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Optimisation of ultrafiltration of a highly viscous protein solution using spiral-wound modules

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Abstract

The ultrafiltration process of highly viscous protein process water with spiral-wound modules was optimised by analysing the fouling and developing a strategy to reduce it. It was shown that the flux reduction during filtration is mainly caused by the adsorption of proteins on the membrane and not by the high osmotic pressure. In laboratory experiments, the concept of the critical flux was proved to reduce fouling. Additionally, the reduction of the effect of concentration polarisation by spacers at laboratory and pilot scale was evaluated. While at laboratory scale the spacers influenced the mass transfer, the effect in spiral-wound modules was low. However, pilot plant experiments showed that operating at low pressures to reduce the fouling and avoid local fouling required a spacer with a low pressure drop along the module. A cleaning strategy including a hygienic evaluation was tested. An enzymatic cleaning followed by a caustic cleaning step gave sufficient results. This investigation has also shown that the concentrated protein solution as well as the produced water in the permeate are hygienically safe, and, in principle, the latter could be reused somewhere else within the production process.

Keywords: Ultrafiltration; Protein; Spiral-wound module; Spacer; Cleaning; Hygienic quality; Water reuse

1. Introduction

Spiral-wound modules are usually not the most favoured choice to filter highly viscous protein water. However, their low price vs. membrane area relation and their easy replacement makes them attractive as an alternative to other types of modules. Once a company has chosen this type of module as their favoured option, the degree of freedom to reduce the effect of concentration polarisation and fouling is fairly low. The aim of this paper is to present options to reduce the fouling and the effect of concentration polarisation by selecting proper module spacers for the purpose. Therefore, the fouling is analysed and

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the effect of concentration polarisation in spacer filled channels is compared with different models.

During the production of functional proteins, the proteins are concentrated out of pig rind by means of filtration at 60°C in order to decrease the viscosity and to reduce or eliminate the potential bacterial growth. An ultrafiltration process is aimed at reducing the water content in the protein solution and to produce water that may be reused.

The main problem associated with highly viscous protein solutions is the flux decline due to:

1) Changes of viscosity in the boundary layer.
2) A high osmotic pressure which decreases the transmembrane pressure.
3) The internal and external fouling of the membrane.
4) The formation of a gel layer on the surface of the membrane.

In order to optimise the process, the strength and the influence of the different effects have to be analysed and suitable solutions have to be found. While spacers can influence the concentration gradient on the membrane surface, and, therefore, cause viscosity changes, the problem of a high osmotic pressure could easily be solved by operating with a denser membrane at high pressures.

Fouling can be reduced by operating below the critical flux [1]. In spiral-wound modules, this option is only suitable to a certain extent due to the changing pressure and concentration along the module. Therefore, the fouling can be reduced but not completely prevented. A sufficient cleaning strategy is required to restore the membrane properties and to fulfil the hygienic requirements of food manufacturing companies. Two cleaning options have been tested; one including an enzymatic cleaning step. It was evaluated how many cleaning steps are required to clean the membrane and the system. This investigation was also intended to check the hygienic quality of both the concentrated protein solution and the outcoming water.

2. Theory of the limiting flux during ultrafiltration

Saving energy and operating costs are of major importance in an industrial membrane process. Hence, it is required to operate below the limiting flux, otherwise a rise of the pressure would mainly result in an increase in the operating costs and not in the permeate flux. Mainly, two different models describe the limiting flux. These are the osmotic pressure and a viscosity gradient in the boundary layer. The effect of the osmotic pressure on the limiting flux has been described for dextran and whey proteins by Jonsson [2]. At constant resistance, the water flux can be expressed as follows:

$$J = l_p(\Delta p - \pi) \tag{1}$$

The osmotic pressure is a function of the surface concentration (C_m), and can be described by the virial expression:

$$\pi = A_1 C + A_2 C^2 + A_3 C^3 \ldots \tag{2}$$

Knowing the virial coefficients and calculating the osmotic pressure with Eq. (1), by knowing the water permeability (l_p), the surface concentration can be calculated by solving Eq. (2).

The limiting flux for whey proteins and dextran could be described using this model. Additional vortices on the membrane due to high fluxes were described. These vortices influence the mass transfer coefficient (k) and lead to a different behaviour in empty channels and spacer filled channels [3]. This change on the mass transfer coefficient should also influence the limiting flux.

Another theory predicts the limiting flux by using the viscosity variation. This was evaluated by Field et al. [4] and was further developed by Howell et al. [5]. The model combines the film model Eq. (3):

$$J = k \ln\left(\frac{C_m}{C_b}\right) \tag{3}$$