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RESEARCHES FOR CAPITALIZATION AT A HIGHER QUALITY OF THE WHEY

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SUMMARY

In the processing of the milk, the whey is considered in many cases as a product without important value. In recent years it can see the increasingly of the possibilities of superior utilization of the whey. It is recognized for the health benefits of the whey with the both ways for people like prophylactic and also as treatment in the various diseases, including cancer. For greater of the whey value, it can be processed by different technologies in relation with the destination.

The paper contains a synthetic overview of the possibilities of recovery of the whey, detailing the use of membrane distillation method for the separation and concentration of whey. For investigation it was applied the method using Russian film composite membranes of the type MFFK-3. For that it has been a study about some influences of natural convention on the specific productivity of the used membranes. The scope of the experiments is the preparation of the membrane distillation (MD) technology for to apply on industry scale for a increasing of the performances of the whey utilizations.

Key words: *whey, capitalization, membrane distillation, performances*

INTRODUCTION

Whey or *milk serum* is the liquid remaining after milk has been curdled and strained. It is a by-product of the manufacture of cheese or casein and has several commercial uses. *Sweet* *whey* is manufactured during the making of rennet types of hard cheese like cheddar or Swiss cheese. *Acid whey* (also known as "sour whey") is obtained during the making of acid types of cheese such as cottage cheese.

For aged people, consumption of whey protein helps prevent bone loss. A diet, rich in whey protein, would help keep bones and muscles healthy and strong. Another effective benefit of whey protein is that it helps in supporting both healthy weight-loss, as an appetite suppressant and muscle enhancing nutritional programs. The market interest manifested is increasingly higher than for using whey proteins as nutritional supplements, in the sports, especially for bodybuilding practitioners. Whey protein is a rich source of essential amino acids for muscle growth healthy nails, skin and other connective tissues, thereby improving body composition and athletic performance enhancement for both adults and children, even infants. In its pure form, whey protein no contain little to no fat, lactose and cholesterol.

For to reap from the greatest whey value, it is necessary that to be studied in different processing possibilities by various technologies related to the destination. For the increasing of the percent from industrial recovery whey, more research is needed, using modern methods of treating whey. One of the most interesting methods of processing whey is using *membrane distillation (MD)*. This method performs basically a liquid evaporation process through the pores of the hydrophobic membrane. The driving force of MD is the difference in vapor pressure of the solvent on both sides of the membrane which is created by the temperature differences between the initial solution (giving side of the membrane) and the permeate (or refrigerant) on its receiving side. If to compare MD with baro-membrane methods (reverse osmosis, nano-, ultra- and microfiltration) MD has the advantage of being able to concentrate solutions of many non-volatile organic and inorganic substances to the concentrations almost close to the limit of their solubility (Bryk and Nigmatullin, 1994). At the same time permeate productivity remains satisfactory and the level of permeate purification is high. Therefore the usage of this process for juice concentration (Jiao *et al* 2004, Deshmukh *et al.* 2011), sugar-cane concentration (Nene *et al.* 2002), desalination of see-water (Al-Obaidani *et al.* 2008) and wastewater treatment (Gryta *et al.* 2006) is well known.

Great amount of whey is produced in dairy industry while making casein, soft and hard cheeses. It is used in obtaining a valuable lactose product (milk sugar). In order to do this, whey is clarified (remnants of milk fat and casein are separated), purified from ballast substances (whey proteins, mineral salts) and then lactose is concentrated and the solution with 50÷60 % of dry matters is directed for crystallization and drying.

However before being able to create effective equipment it is necessary to study the influence of the reciprocal direction of the mass transfer and natural convection, as well as influence of the amount of dry matters to the specific performance of the membranes at the temperatures close to industrial conditions.

For good capitalization at a higher quality of the whey, this paper want to establish some directions for the optimization of the conditions for the using MD whey, from the perspective of industrial extension. But, one of the preliminary priorities of industrial equipment design is to study the MD whey process, aiming at determining the equipment based on specific membrane performance in function of the dependence of the amount of dry matter and influence the direction of mass transfer mutual and natural convection.

MATERIALS AND METHODS

Membrane

For the researches it was taken the hydrophobic porous membranes MFFK-3 (Russia), with a nominal mean pore size of 0.45 μm and a porosity of 80÷85 %. They are characterized by the highest specific productivity in comparison with other membranes of the MFFK series. The selectivity of the MFFK-3 in sodium chloride (NaCl) during MD process is over 99,7% (Zmievskiy et al 2010, 2011).

Preparation of Solutions Model Solutions of Lactose and Whey

The model of the solutions of lactose were prepared by the dilution of the crystalline food lactose (TOV "Himlaborreaktiv", Ukraine) in distilled water that was heated up to 323±5 K. At first, whey obtained during the production of the fermented milk curds at the industrial plant was purified from the residue of milk fat and casein by microfiltration. To do this, a circulation installation with the filter element (BCCF, Aquafilter, USA) cartridge and pores with the diameter of 5 microns was used.

The whey circulation in closed circuit made it possible to form the dynamic membrane on the surface of the filter element and keep mentioned components. Whey was selected after 20÷25 cycles. Further on the filtrate was pasteurized by heating to 345±2 K and by holding during 15÷20 s with a further rapid cooling to the temperature of 288÷293 K. Whey proteins were separated by ultra-filtration circulation setup with flat membranes UPM-50 (Russia) of round form and area of $2{,}35 \cdot 10^{-2}$ m^2. Due to the fact that these ultra-filtration membranes transmit about 5 % of whey proteins, whey proteins are denatured by heat and can contaminate the membrane in the MD process. To avoid this, the ultra-filtration permeate was kept at the temperature of 333 K and 20÷30 minutes later it was filtered through filter paper.

Experimental Setups

The laboratory setup (Fig.1) was consisted of two circulation loops – a “hot” one (for whey) and a “cold” one (distilled water). The principle of operation and the composition of the setup is clearly shown on Figure 1.

Depending on the purpose of the experiment whey was given to the upper or lower chamber of cell 1, which was installed vertically or horizontally. Volume rate of the solutions in both circuits was 0.025 dm^3/s. Two types of cells 1 were used: with circular or rectangular shape. The working area of the membrane was $6.64 \cdot 10^{-3}$ m^2 and $4.8 \cdot 10^{-3}$ m^2 respectively. These cells were used for separation of model solutions of lactose and for whey separation respectively.

For to make the study it was used the known theory (Aleksandrov and Rivkin 1975) that the partial pressure of water vapor over concentrated solutions is less than over water without additives. This can be characterized by a parameter called as water activity a_w ($a_w \leq 1$). This indicator is defined by a well-known formula:

$$a_w = \frac{p}{p_w} \quad (1)$$

where: p, p_w – are partial pressure of water vapor over concentrated solution and fresh water accordingly, Pa.

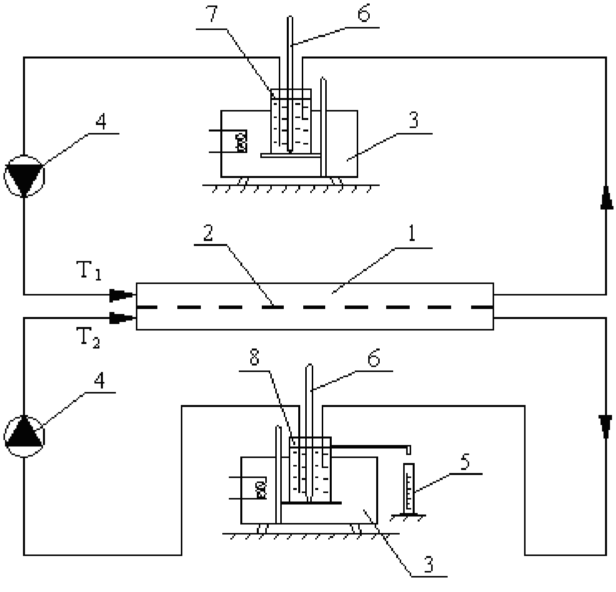

Fig. 1 Schematic of the experimental setup; (1) Membrane cell, (2) membrane, (3) thermostats, (4) peristaltic pumps, (5) volumetric flask, (6) thermometers, (7) container for whey, (8) container for distilled water.

For the explanation of the experimentally established fact the values of Gr·Pr by Eq. (2) were calculated for the camera with buttermilk. The values are presented in the table. It is known (Yurnev and Lebedev 1976) that the critical value of $Gr \cdot Pr_k$ is equal to $7 \cdot 10^5$. If $Gr \cdot Pr_k \geq 7 \cdot 10^5$ the effect of natural convection must be take into account and the type of fluid flow will be laminar even with $Re < Re_k$.

$$Gr \cdot Pr = \frac{g\beta_1 \Delta T d_e^3 \rho_1 C_1}{\nu_1 \lambda_1} \quad (2)$$

where $\Delta T = | T_m - T_1 |$, $Tm = 0{,}5\ (T_1 + T_2)$, $d_e = 2 \cdot b \cdot h/(b+h)$ – equivalent diameter, b, h – channel width and height, respectively . Physical properties of solutions were selected at $T = 0{,}5\ (T_m + T_1)$. Kinematic viscosity ν_1 and density ρ_1 were calculated by Eqs. (3) and (4)

(Polyanskiy and Shestov 1975, Polyanskiy and Shestov 1978), which were obtained while studying the properties of lactose model solutions. The choice of these formulas is caused by insufficient knowledge of ultrafiltration of whey permeate properties. According to the results (Byvaltsev *et al.* 1974, Byvaltsev *et al.* 1974) the thermal conductivity (λ_1) and heat capacity (C_1) were considered in calculations equal to λ_1=0,664 W/(m·K), C_1=3740 J/(kg·K). In the absence of data about the value of thermal expansion coefficient for our solution (β1) its value was considered the same as for water and was equal to $\beta_1=4{,}49\cdot10^{-4}$ 1/K.

$$v = \frac{1}{(\upsilon_{H_2O})^{-1} - A \cdot c} \tag{3}$$

where υ_{H2O} – viscosity of water at a temperature t of the solution, °C;

$A=2{,}29\cdot10^4+0{,}0465\cdot10^4\cdot(t-20)$.

$$\rho = \frac{10^5}{a \cdot (100 - c + \frac{e}{a} \cdot c)} \tag{4}$$

where

$$a = 1.0017 - \frac{0{,}15}{\frac{2000}{c} - 19} + 2{,}2 \cdot 10^{-4} \cdot t$$

$$e = 0{,}6058 + \frac{0{,}2}{\frac{2000}{c} - 19} + 5 \cdot 10^{-4} \cdot t$$

where c - is concentration of lactose, %; t - temperature of the solution, °C

Table 1 Dependence of Gr·Pr on the concentration of lactose (T_1=333 K, T_2=298 K)

c, %	$\upsilon\cdot10^7$, m^2s^{-1}	ρ, kg m^{-3}	Pr	$Gr\cdot10^{-4}$	$Gr\cdot Pr\cdot10^{-4}$
5	6,19	1007	3,50	1,881	6,578
10	6,97	1027	4,03	1,472	5,936
15	8,02	1048	4,73	1,113	5,267
20	9,44	1070	5,69	0,804	4,571
25	11,46	1093	7,06	0,545	3,845
30	14,59	1117	9,18	0,336	3,087
35	20,07	1143	12,92	0,178	2,295

The table above shows $Gr \cdot Pr < 7 \cdot 10^5$. However, knowing that the values of $Gr \cdot Pr$ with the level of dry matters at 5 % is 2.25 times higher than at 35 %, the natural convection has its influence on the MD process. The increase of solution viscosity in 3.24 times in this range of solids explains the reason why the difference between lines 1 and 2 (Fig. 4) disappeared.

RESULTS AND DISCUSSION

It has been stated that the optimal temperature while condensation of lactose is 298÷333 K. The solution is heated to 348÷353 K at the final stages when the amount of solids comes up to 50-55 %. This allows dissolving completely the chaotically crystallized lactose and increasing super saturation. Basing on the foregoing, temperature rates for solutions containing lactose have been selected. The temperature of 298 K was mainly kept for "cold" solution (distilled water) because it was easy to implement it at the industrial conditions.

For the first model, solutions of lactose were concentrated. This allowed determining the nature of the changes in the specific performance of the membranes MFFK-3 from the amount of dry matters.

Therefore, in according with formula (1), at the same temperature difference but with the gradual increase of the number of dry matter the driving force and the specific performance of the membranes are decreasing. The MD process is also negatively affected by temperature and concentration polarization (Termpiyakul *et al.* 2005). All this leads to the more rapid decrease of the specific membrane performance in comparison with the water activity. This is clearly shown in Fig. 2.

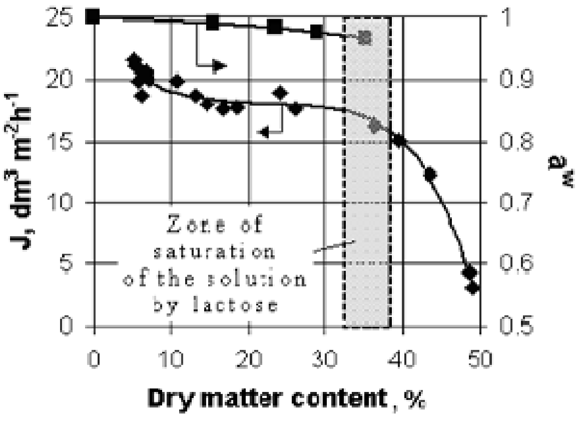

Fig. 2 Dependence of membrane MFFK-3, the specific productivity (J) and water activity a^w (Polyanskiy and Shestov 1975) on the dry matter content in the MD lactose model solutions. $T_1 = 330 \pm 2$ K, $T_2 = 298$ K.

Upon reaching the solubility limit of lactose there is a sharp decrease in permeate flow through the membrane. This can be explained by the increase of solution viscosity as well as by possible deposition of lactose crystals on the surface of the membrane. The presence of mineral and organic matter in real solutions increases the solubility of lactose. That is why whey treated by the mentioned above method is necessary to be thickening to the number of solids 50÷60 % (depending on the proportion of lactose/non sugars).

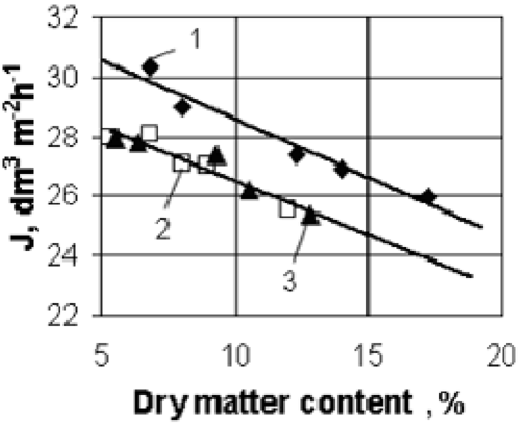

Fig. 3 Dependence of membranes MFFK -3 specific productivity (J) on the dry matter content of whey in MD; (1), (2) horizontal location of the membrane, the "hot" chamber is above and below the diaphragm accordingly (3) vertical position of the membrane. T_1= 333K, T_2= 298K.

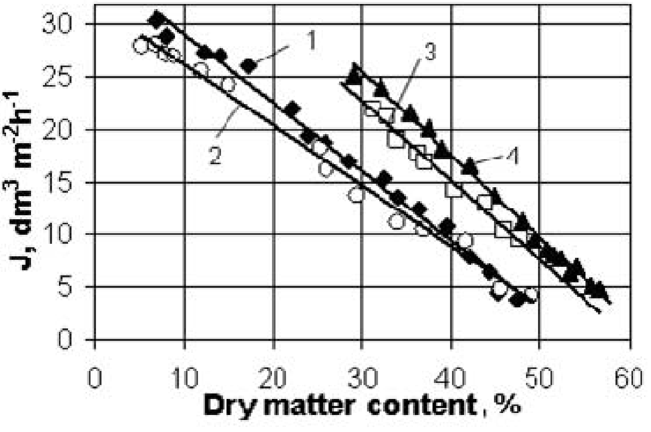

Fig. 4 Dependence of the specific productivity (J) of membranes MFFK-3 on the amount of dry matter of whey with the MD of membrane horizontal arrangement: (1), (2) "hot" chamber is above and below the diaphragm accordingly, T_1 = 333 K, T_2 = 298 K, (3) "hot" chamber is under the membrane, T_1 = 348 K, T_2 = 313 K, 4 - "hot" chamber is under membrane, T_1 = 348 K, T_2 = 298 K.

In further studies the cell membrane (Fig.1) was installed both horizontally and vertically. When the cell was in horizontal position in some cases whey was given into the upper chamber while in other cases it was given into the bottom ones.

Fig. 3 shows that the highest specific capacity of membranes MFFK-3 is reached while concurrence of mass transfer and natural convection directions. It is interesting that the flow of permeate through the membrane is almost the same if the "hot" chamber is located above the diaphragm or vertically. This is obviously the effect of concentration polarization. The direction of natural convection in these cases is not assisting the "dilution" of the diffusion layers of less concentrated solution. We can conclude from the obtained results that the membrane-distillation plants for the separation of whey with horizontal membranes MFFK-3 will have bigger capacity than in the case of vertical arrangement. That is why the further studies were conducted with the horizontal arrangement of the membrane.

As it is shown on Fig.4 the specific productivity of the membranes MFFK-3 is lower on average of 12 % if the direction of mass transfer and natural convection is not the same (line 1 and 2). These values are typical for the beginning of the MD process of whey when the amount of dry matters does not exceed 5-10 %. With increasing of mass fraction of solids discrepancy is reduced and this difference virtually disappears by reaching 35-40 %. This phenomenon is primarily because the viscosity of the solution increases that leads to the deceleration of mass transfer by natural convection in the working chamber volume.

Due to the fact that high temperatures adversely affect the lactose and can be recommended at the final stages of concentration, the separation of whey at temperature 348 K were carried out with the quantity of dry matter above 25 %. The increase of specific membrane performance was observed even at the same temperature difference of the original solutions (line 1 and 3, Fig. 4). This is due to the nonlinear dependence of the partial pressure of water vapor on the temperature. Therefore, at the same temperature difference the driving force of the MD process will be higher at higher average temperatures. For example, when $\Delta T = 35$ K, $\Delta p = 16\,390$ Pa, if $T_1 = 333$ K and $T_2 = 298$ K (without taking into account the temperature polarization); $\Delta T = 35$ K, $\Delta p = 30\,500$ Pa, if $T_1 = 348$ K and $T_2 = 313$ K.

Fig. 4 shows that raising the temperature of whey and the driving force accordingly provides more concentrated solution. The linear dependence of specific performance and number of dry matter indicates the absence of crystallization of lactose in the experimental conditions. Increasing of ΔT enlarges the effect of temperature polarization on the process of MD. For example, Δp (excluding thermal polarization) increases to 12.3 % and specific productivity to 8.5 % (lines 3 and 4).

CONCLUSIONS

From these researches it has been stated that the dependence of the specific performance of the membranes MFFK-3 on the concentration of solids of whey is linear in the range of 5÷58 % solids. When the membrane MFFK-3 was placed In the horizontal position, their specific productivity increases on average to 12 % if the direction of mass transfer and natural convection are the same. However, with the increase of viscosity when the amount of dry matter is 35÷40 %, the effect of mutual direction of mass transfer and natural convection disappears. In other words it is not important the position of the "hot" chamber: under the membrane or over it. Also, the membrane distillation (MD) in setup with membranes MFFK-3, for the separation of whey will have better performance if the membrane is placed horizontally.

Given these optimizations of the equipment of whey processing it will give a high quality of the components from whey, thus increasing the possibilities of capitalization of whey in the industry.

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