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Procedia Engineering 44 (2012) 1910 – 1912
Procedia Engineering
www.elsevier.com/locate/procedia

Euromembrane Conference 2012

[P3.106] The effect of feed pre-treatment by ultrasound on dairy ultrafiltration membranes

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Concentration of whey is a major membrane filtration process used in the dairy industry. However, the economic efficiency of this process is limited by membrane fouling: a sharp reduction in permeate flux and an increase in pressure drop across the membrane requires costly cleaning cycles, and in some cases replacement of the membrane module, in order to restore the original flux.

Several modifications have been proposed to enhance membrane performance and reduce fouling. Feed pre-treatment and ultrasonic enhancement are examples of such modifications. The use of an ultrasonic field, installed alongside the filtration unit, induces localised flow disturbances through vibration and cavitation, enhancing turbulence near the membrane surface and promoting back transport of solutes into the bulk solution. However, the use of ultrasound directly on the membrane surface is expensive and difficult to scale up. In addition, there is a possibility that the membrane structure may be damaged [1, 2].

More recently, Ashokkumar and co-workers [3] have shown that ultrasonic treatment of a dairy whey solution independently of membrane filtration breaks down protein aggregates and decreases solution viscosity. With such a reduction in viscosity, it may be possible to process whey solutions of high solids content in membrane filtration units more easily with a reduction in overall energy requirements. In addition, Ashokkumar *et al.* [4] showed that when sonication was applied to a heated solution of denatured and aggregated proteins, there was a dramatic decrease in particle size and viscosity. It was speculated that the reduction in aggregate size and viscosity is due to the disruption of hydrophobic interactions by shear forces that are generated during acoustic cavitation [5]. Upon further heating, this low viscosity was maintained, overcoming the problem of poor heat stability of reconstituted powders [4]. The combination of heat and ultrasonic pre-treatment is thus a promising approach to alleviating membrane fouling and enhancing productivity while producing heat stable powders.

Although the change in aggregate size and viscosity should assist with membrane filtration, it could also lead to increased fouling cake compaction. The aim of the present work was to confirm whether ultrasonic pre-treatment affected downstream ultrafiltration of whey protein concentrate (WPC80) solutions. The effect of sonication alone and the combination of heat treatment and sonication on membrane fouling were investigated. The change in absolute permeate flux with time for different feed solutions were analysed using Ho and Zydney's combined pore blockage and cake filtration model (Equations 1 and 2) [6]. This model was chosen as it was able to evaluate the effect of heat and ultrasound on both the pore blockage and cake filtration phenomena.

$$Q = Q_0\left[\exp\left(-\frac{\propto \Delta P C_b}{\mu R_m}t\right) + \left(\frac{R_m}{R_m+R_p}\right)\left(1-\exp\left(-\frac{\propto \Delta P C_b}{\mu R_m}t\right)\right)\right] \quad \text{Equation 1}$$

$$R_p = \left(R_m + R_{p0}\right)\sqrt{1+\frac{2f'R'\Delta P C_b}{\mu\left(R_m+R_{p0}\right)^2}t} - R_m \quad \text{Equation 2}$$

doi:10.1016/j.proeng.2012.08.1001

where Q is the volumetric flow rate (m^3/s), Q_0 is the initial volumetric flow rate through the clean membrane (m^3/s), α is the pore blockage parameter (m^2/kg), ΔP is the transmembrane pressure (Pa), C_b is the bulk protein concentration (g/L), t is filtration time (s), μ is the viscosity of the feed (Pa.s), R_m is the resistance of the clean membrane (m^{-1}), R_p is the resistance of the protein deposit (m^{-1}), R_{p0} is the resistance of a single protein aggregate (m^{-1}), f' is the fractional amount of protein that contributes to deposit growth (-) and R' is the specific resistance of the protein layer (m/kg). The permeate flux through the membrane is thus dependent on the rate of pore blockage (α), the initial resistance of the deposit (R_{p0}) and the growth rate of the protein cake layer (described by $f'R'$).

In native and sonicated WPC80 solutions (Figure 1), there is no change in flux decline pattern and the percentage flux reductions in both feeds are similar. The pore blockage parameters for the native and sonicated samples are 1.47 and 1.26 m^2/kg, respectively while the cake growth factors are 3.46 x 10^{10} and 3.63 x 10^{10} m/kg, respectively: both results are of the same magnitude and show no change upon sonication. Hence, pre-treating the feed through sonication produced comparable levels of membrane fouling. The inability of sonication to reduce fouling may be due to the small aggregate size and low viscosity of the native WPC80 so that the changes that occur upon sonication are too small to create a significant impact. However, the lower viscosity of the sonicated feed is likely to lead to lower pressure drops and hence improved energy efficiency for this process.

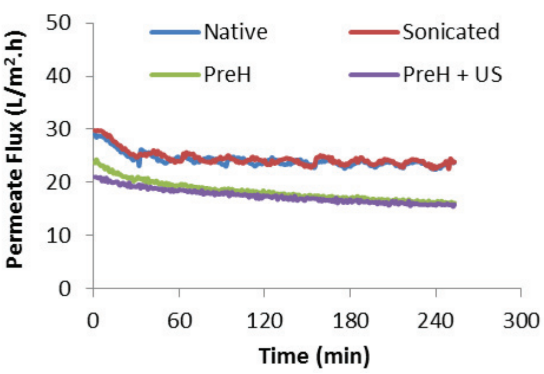

Figure 1: Plot of permeate flux against time for native, sonicated, pre-heated (PreH) and pre-heated and sonicated (PreH + US) feed

For heat-treated samples (Figure 1), the sample that is pre-heated alone (PreH) has a greater flux reduction than the one that is sonicated after heat treatment (PreH + US). In addition, this PreH sample has a higher pore blockage parameter – 3.16 m^2/kg compared to 1.24 m^2/kg when sonication is used. This is also observed in the flux data where a steeper slope is observed at the start of the run. The cake growth factor of the pre-heated sample is also significantly greater at 4.02 x 10^{11} m/kg. Thus, the large protein aggregates in the PreH sample blocked the membrane pores to a great extent and formed a dense cake layer over a shorter period of time. The sample that was sonicated after pre-heating, on the other hand, achieved a higher permeate flux with lesser pore blockage and cake growth. In addition, the protein concentration in both permeates are low at 0.07 wt%.

In conclusion, pre-treatment of a whey protein solution through sonication alone did not alleviate the effects of membrane fouling. However, when a pre-heated whey protein solution was sonicated, there was a decline in pore blockage and fouling cake growth, with no change to the protein concentration in the permeate. Both approaches have the potential to reduce the energy requirements of whey ultrafiltration as they lead to a lower viscosity feed solution.

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Keywords: ultrafiltration, ultrasound, dairy, whey