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How electro dialysis configuration influences acid whey deacidification and membrane scaling

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ABSTRACT

With the rising popularity of Greek-style yogurts in the past few years, the production of acid whey has drastically increased. If sweet whey is usually further processed, the acid whey valorization comes with challenges because its drying is jeopardized by its high mineral and organic acid contents. For this reason, prior demineralization and deacidification are usually performed at industrial scale using a combination of ion exchange resins and electro dialysis. This whole process represents large amounts of resources and energy consumption as well as an important production of effluents. The optimization of the electro dialysis technique, currently the focus of a few studies, could result in the replacement of the serial processes and would provide a cost-effective and eco-efficient alternative. In this work, the demineralization and deacidification of acid whey were compared via 2 electro dialysis configurations: one conventional and one using bipolar membranes. Both configurations allowed to reach interesting demineralization (67%) and deacidification (44%) rates. However, even though the appearance of fouling or scaling has never been reported, scalings of different natures were observed on membranes using both configurations. Amorphous calcium phosphate was identified on the anion exchange membranes for both configurations while calcite and brucite were identified on cation exchange ones using the bipolar membrane configuration. These scaling formations were linked to the migration of divalent ions and water splitting phenomenon caused by a high demineralization rate or by an already formed significant scaling.

Key words: acid whey, deacidification, demineralization, electro dialysis with bipolar membranes

INTRODUCTION

Acid whey is the main co-product from the manufacturing of Greek yogurts, caseinate, and cream or cottage cheeses. It represents around 90% of the input milk volume and contains about 20% of its proteins and almost the entirety of its lactose (González Siso, 1996; Ryan and Walsh, 2016). The past few years have seen a tremendous increase in popularity for Greek-style yogurts, and with it, a constant increase in the volume of acid whey produced (Schultz and Parekh, 2011). In contrary to acid whey, sweet whey, produced during hard cheese production, for example, is usually further processed into whey powder, protein concentrate, and lactose by a drying step (Tsakali et al., 2010), typically realized by spray drying. If drying of sweet whey enables producers to obtain good quality powders, the acid whey drying results in a significantly sticky powder with major operational problems caused by the important amounts of calcium and lactic acid. It has been shown that the presence of said components had a main influence on the powder hygroscopic character and the decrease in lactose glass transition temperature (Saffari and Langrish, 2014; Chandrapala and Vasiljevic, 2017).

Therefore, one solution to allow acid whey processing at industrial scale is to demineralize and to remove lactic acid by combining ion exchange resins and electro dialysis (ED; Houldsworth, 1979; Williams and Kline, 1980; Hoppe and Higgins, 1992). The whole process represents a high investment, energy consumption, and the production of a large amount of effluents, during ion exchange resins regeneration, that needs to be treated. However, the ED step constitutes only one-fourth of the total energy consumption and effluent production (Greiter et al., 2002). The ED optimization for purposes of demineralization and lactic acid removal without the use of ion exchange resins could then provide a most cost-effective and eco-efficient alternative to the actual process. Hence, Chen et al. (2016) carried out laboratory-scale research to assess

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the feasibility of ED as part of the acid whey industrial treatment. They used a conventional ED stack consisting of anion (AEM) and cation exchange membranes (CEM) to treat different models and whey solutions. For a skimmed acid whey treated for 3 h at 45°C, they obtained a similar energy consumption as for the sweet whey process (~0.014 kWh/kg of whey processed), with interesting lactic acid removal (a rate of 41%) and demineralization (a rate of ~57%). They also found out that lactic acid removal was depending on the pH, the temperature, and the amount of other ions present in the whey. Their highest lactic acid removal was obtained with a model solution (99.7% at 45 °C for a lactic acid + lactose + NaCl model solution) while they reached a maximum 74% deacidification rate for acid whey solutions using ultrafiltration permeate. However, the bipolar membrane, which was recently successfully used for the cranberry juice or wine deacidification, up to 80% of acid removal, has never been tested for acid whey deacidification (Calle et al., 2002; Serre et al., 2016).

Acid whey contains a significant amount of calcium involved in the drying issue (Saffari and Langrish, 2014; Chandrapala and Vasiljevic, 2017), and in combination with magnesium, these minerals have been identified, in many studies, as the major scaling agents during ED (Balster et al., 2005, 2007; Casademont et al., 2008; Mikhaylin and Bazinet, 2016). Furthermore, when the limiting current density is reached during an ED demineralization treatment due to a high demineralization rate, the water dissociation phenomenon appears. Water splitting leads to the dissociation of water into protons and hydroxyl ions influencing the formation of scaling such as brucite (MgOH₂) and calcite (CaCO₃; Casademont et al., 2010; Zeppenfeld, 2011; Mikhaylin et al., 2016). However, in the work of Chen et al. (2016) on acid whey deacidification, although they reached the limiting current density during their experiments in the presence of divalent ions (calcium and magnesium present in whey), they did not mention the occurrence or not of a scaling/fouling phenomenon on membranes. This aspect is nonetheless relevant as both the cleaning and replacement of membranes represent the major cost of the ED process (Xu, 2005; Strathmann, 2010).

In this context, the modification of the electrodiolytic parameters and configuration could influence acid whey deacidification and demineralization with an effect on ionic species equilibrium and migration evolution. The objectives of the present work were to (1) compare 2 different ED configurations, one stacking only AEM and CEM (as used by Chen et al., 2016) and one stacking anion and cation exchange as well as bipolar membranes in terms of lactic acid deacidifica-

Table 1. Composition and physicochemical characteristics of the raw acid whey (Panesar et al., 2007; Saffari and Langrish, 2014; Chen et al., 2016; Bédas et al., 2017)

Item	Acid whey ¹	Values reported in the literature
TS (g/L)	59.8 ± 4.2	50.0–70.0
Total protein (g/L)	6.5 ± 0.7	4.2–10.0
Lactose (g/L)	41.2 ± 0.9	38–49
Minerals (g/L)	5.1 ± 1.1	4.7–7.0
P (g/L)	0.55 ± 0.01	0.44–0.90
Ca (g/L)	0.86 ± 0.02	0.43–1.60
K (g/L)	1.26 ± 0.05	1.28–1.82
Mg (g/L)	0.09 ± 0.00	0.09–0.19
Na (g/L)	0.39 ± 0.03	0.40–0.61
Lactate (g/L)	7.00 ± 0.14	5.18–8.00
Ratio lactate/lactose	0.17	0.12–0.15
pH	4.4	4.0–4.6
Conductivity (mS/cm)	7.05 ± 0.24	8.27 ± 0.42

¹Values (±SD) obtained by the average of at least 3 repeated measurements.

tion and demineralization; (2) study the influence of the configuration on scaling/fouling formation; and (3) identify the nature of the potential fouling/scaling in relation to the configuration used.

MATERIALS AND METHODS

Whey

The raw acid whey was obtained from a dairy processing plant owned by Parmalat-Canada (Victoriaville, Quebec, Canada). The acid whey samples were transported at 4°C from the plant and then stored at –30°C. Samples were thawed at 4°C before each experiment. The composition of the acid whey is described in Table 1 and was found to be consistent with that reported in the literature.

Electrodialytic Configurations

Electrodialysis experiments were performed using a MP type cell (ElectroCell AB, Täby, Sweden) with an effective surface area of 100 cm². Two different ED configurations (CACAC and BACBAC) were tested as shown in Figure 1. Both were selected after preliminary testing of 8 different configurations (combination of membranes and solutions). For each, the anode was a dimensionally stable electrode (DSA-O₂) and the cathode was a food-grade stainless-steel electrode. The potential difference was generated by a power supply (model HPD 30–10, Xantrex, Burnaby, BC, Canada). The solutions were circulated using centrifugal pumps and the flow rates controlled by flow-meters (Aalborg Instruments and Controls Inc., Orangeburg, SC). Both configurations consisted of 2 deacidification units.

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