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Cleaning kinetics and related mechanisms of *Bacillus cereus* spore removal during an alkaline cleaning of a tubular ceramic microfiltration membrane

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ABSTRACT

In membrane separation processes, biofouling of membranes is now well recognized as a major impediment to their efficient operation and overall performance. This study focuses on the first (attachment) phase of biofouling. We have investigated experimentally the cleanability of a ceramic microfiltration membrane fouled by *Bacillus cereus* spores in terms of both hydraulic and microbiological cleanliness and examined the interrelationship between the two types of cleanliness. Cleaning kinetics was described in terms of both the hydraulic membrane resistance changes during cleaning and the number of residual adhered spores per unit membrane surface area as a function of time. Hydraulic cleanliness was evaluated using three parameters: percent flux recovery (FR), percent irreversible removed fouling (RF) and a hydraulic cleanliness criterion (HCC, i.e. $(R_n - R_m)/R_m < 0.05$). Microbiological cleanliness was assessed by the measurement of the residual microbial population adhered to the membrane surface left after cleaning. A single-stage cleaning consisted of the recirculation in turbulent flow regime of a 0.5 wt% sodium hydroxide solution. The hydraulic membrane resistance changes during cleaning fitted a first order kinetics which predicted a useful cleaning duration close to 10 min above which membrane resistance was quasi-constant. The detrimental effect of time on cleaning efficiency was highlighted: the hydraulic membrane permeability could not be restored beyond a cleaning duration of 15 min due to the redeposition on the membrane surface of spore cells previously released in the cleaning solution. A simple model (first order reaction) combining removal and deposition rates provided a fairly good fit of the variation with cleaning time of the adhered spore population ($r^2 = 0.97$, $p < 0.0001$, $n = 11$). The residual adhered population left after cleaning was positively correlated with the hydraulic cleanliness criterion, HCC ($r = 0.65$, $p < 0.05$, $n = 12$). Nevertheless, residual contamination was not statistically correlated ($p > 0.05$), neither with the standard percent flux recovery nor with the measured fouling resistance left after cleaning. Percent flux recovery was insufficient in indicating accurately the microbiological cleanliness.

Keywords: Cleaning-in-place; Microfiltration; *Bacillus cereus* spores; Cleaning kinetics; Sodium hydroxide; Removal kinetics

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