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Deacidification and concentration of sugar solution using electrodialysis and reverse osmosis

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Abstract: This study discusses the performance of an innovative treatment process to deacidify and concentrate sugar-rich water with originating from the biorefinery industry. The sugar solution was processed on lab-scale using two technologies. First, electrodialysis (ED) was used to deacidify the sugar solution and recover hydrochloric acid (HCl), then reverse osmosis (RO) was used to concentrate the deacidified sugar solution. The concentration of ions was measured by monitoring the electrical conductivity. The electrical conductivity of the sugar solution was decreased by 99.9% by ED. Subsequently, the deacidified sugar solution was concentrated from 1.3 wt% to 16.6 wt% of sugars by RO. In both processes, losses <1% of sugar were observed.

Keywords: Sugar solution; Electrodialysis; Reverse Osmosis

Introduction

The demand for sustainability due to increased population and finite natural resources has been the main driver for the development of the biorefinery industry [1]. In this context, sugars – mainly glucose, become crucial building blocks for the development of bio-based products through fermentation processes [1]. However, the availability of cost-effective sugar sources has been a challenge for the expansion of this industry [2]. Recently, innovative processes have been developed to extract sugar from plant-based materials such as wood chips or wheat straw, to increase the availability of feedstock material for sugar production [3]. In one of these processes, the plant-based feedstock is hydrolysed using hydrochloric acid (HCl) and after that, the sugar is extracted from the bulk solution into a solution with a relatively high concentration of sugar and acid. Before being converted to products, the sugar solution needs to be completely deacidified and concentrated to make it suitable for the downstream fermentation process. To carry out these two steps, currently ion exchange (IEX) for deacidification is combined with evaporation to concentrate the sugar solutions. This process requires large amounts of chemical use for IEX regeneration and has a high energy consumption for the evaporator. As an alternative, we propose an innovative process train in which electrodialysis (ED) is applied to remove and recover HCl, while using reverse osmosis (RO) to achieve the desired concentration of sugars. These processes do not rely on chemicals and heat (often generated from fossil-resources), but only electricity, which can be generated sustainably. The proposed process was tested and validated on lab-scale units using a 1.3 wt% sugar solution containing ~1.0 wt% HCl.

Material and Methods

An ED lab unit with 10 cell pairs was used for the deacidification of 40 L of sugar solution. During this process, HCl was transported from the sugar solution (ED diluate) to the so-called ED concentrate stream, whereas the sugars remained in the ED diluate. The ED diluate had an initial sugar concentration of 1.3 wt%, a pH of about 0.7, and an initial electrical conductivity (EC) of 77 mS/cm, whereas the ED concentrate initially consisted of demineralised water. The deacidification of the sugar solution was executed in batch-operation. A constant voltage equal to 20 V was applied to the ED stack until the EC of the diluate was decrease to 0.1 mS/cm. After the ED step, the sugars in the ED diluate were subsequently concentrated in a lab-scale RO unit equipped with a spiral-wound RO membrane. The RO step was also operated in batch by recirculating the RO concentrate stream to the RO membrane, while the RO permeate was discharged. The unit was operated at a fixed permeate flux of 20 $L\cdot/m^{-2}/h^{-1}$. The process was stopped once the feed pressure reached 45 bars. During both deacidification and concentration process, periodic samples were taken and analysed for sugar concentration in each stream (ED feed, ED diluate, ED concentrate, RO feed, RO permeate and RO concentrate). In addition, EC, temperature, and pH of each stream were continuously monitored during the experiments.

Results and Conclusions

The EC of the sugar solution was successfully decreased to below 0.1 mS/cm by ED, with a final pH of 3.7 of the ED diluate. A slight volume decrease was observed in the ED diluate. This reduction was caused by water migration from the diluate to the concentrate stream due to osmosis and electro-osmosis. During deacidification by ED, less than 1% of the sugars were lost to the ED concentrate stream. Besides, 40 L of 0,78 wt% HCl solution was obtained in the ED concentrate stream. This may enable reuse of HCl in the upstream hydrolysis process which could further cut the overall chemical use during the sugar extraction process. After the deacidification process, the ED diluate was concentrated by RO. The sugar concentration was increased from 1.3 wt% to 16.6 wt%, corresponding to a concentration factor of 12.7. However, a higher concentration of sugar can be achieved by increasing the maximum feed solution pressure in the RO process. Considering these results, the process will be scale-up in the next future to further assess the energy consumption and longer-term operation.

To conclude, ED proved to be an effective technology for the deacidification of sugar solutions. The target reduction can be achieved without use of chemical and minimal sugar losses toward the concentrate stream. In addition, the HCl can be potentially recovered and reused in the upstream hydrolysis process of feedstocks. In addition, RO also showed satisfying results in concentrating sugars, being able to concentrate the sugar, while only using electrical energy.

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