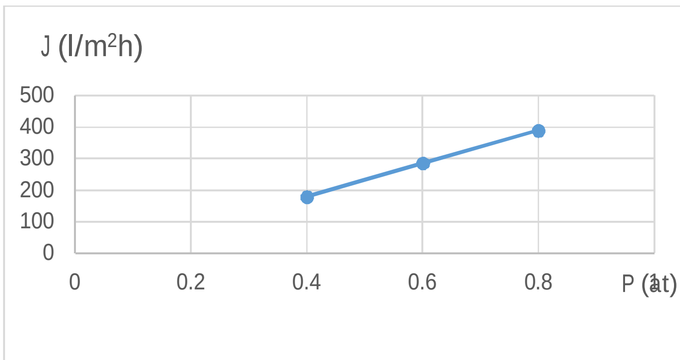

Fig. 1. Graphical representation of the dependence of performance on pressure during the nanofiltration process.

As can be seen from Fig. 1, the dependence of the performance on the pressure at the same velocities in the laminar regime during the nanofiltration process is linear.

According to the ISO standard "ZDK", the value of barium in mineral waters should not exceed 1 mg/l, fluoride - 5 mg/l. Also, the permissible range of calcium is 35-130 mg/l, and chlorine - 102-380 mg/l {3,10}.

Experiments for partial defluoridation-debarrierization of Borjomi mineral water were conducted in two stages. The first stage was ultrafiltration through a 0.2 μm membrane, which guaranteed purification from particles of 0.2 μm in size, which made the resulting liquid transparent and ensured sterilization. The transparency of the liquid treated through this process was 0.09 FTU, and with nanofiltration - 0.06 FTU.

Experiments were conducted on two types of membranes: K and S. The results of the experiments are given in Table 3

Table 3. Quantitative indicators of the chemical components of Borjomi mineral water well 37 for the initial and laminar mode treated liquid.

Technology	Ba, mg/l	F, mg/l	Ca, mg/l	Cl, mg/l
Unprocessed	3,27	5,26	51,7	386
Processing Membrane K	1,60	3,82	28,2	348
Processing Membrane S	1,05	4,11	38,5	359
"ZDK" normative values	1,0	2,0-5,0	35-130	102-380

As can be seen from Table 3, the fluid treated with Membrane S meets the "ZDK" normative values.

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ნანოფილტრაციული გაყოფის პროცესის თეორიული და ექსპერიმენტული კვლევები ლამინარული ნაკადის პირობებში

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ნაშრომში წარმოდგენილია ბორჯომის, კერძოდ ჭაბურღილი №37-ის მინერალური წყლის ნანოფილტრაციული პროცესით დამუშავება, რომელსაც წინ უძღვის თეორიული კვლევები,რომლის შედეგად მუშა სადაწნეო საკნის სხვასხვა სიმაღლის შემთხვევაში დადგენილ იქნა ლამინარული რეჟიმის განსახორციელებლად სიჩქარეთა დიაპაზონი.
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