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Chemical foam cleaning as an alternative for flux recovery in dynamic filtration processes

B. Gahleitner*, C. Loderer, W. Fuchs

Department for Agrobiotechnology, IFA-Tulln, University of Natural Resources and Life Sciences, Vienna, Austria

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ABSTRACT

In this study, the suitability of a new foam cleaning method for dynamic filtration modules was investigated. Foam was produced from a commercially available cleaning agent in a foaming device constructed in house. First, characterization experiments proved the ability to produce foams of a defined quality and stability. In subsequent lab-scale cleaning experiments, the optimal cleaning parameters such as pH, incubation time, temperature and NaOCl concentration were evaluated with image analyses of filter samples. Based on these results the best composition of the cleaning foam was chosen.

Foam from 5000 ppm NaOCl liquid solution (or ~270 mg NaOCl/L foam volume) was successfully applied to clean a flat-sheet mesh-filter module established in a pilot plant. It was shown that even after consecutive application the initial filtration performance could be recovered after chemical foam cleaning. No difference in cleaning efficiency was observed compared to a reference method using a liquid cleaning agent.

The newly developed foam cleaning method shows high potential for dynamic filtration processes, particularly in the large scale where CIP cleanings with liquid cleaner cannot be performed due to the large pore size of the filter.

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1. Introduction

Membrane bioreactors (MBR) that use ultra- or microfiltration for separation of activated sludge are one of the most promising advanced wastewater treatment technologies. The main driving forces for the application of this process are the excellent effluent quality as well as the low footprint [1]. In 2006, more than 2200 full scale MBR plants were in operation or under construction worldwide. The restricted land availability in Europe and Asia has boosted MBR research and application [2]. However, a more widespread application of MBRs is hindered by membrane fouling and its consequences in terms of plant maintenance and operating costs [3,4]. A new approach to improve membrane bioreactor performance is the use of self-forming dynamic membranes. Such a dynamic membrane is formed on an underlying support material when the filtered solution contains suspended solid particles such as microbial cells and flocs [5]. For this application cheaper filter materials such as filter cloth, woven and non-woven coarse pore mesh can be used. Recent findings showed that this process provides an attractive alternative to improve the performance and to mitigate fouling in MBR technology [6]. Effluent qualities similar to or better than conventional activated sludge systems (CAS) can be achieved by using a mesh filter having a pore size in the range of 25 and 140 μm. High flux rates of up to 150 $L\,m^{-2}\,h^{-1}$ and long term filtration processes without chemical cleaning or only with mechanical cleaning have been reported [7,8].

Nevertheless, any technical filter or membrane submerged in biologically active biomass will be subject to biofilm growth and attachment of organic or inorganic fouling layers. Hence chemical cleaning is inevitable for the long term operation of any type of MBR system. Chemical cleaning uses backwashing with cleaning agents in place (CIP), in biomass or on air, and occasionally intensive cleaning out of place (COP). All main MBR suppliers such as Kubota, Memcor, Mitsubishi and Zenon propose their own chemical cleaning methods and concentrations. Chlorine solution for oxidative removal of fouling layers is the most widely applied cleaning agent due to its cheapness and effectiveness. Typical concentrations range from 0.01–0.02 wt% NaOCl for maintenance cleaning to 0.2–0.5 wt% NaOCl for recovery cleaning [3,9].

With respect to cleaning of dynamic membrane filters, so far only limited studies that directly address this subject are available [5] and out of place cleaning techniques were mainly employed.

However, out of place cleaning involves high man power effort and causes long down time of the filtration process. For the competitiveness of dynamic membrane processes, in place

* Corresponding author. Tel.: +43 2272 66280 555; fax: +43 2272 66280 503.
E-mail address: bernhard.gahleitner@boku.ac.at (B. Gahleitner).

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cleaning strategies must be developed [10,11]. Due to the large pore size of the filter mesh the standard chemical in-situ or on-air cleaning protocols are not appropriate. Any liquid cleaning agent applied drains quickly and homogenous distribution of the cleaner and sufficient contact time of the chemicals with the filter cannot be assured.

An interesting alternative to overcome the above-mentioned problems is the use of foamed cleaning agents. An extra advantage is that foamed cleaning agents can also help to minimize the volume of cleaner required and therefore reduce the use of cleaning agents such as chlorine. It is important to bear in mind that much of the liquid volume is only necessary to fill the pipes and that most of the cleaner is not in contact with the fouled filter or membrane. Due to the achieved volume expansion by foaming, higher concentrations in the liquid stock-solutions can be used for the cleaning and reaction times can be reduced.

In this study, the characterization of cleaning foams as well as screening tests for evaluating cleaning efficiency in comparison to standard cleaning procedures are presented. In a subsequent experiment in a 500 L mesh filter bioreactor treating municipal wastewater, the suitability of the newly developed foam cleaning method was tested and compared to ex situ liquid chlorine cleaning over a long-term period of 4–6 months.

2. Background of the scientific approach

Foamed cleaning agents are already applied to a certain extent in industrial cleaning processes such as CIP of pipes and vessels in the food and pharmaceutical industries and cleaning of heat exchangers and turbines. However, scientific literature on such applications is almost nonexistent. In particular the application of foamed cleaning agents for regeneration of membranes and filter materials has not been reported yet.

Broadly speaking, foams are a dispersion of gas bubbles in a liquid. Ideal cleaning foams need to contain sufficient levels of active cleaning component and have to keep the chemical in place on the filter surface long enough for the active ingredients to penetrate the pores and remove the deposits. Foulant dissolution occurs in the liquid phase by a reaction of the cleaning agent with the fouling layer. Foams should be wet enough to allow rapid replenishment of the spent chemical through diffusion. Therefore, foams that are too dry will not be effective. According to literature, good cleaning foams are normally composed of equal to or less than 95% gas phase [12]. On the other hand, it was found that if the foam is too wet it will decay rapidly. Hence foam stability is another important criterion. When the gas fraction is high, the bubbles come into contact with each other and deform, creating lamellae (thin films). These thin films are stabilized by surfactants and foam decay is largely determined by the drainage and rupture of these thin films.

Control of foam characteristics is of critical importance in several industrial applications. The food industry is the most prominent example. Many of the foam investigation techniques used in this study are based on methods developed for characterization of, for example, beer or milk foams and had to be adapted to the given purpose.

For another aspect of this study, the measurement of cleaning efficiency, it was necessary to develop new characterization and testing methods. In membrane filtration the routine procedure to investigate membrane status, and by such means also the efficiency of an applied cleaning step, is the determination of the membrane permeability, i.e. the flow rate at a certain trans-filter-pressure (TFP) which is inversely proportional to the intrinsic filter resistance. However, with respect to cloth/mesh filtration it was observed that even after longer operation time, the intrinsic filter resistance almost does not change since the resistance of the dynamic membrane dominates the filtration process [11,13]. The contribution of the fouling resistance to the total filter resistance is low and largely disguised by the experimental error.

Measuring permeability was a useful tool to monitor the performance of the mesh bioreactor, because in this case it is affected by both the intrinsic resistance (filter mesh) and dynamic membrane resistance. However, all cleaning procedures removed the dynamic membrane. The residual deposits on the mesh filter did not cause measurable changes of the permeability. Therefore an alternative test scheme for the evaluation of the cleaning procedures had to be developed. Due to the large size of the mesh openings ($\sim$30 μm) as well the regular geometric structure of the mesh, direct optical inspection including digital image analyses was considered to be an appropriate method.

It was necessary to work out a reference cleaning method using a liquid NaOCl solution. The influence of reaction time, pH and temperature on the percentage of total recovered open pore area was assessed. This standard approach in membrane cleaning was used, on the one hand, to develop and check the validity of the optical methods applied to determine cleaning efficiency. On the other hand it served as the benchmark to judge the efficiency of foam cleaning.

A final aspect that needs to be explained is the concentration range of NaOCl chosen for the foam cleaning in these experiments. The solutions used for foam production were in the low range of recommended mixing ratios according to manufacturer's instructions. Nevertheless, the resulting concentrations in the liquid phase (2000–5000 ppm) seem to be quite high compared to the usual concentrations used in liquid membrane cleaning. However, it should be noted that the applied foams consisted of more than 90% air. Therefore the concentration in terms of active substance per volume is much lower than the concentration in the liquid phase (87–459 mg NaOCl/L foam volume). When comparing the efficiency of liquid and foamed cleaning agents it was presumed that a fair evaluation of the performances should be on basis of the applied dose, i.e. the total amount of active cleaning agent per volume liquid or foam, respectively.

3. Material and methods

3.1. Foam production and characterization

3.1.1. Cleaning chemicals

Hypochlorite cleaning solutions of the given concentration were freshly prepared each time through dilution of a concentrate (NaOCl, technical grade, $\sim$12% active chlorine, Neubers Enkel, A). Hypochlorite loses activity with time. Therefore, the actual concentration was determined prior to every preparation of a cleaning solution in accordance with the following procedure: hypochlorite liberates free iodine from potassium iodide solution, the iodine liberated, which is equivalent to the amount of active chlorine, is titrated with standard sodium thiosulphate solution using starch as indicator [14]. Where mentioned, pH adjustment was done with NaOH (technical grade, 50%, Brenntag, BE).

Foamed cleaning solutions were prepared from Calgonit CF 314 (Calvatis GmbH, DE), a commercially available liquid alkaline foam cleaner containing active chlorine and NaOH. The foaming component is a non-ionic detergent; details and the specific concentration are not provided by the manufacturer. The active chlorine concentration is $\sim$3.6% and the pH is 12.6 (on 1% dil.). The liquid concentrate was diluted with RO water according to the pre-assigned NaOCl concentration. Each time the actual hypochlorite concentration was determined as described before.

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