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The use of integrated flotation and ceramic membrane filtration for surface water treatment with high loads of suspended and dissolved organic matter

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ABSTRACT

In this work, we present results of surface water treatment pilot testing of ceramic MF/UF membranes using surface water from the River Spree in Berlin, Germany. The river water is characterized by high fluctuations in quality parameters with recurring spikes in dissolved organics, turbidity and microalgae concentration. The goal of this study was to evaluate the techno-economic applicability of a novel integrated treatment process using coagulation, flocculation, induced air flotation and ceramic membrane filtration based on a 12 m^3/d pilot system. It was shown that flotation serves as an effective pre-treatment for membrane filtration, allowing a flux of 112 l/m^2 h with only limited and controllable fouling. Different parameters were tested in the pilot including chemical dosings, air supply, filtration fluxes etc. Turbidity and TOC levels of both the feed and the product water were continuously monitored. Finally, using an economic analysis (net present value) it is shown that ceramic membranes are comparable in overall costs to polymeric membranes or even lower when high fluxes (150 l/m^2 h or higher) are implemented.

1. Introduction

The use of low-pressure membrane filtration (microfiltration/ultrafiltration) for surface water treatment is growing in popularity, e.g., due to global decrease in surface water quality [1]. A market profile from March 2014 shows that the USA and China are the leading markets with a significant increase of installed capacities for drinking water purification (including surface water) and wastewater treatment [2]. Despite being dominated by polymeric membranes (typically PES or PVDF in hollow fiber configuration), the interest and popularity of ceramic membranes (typically of Al_2O_3 or SiC) is growing due to their advantages in terms of: lifetime, robustness (chemical, mechanical and thermal), fouling resistance and the operability with high fluxes [3]. Lee et al. have examined the fouling behavior of ceramic membranes with surface water and showed that the same fouling models used for polymeric membranes are applicable for ceramic membranes [4]. Table 1 summarizes some of the differences between ceramic and polymeric membranes.

Ceramics still do not enjoy a wide acceptance level in drinking and municipal wastewater treatment outside of Japan [5,6]. Despite clear advantages, the higher purchase price limits the use of ceramics to special industrial applications where polymeric membranes are inadequate (harsh chemical/thermal environment). Nevertheless, the price of ceramic membranes has dropped in the last few years and should continue to drop due to new manufacturers entering the market and economy of scale (see Fig. 1). Loi-Brugger et al. have shown promising results with high fluxes and low maintenance for coagulation and ceramic microfiltration of river water [7]. High flux operation makes ceramic membranes especially competitive in overall water treatment costs when compared to polymeric membranes [8].

The use of in-line coagulation as pre-treatment for low-pressure ceramic membrane filtration in surface water applications is known to have a clear positive impact both on reducing irreversible fouling as well as on the removal of organics [9–11]. Dissolved foulants are agglomerated by coagulation and subsequently precipitated before they reach the filtration stage. Other pre-treatment technologies, such as flotation were also found to improve ceramic membrane fouling performance and organics removal (e.g., for waters containing microalgae or oil [12,13]).

In reverse osmosis (RO) applications for surface water treatment, controlling RO membrane fouling is still a key issue in

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Table 1
Comparison between polymeric and ceramic membranes.

Property	Ceramic MF/UF	Polymeric MF/UF
Hydrophilic character	High	Moderate
Permeability	High	Moderate
Stability (thermal, chemical, mechanical)	High	Low/moderate
Life time	10–20 years	5–7 years
Recyclability	Yes	No
Operation costs	Low	High
Capital costs	High	Low

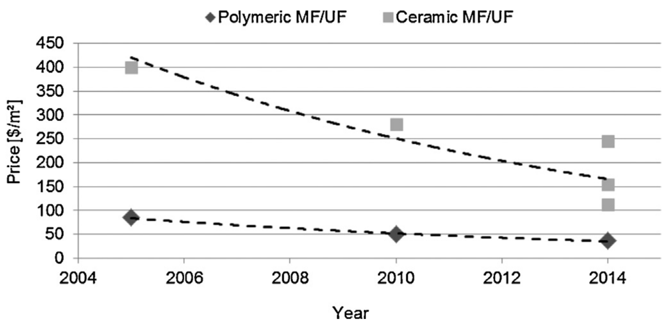

Fig. 1. Purchase price of ceramic and polymeric MF/UF membrane modules based on quotes solicited by the TU Berlin and akvola Technologies.

having a plant operating at its design specifications. Efficient pretreatment is considered a prerequisite and in some cases, such as open intake seawater desalination, a none-resolved issue [14]. Two clear trends, especially in coastal areas of impaired seawater quality suffering from occasional algae blooms, are membrane (MF/UF) pretreatment and dissolved air flotation (DAF) [15].

In this work, the use of flocculation–flotation combined with ceramic membrane filtration of river water was studied and tested on a pilot scale plant in Berlin. The pilot plant test procedure is based on a guideline of the American Membrane Technology Association (AMTA) [16]. This guideline outlines the target of a pilot testing in consideration of plant performance parameters as well as the influence of environmental conditions. The water treatment costs were projected and compared to those of conventional dissolved air flotation and polymeric membrane filtration.

2. Materials and methods

In the pilot plant, water from the Berlin city canal, Landwehrkanal (branch of River Spree), was treated during summer to autumn 2013. The period was characterized by fluctuating levels of total organic carbon (TOC) and turbidity. The slow flow (10 cm/s) of the canal and low depth (2 m) promotes the occasional

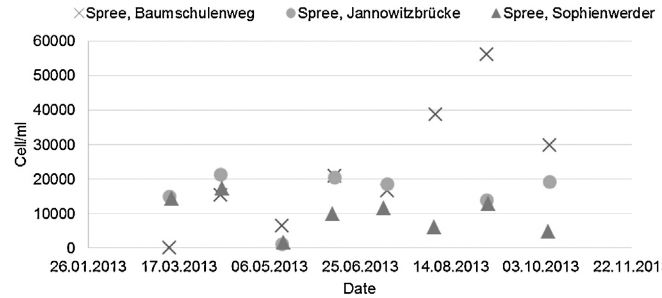

Fig. 2. Measured phytoplankton cell count at different points along the Spree river (Baumschulenweg and Jannowitzbrück are up river) during 2013 determined by the local authorities [17].

algae bloom in summer. Furthermore, the canal is used to relieve the sewage system at heavy rain events. Additionally, a sluice for boats is operated next to the raw water inlet, which has a significant effect on the turbidity (>10 NTU during operation). The counted algal cell concentration of phytoplankton at three different spots along the river is given in Fig. 2. The algae are mostly composed of cyanobacteria and diatoms ranging in size between 3 μm and 80 μm [17]. This data was provided by the municipal authority (up river to the plant location) and the algae load at the plant's intake point is considered to be in the same range or higher.

In August 2013, the canal experienced a short algae bloom at the intake point of the pilot plant (see Fig. 3). These aerial images were made from the platform in 2 m height next to the intake point. The milky surface showed a bright green superficial layer. The green was adapted to the grayscale shades in Fig. 3.

The daily measured TOC, pH and temperatures during the pilot test were logged. The monthly average values are shown in Fig. 4. The turbidity fluctuated frequently between 6 and 13 NTU depending on weather conditions, time of day and boat traffic in the canal.

The 12 m^3/d pilot plant (Fig. 5) consists of a 300 l tank integrating flocculation, induced flotation and submerged ceramic membrane filtration in a single vessel. The design of this hybrid process unit also known as akvoFloat coincides with the basic concept of process intensification: process integration using advanced process equipment [18]. The intake water is pre-sieved with a 300 μm stainless steel automatic filter to reduce sand and large suspended solids, reaching feed tank B1. From B1 water enters the integrated tank, B2, after continuous rapid inline coagulation with $FeCl_3$ at 10 mg/l_{Fe} based on initial jar tests. When entering the flocculation zone of B2, a flocculation aid (polyacrylamide, 0.1 mg/l) is added, to enhance floc growth and floc strength. The total flocculation time was less than 10 min. When the water enters the flotation zone, the flocs attach to micro air bubbles supplied by novel ceramic diffusors operating at a pressure of 2 bar, providing an air flow of

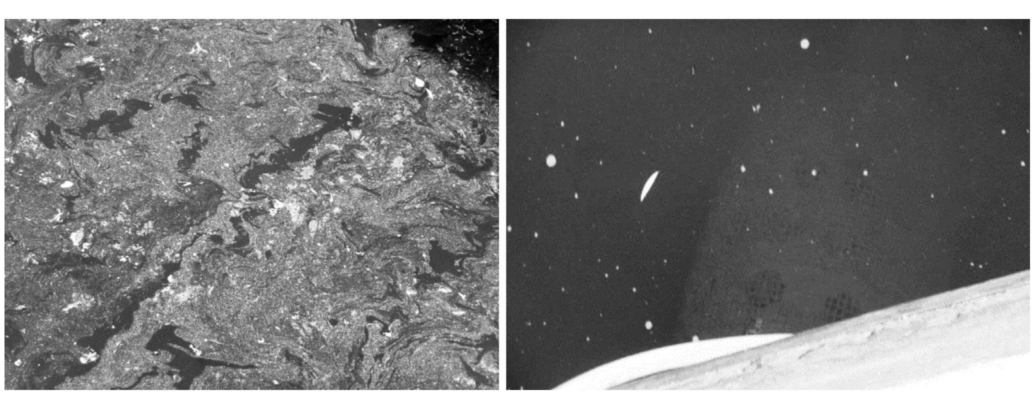

Fig. 3. Aerial images from a height of 2 m of the intake point during an algae bloom (left).