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Demineralization of natural sweet whey by electrodialysis at pilot-plant scale

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ABSTRACT

Demineralization of sweet whey was performed in a pilot electrodialysis unit EWDU-P1 provided with EDR stack with 50 membrane pairs of membranes RALEX CMH-PES and AMH-PES. Experiments were carried out at 15°C, which was chosen to reduce microbial growth and to minimize microbial degradation of organic components with nutritional value (especially lactose). Batch process of whey demineralization was ended when the conductivity of diluate decreased of 90% (87% decrease of ash content). During the process constant outer voltage was kept. The influence of different outer voltage and spacer thickness (0.8 mm and 1 mm) on the velocity of salt transport and energy consumption was studied. At higher outer voltage 90% demineralization was reached earlier, but energy consumption increased too. The spacer thickness did not have significant effect on the length of the process and energy consumption. The transport of individual salts and losses of organic components were studied too. Removal of chloride (up to 99%) and potassium (95%) was the most effective; the lowest cut appeared for magnesium (75%) and calcium (80%). Losses of lactose were negligible; decrease of crude protein content was maximally 5%. Decrease of titratable acidity was observed too.

Keywords: Whey; Demineralization; Electrodialysis; Ion exchange membranes; Ion transport

1. Introduction

Whey is a by-product from production of cheese, curd or casein. It is a source of quality proteins and lactose, but relatively high concentration of salts has a negative effect on functionality and organoleptic properties of whey [1,2] and limits its utilization in food industry. Whey can be demineralized either by means of ion-exchange resins, by membrane separation processes [3,4] or by combination of both types of technologies. Among the membrane processes electrodialysis (ED) or nanofiltration (NF) can be applied. Nanofiltration is suitable only for partial demineralization of whey, whereas electrodialysis and ion-exchange are convenient for achieving higher levels of demineralization.

During electrodialysis small electrically charged ions are transported through ion-permselective membranes (ion-exchange membranes) from desalted stream (diluate) to stream with higher concentration of salts (concentrate). The driving force of the processes is the difference of electric potential. Ion-exchange membranes are permeable only for small molecules; larger molecules cannot pass through membranes and are retained in diluate stream. In diluate stream large organic molecules can deposit on the membrane surface causing fouling of membranes which leads to the decrease of active membrane area and lower process

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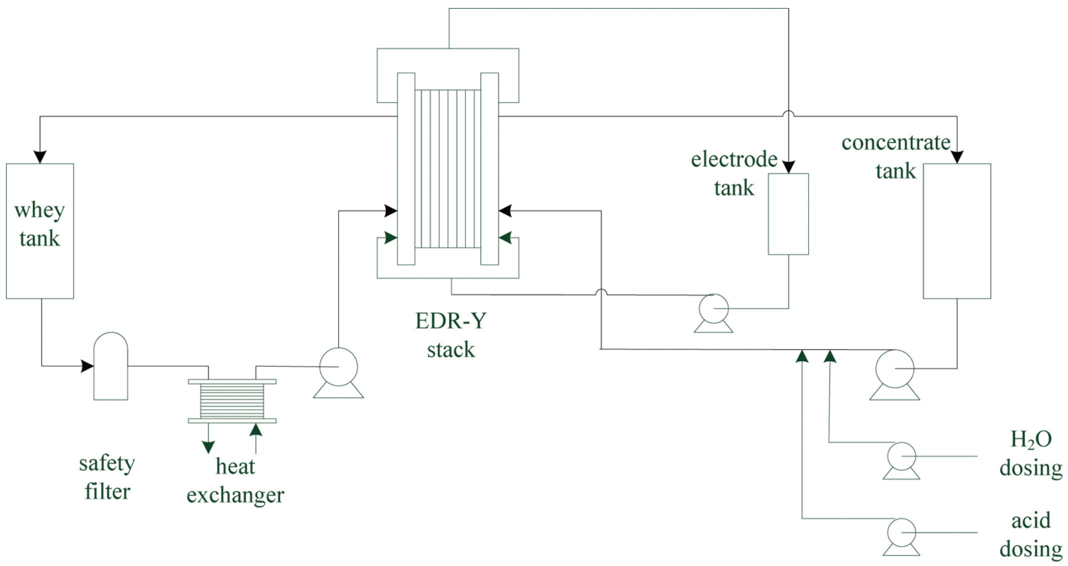

Fig. 1. Scheme of the electrodialysis unit.

efficiency. In concentrate stream scaling layers of salts (usually containing Ca^{2+}, Mg^{2+}, PO_4^{3-}, SO_4^{2-} or CO_3^{2-}) appear during electrodialysis [5–7]. Fouling can be minimized by choosing appropriate operating conditions (flow-rate, type of spacer, spacer thickness etc.) and by using suitable membranes which are less susceptible to fouling. Regular regeneration cycles are carried out to remove fouling and scaling and to prevent microbial contamination.

All kinds of whey (e.g. sweet, acid, sweet salty) can be desalted by electrodialysis, but whey has to be pretreated to minimize fouling. During pretreatment large particles (e.g. casein fines) and fat are removed. For industrial applications it is favorable to process concentrated whey (approximately 20% TDS), which enables performance at higher current density; usually combination NF + ED or evaporation + ED are used [8]. Demineralization of natural whey might be interesting for smaller dairy companies which do not want to invest in technologies for whey concentration.

Electrodialysis can be operated in three modes: batch, feed-and-bleed (continuous with recycle), and continuous. Batch mode is the most suitable for whey desalination, because it enables to obtain high levels of demineralization. Feed-and-bleed system is less convenient, for achieving desired levels of demineralization several electrodialysis stacks in series are needed. Continuous operation is not used for whey demineralization; the reason for this is that only low demineralization levels are achieved during one pass through an electrodialysis unit.

Demineralized whey can be characterized by several parameters. Ash content, content of proteins, lactose, fat, pH, and titratable acidity belong to parameters which are important for producer of demineralized whey. Among these parameters only pH can be continuously monitored during the process. As the ash content has the influence on conductivity, whey conductivity can be measured on-line, but there is a need for calibration for different kinds of whey.

The goal of optimization of demineralization process is to have high capacity of industrial units with low energy consumption and to have minimal losses of valuable compounds (proteins, lactose etc.). Demineralization is affected by construction of electrodialysis unit (type of membranes and spacers), type of whey, and operating conditions (DC voltage, linear velocity, concentrate conductivity, temperature).

This study was focused on optimization of desalination of natural sweet whey; especially on the influence of voltage and spacer thickness on the process. Other concern of the study was to characterize transport of individual ions during electrodialysis and to quantify losses of organic compounds (proteins and lactose).

2. Materials and methods

2.1. Electrodialysis

Electrodialysis pilot unit EWDU-P1 (MEGA a.s., Czech Republic) was used in the experiments. The scheme of the unit is in the Fig. 1. EDR stack contained 50 cell pairs of membranes RALEX AMH-PES and CMH-PES (MEGA a.s., Czech Republic); the effective area of each membrane was 400 cm^2. Cation exchange membranes were placed next to electrode

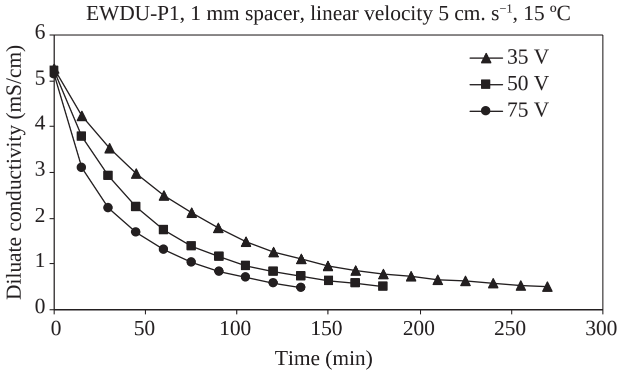

Fig. 2. Decrease of diluate conductivity in time at different DC voltage.

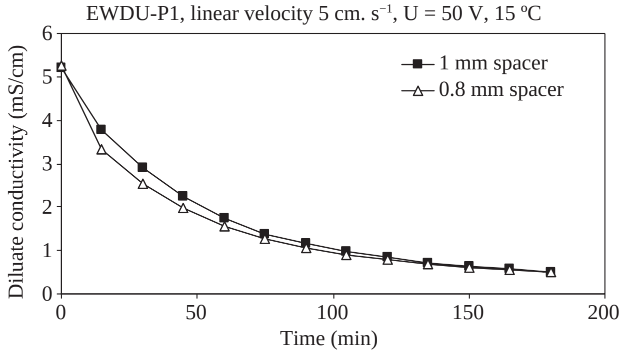

Fig. 3. Decrease of diluate conductivity in time at usage of spacers of different thickness.

compartments. Spacers were of net-type and their thickness was 0.8 or 1.0 mm.

Diluate solution was natural sweet whey with approximately 5.5% TDS obtained from diary Moravia Lacto (Czech Republic). Whey was pretreated by centrifugation. Diluate was demineralized in batch mode; process was terminated when diluate conductivity decreased of 90%. Drinking water was used as a concentrate solution. To prevent precipitation of salts, especially calcium phosphate, week acidic pH was kept by adding nitric acid. More over, constant conductivity was maintained by diluting of concentrate with drinking water. Electrodes were rinsed with a solution of $NaNO_3$.

Linear velocity was 5 cm s^{-1}. Constant temperature 15°C was held to minimize microbial growth and to ensure stability of whey during the process.

After each experiment regeneration procedure was carried out. It consisted of rinsing diluate and concentrate chambers with different solution according to the following procedure:

1. water rinsing
2. acid rinsing
3. water rinsing
4. alkaline rinsing
5. water rinsing
6. rinsing with weekly acid water (pH 4–5)
7. water rinsing

2.2. Analysis methods

2.2.1. Conductivity and pH

The electrodialysis unit was equipped with pH sensors InPro 3250 SG (4260) and conductivity sensors InPro 7108-25-VP (Mettler Toledo, Switzerland) connected with transmitter M300 (Mettler Toledo, Switzerland) which enabled continuous measurement of diluate and concentrate conductivity and pH. Multimetr pH/cond 340i (WTW, Germany) was used for checking pH and conductivity of electrode solution.

2.2.2. Dry mass, ash, content of salts and organic compounds

Content of TDS was determined by drying at 103°C and ash content by calcination at 550°C. Analysis of crude protein nitrogen was done by Kjeldahl method, analysis of lactose by HPLC with refractometric detection and analysis of fat by Rose-Gottlieb method. Content of Na, K, Ca and Mg was analyzed by ICP-OES. Phosphorus was determined by spectrophotometeric method and chlorides by potentiometric titration.

3. Results and discussion

3.1. Influence of DC voltage

Electric potential is a driving force for ion transport in electrodialysis. Unless the limiting current density is reached the velocity of salt transport is higher at higher voltage. We studied the influence of different DC voltage on total demineralization time. At higher voltage demineralization time was shorter (see Fig. 2), but energy consumption for salt transport increased with voltage too. Similar results obtained Demircioglu et al. [9] for desalination of NaCl solution. As the shorter demineralization time means higher capacity of industrial application, there is a compromise between high capacity and high energy consumption for salt transport. Energy requirements for pumping, cooling etc. should be considered for evaluation of energy demands of industrial electrodialysis unit.

Table 1
Inlet and outlet composition of whey during electrodialysis experiment

	TDS (g L^{-1})	Crude protein (g L^{-1})	Lactose (g L^{-1})	Fat (%)	Ash (g L^{-1})	Cl (mg L^{-1})	P (mg L^{-1})	K (mg L^{-1})	Na (mg L^{-1})	Ca (mg L^{-1})	Mg (mg L^{-1})
ED inlet	51.3–57.6	6.31–7.25	36–41	<0.1	4.3–4.7	925–1,030	249–281	1,170–1,300	330–430	330–400	62–81
ED outlet	49.4–52.7	6.11–7.05	37–42	<0.1	0.5–0.6	10–19	39–59	50–72	49–76	51–91	15–22

3.2. Influence of spacer thickness

When thinner spacer was used in electrodialysis stack decrease of diluate conductivity at the beginning of demineralization process was quicker (i.e. the velocity of salt transport was higher) but at the end the velocity of salt transport was slower than when the thicker spacer was used. Total demineralization time did not depend on the spacer thickness. Quicker demineralization at the beginning of the process at usage of thinner spacer is caused by decrease of thickness of working chamber resulting in the decrease of electric resistance of electrodialysis stack; lower demineralization rate at the end of process might be caused by more intensive fouling in thinner chambers.

Usage of a thinner spacer is a benefit especially if we need to achieve lower levels of demineralization (e.g. 70%), at 90% demineralization the spacer thickness did not have effect on total demineralization time and on energy consumption.

3.3. Transport of individual salts, losses of valuable compounds

The preference of ion transport was observed during demineralization of whey. Among inorganic ions monovalent ions were transported preferably. At 87% decrease of ash content there was 99% removal of Cl, 95% of K, 83% of Na, 82% of P, 80% of Ca and 75% of Mg. Organic ions such as lactate were transported too, resulting in decrease of titratable acidity (up to 60% decrease).

Losses of valuable organic compound were low. Losses of lactose were 3% at the most. Losses of crude protein content did not exceed 5%. This loss is most probably caused by transport of compounds which belong to non-protein nitrogen compounds. The inlet and outlet composition of whey is summarized in Table 1.

4. Conclusions

Natural sweet whey can be demineralized by electrodialysis with 90% cut of conductivity. Voltage had a strong influence on demineralization time and energy consumption, application of higher voltage resulted in shorted demineralization time and higher energy consumption. Spacer thickness did not affect total demineralization time and energy consumption.

The selectivity of transport of inorganic ions was observed; monovalent ions were transported preferably. Losses of valuable organic compounds were negligible.

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