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Periodic air/water cleaning for control of biofouling in spiral wound membrane elements

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Abstract

The main problem during the operation of nanofiltration or reverse osmosis membrane plants is fouling of feed spacers in membrane elements due to biofouling and particulate fouling. In order to control biofouling and particulate fouling in membrane elements, both daily air/water cleaning (AWC) and daily copper sulphate dosing (CSD) were investigated and compared to a reference without daily cleaning. A pilot study was carried out for 110 days with three parallel spiral wound membrane elements; AWC, CSD and the reference which were fed by tap water enriched with a biodegradable compound (100 μg acetate-C/L). The CSD element, which combined daily copper sulphate dosing and sporadically air/water cleaning, performed best with an increase in pressure drop of 18% and a biomass concentration of 8000 pg ATP/cm^2 within 110 days. This was followed by the AWC element with a pressure increase of 37% and biomass concentration of 20,000 pg ATP/cm^2 within 110 days. The reference element showed a pressure increase of 120% within 21 days. The presented approach is considered very successful in controlling particulate fouling and biofouling, especially when air/water cleaning is combined with copper sulphate dosing.

Keywords: Biofouling; Particulate fouling; Membrane cleaning; Air/water cleaning

1. Introduction

Application of membrane filtration in water treatment is in many cases hampered by the occurrence of membrane fouling. Four types of fouling are generally distinguished; organic fouling, inorganic fouling (scaling), fouling by particulates and biofouling [1]. Biofouling is the most persistent problem and usually occurs when membranes are applied for the production of drinking water, process water and for desalination of seawater. Biofouling occurs due to accumulation of biomass on the membrane surface by growth and/or deposition leading to operational problems [2]. Biomass formation is usually accompanied by the accumulation of inorganic particles which accelerates the fouling process. The accumulation of biomass is caused by the presence of biodegradable components and biomass in the feed of the membrane installation.

A major problem of nanofiltration or reverse osmosis membrane plants is the fouling of feed spacers in spiral wound membrane elements due to biofouling and particulate fouling. As a result of this, the pressure drop over the membrane elements increases which disturbs the flow distribution in the feed spacer channels. This results in operational problems in the membrane installation. It is important to reduce and/or prevent this phenomenon as efficiently as possible. Many means and methods are available in practice to inactivate biomass during membrane cleaning or during biocide dosing [3]. However, in practice sometimes chemical cleaning alone is not sufficient to control biofouling, because foulants are insufficiently removed by chemical cleaning [4]. Debris from inactivated biomass which is not removed from membrane elements can lead to an accelerated regrowth of biomass during normal production after membrane cleaning [4]. Biomass has to be physically removed. In order to remove (inactivated) biomass from membrane elements, both hydraulical and chemical action can be used which are both

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investigated in this paper to prevent and control biofouling problems expressed as feed channel fouling.

2. Theory

2.1. Air/water cleaning

Among the many cleaning strategies for membrane elements the application of air is a relatively new, cost effective and environmental friendly alternative. The application of air in membrane processes in water treatment began in the 1990s and is known by many different names, such as air sparging, air/water flushing, air lifting, air scrabbling and air scouring. Different strategies for the use of air were described in literature, and can be distinguished between prevention of fouling by injecting air during filtration and cleaning of membranes by air injection between modes of filtration. In this work the term air/water cleaning is selected for the latter strategy to indicate that the combination of air and water contributes to the (hydraulical) cleaning action.

Using air during filtration and air/water cleaning in literature is mainly focussed upon micro- and ultrafiltration (MF/UF) for both tubular [5–11] and hollow fibre geometries [7,12–15]. Although the process conditions and the dimensions of the fibres vary widely, it is clear that the use of air leads to an enhancement in flux. Only a few references were found on the hydraulic effect on nanofiltration or reverse osmosis membranes using air both for spacer filled channels [16,17] and submerged flat sheets [18]. Cui and Taha [7] concluded that the flux enhancement due to the use of air was more significant for tubular and flat sheet membrane elements compared to hollow fibre and spiral wound membrane elements. Most of the literature is focussed on using air injection during filtration, while only a few studies deal with air/water cleaning [11,13].

Using air in MF/UF is reported in literature on different types of water, such as drinking water [11,14,19] and wastewater [5,9], and on different foulant types, such as particular or colloidal matter [8,12–13,15], activated sludge [5], proteins [6] and oil in water emulsions [16]. Using air is found to be very efficient in removing particulate fouling, resulting in a considerable flux enhancement [8,12–13,15]. Using air to remove or control other types of foulants also proved to be effective [5,6,16]. The effect of air/water cleaning on biofouling is not reported in literature and is the topic of this work.

Adding different amounts of air to water in canalised flow results in different hydrodynamic regimes. In membrane filtration the hydrodynamic regime during air/water cleaning depends on the geometry of the membrane element, the air velocity and the water velocity (air to water ratio). It was found for tubular configurations that slug flow is the optimum hydrodynamic regime for flux enhancement [8,12,15]. No uniformity exists in literature between the definitions of the air to water ratios, which is an important factor for the optimisation of flux enhancement as a result of using air during filtration and air/water cleaning.

Using air in MF/UF is usually applied in a cross-flow mode or during the backwash sequence in semi dead-end mode [11,13]. The position of the membrane elements are investigated by several researchers [6,10,14], and it was concluded that vertically positioned membrane elements benefited more from air injection than horizontally positioned membrane elements. Kennedy et al. [14] even reported a negative effect on flux behaviour of the use of air in horizontally positioned hollow fibre modules. The direction of the air/water flow is in most cases from bottom to top, although Cui and Taha [7] found good results with a reverse flow direction for tubular membranes. Continuous or intermittent air injection during membrane filtration gives contradictory results from literature. Whereas Cabassud et al. [12] found intermittent air injection to be less effective than continuous flow, the opposite was reported by Chang and Judd [5] and Verberk et al. [11]. It appears that the effectiveness of air injection strongly depends on the frequency and duration of intermittent use of air. Both parameters are poorly investigated in literature.

In this paper, the effect of air/water cleaning on biofouling of spiral wound nanofiltration membrane elements is investigated.

3. Methods

3.1. Materials

Three 2540-type ESNA2 (Hydranautics) nanofiltration spiral wound *membrane elements* were used during the experiments with a membrane area of 2.5 m^2 per membrane element. The membrane material consists of a thin film composite polyamide layer, supported by a polysulfon substructure. A diamond pattern feed spacer with a thickness of 1.27 mm is present in the feed flow channel, which determines the hydraulic flow pattern. The membrane elements were vertically mounted into the pilot set-up with the permeate port closed to prevent production of permeate. In previous work [20] it was found that the influence of permeation on biofouling behaviour was negligible, both from pressure drop increase and biomass concentration on membrane surfaces, which motivates omitting permeation in this research. Three membrane elements are tested in parallel; a reference element (REF) which is only air/water cleaned when the pressure drop increased more than 150%, a daily air/water cleaned element (AWC) and an element (CSD) which is treated daily with copper sulphate.

The *feed water* was tap water supplied by pumping station Tull en't Waal and was prepared from anaerobic groundwater, treated by aeration and rapid sand filtration. The feed water contained traces of iron and manganese (<0.01 mg/l) [18]. The water was furthermore pre-treated by cartridge filters with a 1.0 μm pore size to eliminate particulate matter before entering the pilot set-up in order to prevent feed spacer blockage.

In order to speed up the biofouling process, *sodium acetate* was dosed into the feed water as an easily assimilable organic carbon source (AOC). Sodium acetate was dosed into the feed water at a concentration of 100 μg C/l which entered the pilot set-up and is known to cause biofouling problems within a few weeks [21].

Air/water cleaning with pressurized air was used in order to periodically clean one of the membrane elements (AWC). Furthermore air/water cleaning was used to clean the element that was used as reference (reference).