Selective secretion of lactic acid from fermentation broth using *in situ* ultrafiltration membranes

ABSTRACT

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The research objective of this PhD thesis is the development of a lactic acid production method via fermentation and secretion of a secondary material using an *in situ* ultrafiltration membrane. The research was conducted at the Institute of Chemical Engineering and Environmental Protection Processes of the Szczecin University of Technology (currently the West Pomeranian University of Technology). The primary focus of this thesis was the investigation of ultrafiltration process combined with dynamically formed hydrated zirconium(IV) oxide membrane as a suitable method for the separation of lactic acid from the fermentation broth obtained in the fermentation process of lactose contained in whey. In particular, the dynamically formed ZOSS (zirconium oxide stainless steel) membrane was tested for continuous secretion of lactic acid to prevent the inhibition of fermentation process caused by accumulation of product.

Literature studies provide an overview of the diary industry's impact on the environment and examples of the usage of fermented broth as a raw material developed by various industries. The literature review also concerns selected aspects of pressure-driven membrane filtration, in particular mathematical modelling for a resistance-in-series model and a relaxation model.

Data obtained during the literature search formed the basis for the definition of extend of research and the methodology for data acquisition and analysis discussed in the experimental part of this thesis. The chapter is organised in two main sections. The first section summarises investigated influence of temperature (307 - 313 K), lactose concentration (0.172 - 6.71 wt.%) and *Lactobacillus acidophilus* bacteria concentration (0,005-25 $kg \cdot m^{-3}$) on the lactic fermentation using periodic reactors in combination with standard fermentation solutions. The preliminary research provided a foundation for the detailed studies using a bioreactor and an *in situ* ultrafiltration membrane.

The second section of the experimental part describes a series of experiments using a bioreactor equipped with ZOSS ultrafiltration units tested for continuous removal of lactic acid from the fermentation broth, potentially suitable for the synthesis of biodegradable polymers. The research was conducted using standard whey solutions derived from whey powder and actual medium, i.e. whey from a dairy manufacturing plant, under following conditions: lactic acid concentration in the permeate, C_L = 0.25, 2.5 and 3.83 wt.%; bacteria concentration, C_b = 0.07, 0.14 and 1.0 $kg \cdot m^{-3}$; transmembrane pressure Δp = 1 and 2 MPa;

cross-flow velocity, u = 0.5, 1.0 and 2.6 $m \cdot s^{-1}$; temperature, T = 310 and 313 K; pH=4.0; pH=4.6; pH=5.0 and time, t = 12 h.

The experimental results helped to determine the yield and selectivity of ZOSS membrane in the ultrafiltration process of lactic acid as a function of transmembrane pressure, cross-flow velocity and pH. Fouling resistance and concentration polarisation were estimated using the mathematical resistance–in–series model. The model showed that the highest investigated transmembrane pressure (Δp = 2.0 MPa) and cross-flow velocity (u = 2.6 ms^{-1}) resulted in the smallest fouling resistance and the highest ultrafiltration yield. The highest lactic acid concentration in permeate obtained for u = 0.5 m s^{-1} and Δp = 1 MPa resulted however, in low membrane yield and high fouling resistance. The time constants t_0 and the constant t_{Ro} were determined using the mathematical relaxation model. Empirical initial flux (J_0) and equilibrium-saturation fluxe (J_∞) allowed to calculate interim permeate flux (J_v) values.

The experimental results and mathematical model allowed to define the influence of operating parameters on the ultrafiltration yield and selectivity and to propose optimum operating conditions for the ZOSS type membranes. The outcome of this work provides a basis for the potential development of environmental friendly whey utilisation method, which is a waste product of the dairy industry.

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