Treatment of Wastewater containing Powdered Activated Carbon with Inside-to-Out Ultrafiltration Membranes

Christian Staaks, inge GmbH, Germany; Denis Vial, inge GmbH, Germany;
Grit Hoffmann, University Duisburg-Essen, Germany;
Patrick Buchta, inge GmbH, Germany; Roland Winkler, inge GmbH, Germany;
Stefan Panglisch, University Duisburg-Essen, Germany;
Peter Berg, inge GmbH, Germany

Abstract

This study presents the results of filtration tests with inside-to-out polyethersulfone ultrafiltration membranes combined with coagulant and powdered activated carbon addition to polish wastewater before discharge. Long-term follow-up of the operation demonstrates that such membranes can be used as a polishing step and that the membranes do not suffer from any performance or integrity loss. Results show that organic content is reduced by approximately 33 % for DOC, 54 % for COD and that an overall reduction of 80% of the micropollutants can be reached with such hybrid process. The study finally presents reductions of the operational expenditures which can be achieved by discontinuous coagulant dosing.

Keywords: Powdered Activated Carbon; Ultrafiltration; Waste Water; Micro Pollutants; Organic Compounds

Introduction

Literature suggests that 10 mg/L of powdered activated carbon (PAC) can remove most micro-pollution from secondary wastewater [2], while the removal efficiency still depends on the micropollutant, the type of PAC [1] [3] [4] [6], as well as mixing conditions and in particular contact time. Alt [1] reports that the addition of PAC has beneficial effects in removing chemical oxygen demand (COD) and total organic carbon (TOC). PAC can be removed with sand filters or low-pressure membranes. Even if some polymeric membranes experienced fouling issues [5], the use of ultrafiltration (UF) membranes results in many advantages over sand filter as among them footprint savings, removal of microorganisms (even viruses) and a constant low filtrate turbidity independent of feed turbidity. Considering that PAC alone also forms a carrier for bacterial growth, UF is an effective barrier against multi-resistant bacteria and even multi-resistant genes with total elimination rates for selected UF membranes[6].

Material and Methods

Two pilot units have been employed in this research at two waste water treatment plants in Germany (Site A and Site B). Both sites consist of screening, clarification, biological treatment and secondary clarification. On Site A, a contact reactor with 5 to 20 mg/L PAC addition followed by tertiary clarification and sand filtration is installed to remove the PAC. The pilot unit is fed by the effluent of the tertiary clarification and has two identical lines (Line I and Line II) each equipped with a 1 m² module. On Site B the PAC is added into the feed tank of the pilot unit with concentrations up to 240 mg/l simulating a maximum breakthrough. At this site, the pilot unit is equipped with an 80 m² dizzer® type module.

At both locations, tests were conducted with a fully automated UF pilot unit provided by inge GmbH and equipped with several components:

- feed and backwash pumps with frequency-controlled drives to enable constant flow rates,
- feed and filtrate holding tanks,
- chemical dosing pumps for different chemicals (acid, caustic and chlorine),
- instrumentation (pressure sensors, pH and temperature probes, turbidity and flow meters) and
- automatic data logging.

The UF modules used for the study contain inside-to-out Multibore® fibers with seven capillaries (Figure 1). The inner layer of each capillary (internal diameter of 0.9 mm) represents the very thin active filter surface. The pore size of the filtration layer is approx. 20 nanometers. Between the capillaries is the foamy supporting structure which has a permeability approx. 1000 times higher than that of the membrane surface. This ensures an even distribution over the entire cross-section of the fiber. In addition, this unique structure allows a very high stability of the membrane.

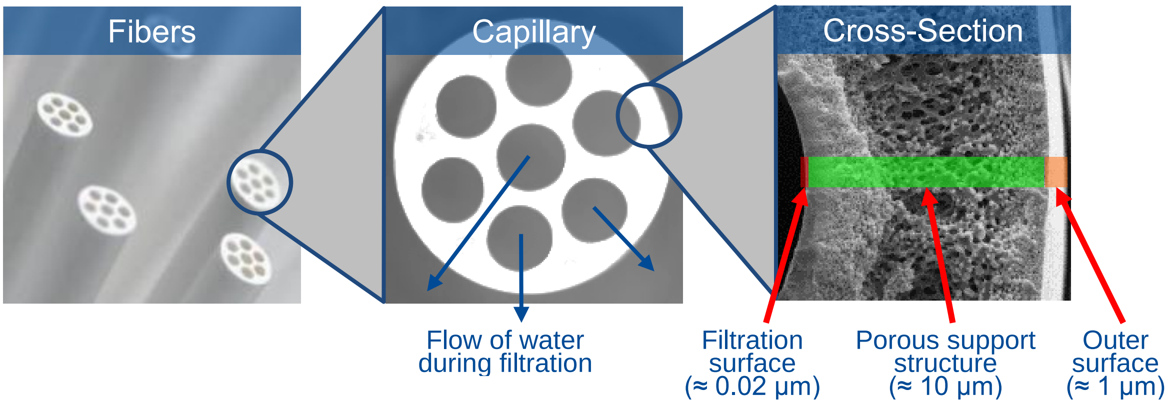

Figure 1: Multibore® Membrane

The material of the Multibore® fibers is modified polyethersulfone (PES) with a high pH tolerance of 1-13, which enables efficient cleanings even under extreme conditions. Thus, changes in membrane properties caused by fouling can often be reversed by e.g. normal backwashes or chemical cleanings [7].

Results and Discussion

On Site A, the two lines were operated with similar conditions: flux rate of 70 $L/(m^2 \cdot h)$, filtration duration of 45 min, injection of polyaluminumchloride (PACl) at 3 mg/l as of Al^{3+} prior to the UF. In Line I, PACl was dosed continuously , while in Line II, PACl was dosed during one-fourth of the total filtration duration at the beginning of the cycle (intermittent dosing also called coating procedure). For Line I, permeability varied from 130 to 200 $L/(m^2.h.bar)$ at 20°C, while for Line II, permeability was recorded at slightly lower values between 100 to 150 $L/(m^2 \cdot h \cdot bar)$ at 20°C. Both permeabilities being stable, one can conclude that there is no evidence of any clogging of the capillaries thanks to the effectiveness of the backwash. For both lines, a constantly low turbidity in the filtrate suggests that there is no weathering on the membranes nor integrity issues. COD and phosphate were monitored to evaluate the removal and hence, biological regrowth potential. No significant filtrate quality difference between continuous and intermittent dosing was observed as similar COD and phosphate removal were achieved for both lines, 26 to 46%, and 40 to 87%, respectively. Additionally, qualitative measurements of multi-resistant genes and bacteria in the feed and filtrate of the UF endorsed full elimination of the latter. Considering chemicals for cleaning, coagulants and energy consumption for pumps, calculations show that operational expenditure (OPEX) is reduced significantly when coating is applied compared to continuous dosing.

On Site B, the filtration flux was set to 60 L/(m²·h) with a filtration duration of 45 min. PAC concentrations from 30 to 240 mg/l were applied at continuous dosing into the feed tank for process stability tests. No adverse effect on membrane fouling had been observed as can be seen from Figure 2.

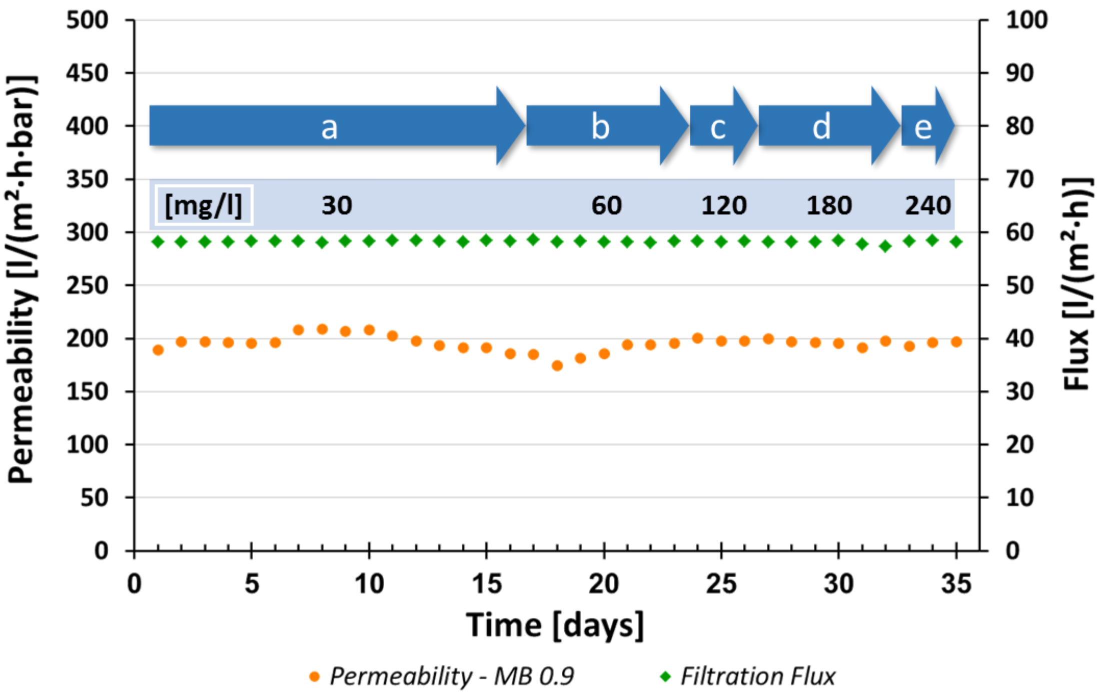

Figure 2 inge ultrafiltration performance at increased PAC concentrations

Subsequent addition of PACl at a concentration of 4 mg/l as of Al^{3+} stabilized the fouling behavior reflected in a permeability level around 200 L/(m²·h·bar) at 20°C. Further tests using 15 mg PAC/L revealed a reduction of 33 % for DOC and 54 % for COD by PAC/coagulation/UF. Concentrations of selected micropollutants have been determined in the influent as well the effluent of the waste water treatment plant and in the filtrate of the UF.

An overall removal of 82% could be achieved for Clarithromycin, Diclofenac, Sulfamethoxazol, Metoprolol, 1H-Benzotriazol, and Carbamazepin as is illustrated in Figure 3 meeting the requirements of the competence centre for micro pollutants of North Rhine Westphalia.

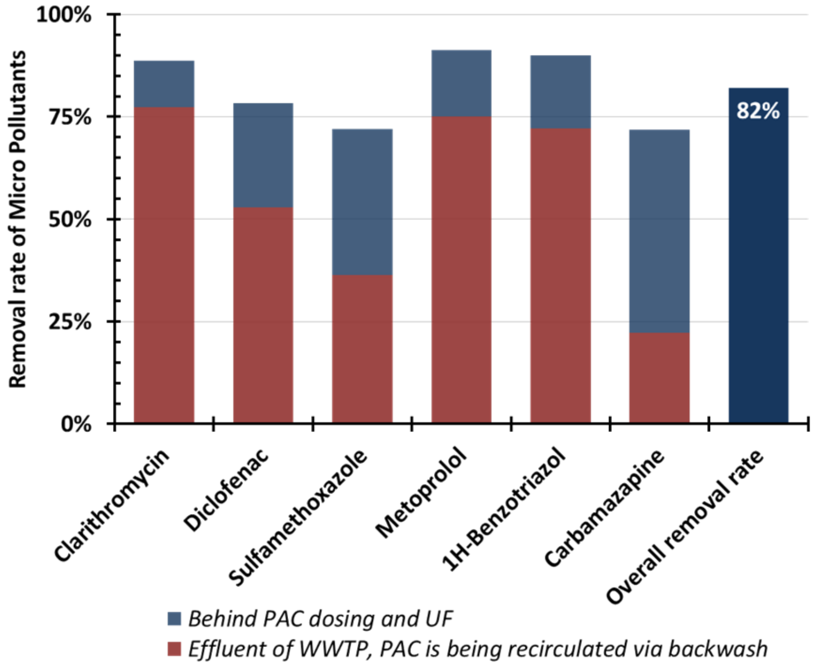

Figure 3 Removal of selected micro pollutants by PAC and UF

Based on adsorption kinetics and physico-chemical properties of the selected micro pollutants, it can be derived from the figure that in particular the recirculation of the PAC with the UF backwash into the biological treatment step has major impact on the overall removal efficiency. Supplementary, the short contact time of PAC (30 sec) prior to the UF adds up significantly to the overall removal.

Conclusions

This study illustrates that inside-to-out polyethersulfone membranes can be operated on wastewater effluents containing powdered activated carbon for long periods of time without experiencing any weathering. Also, concentrations up to 240 mg/l did not have a harmful effect on the overall operating performance. It is proved that stable permeabilities on different levels can be maintained depending on the way coagulant is added (continuous dosing or coating procedure). It is observed that there is no difference in chemical oxygen demand or phosphate removal rates when coating is used compared to a continuous dosage of coagulant. It could be assessed that the dissolved organic carbon could be reduced by 33%, and that an overall removal of micropollutants of more than 80% could be achieved by the waste water treatment plant followed by powdered activated carbon and ultrafiltration. Finally, it is demonstrated that the coating procedure significantly reduces operational expenditure.

References

[1] Alt, K., & Mauritz, A. (2009). Projekt zur Teilstrombehandlung mit Pulveraktivkohle im Klärwerk Mannheim. gwf-Wasser/Abwasser.

[2] Hildebrand, A., Metzger, S., & Prögel-Roy, C. (2013). Mit Aktivkohle gegen Spurenstoffe im Abwasser. *Sonderdruck Aus KA- Korrespondenz Abwasser, Abfall*, (3), 170–174.

[3] Meckes, J., Metzger, S., & Kapp, H. (2014). Untersuchungen zum Spurenstoffbindungsverhalten von Pulveraktivkohle unter anaeroben Bedingungen, 52.

[4] Metzger, S., Kapp, H., Seitz, W., Weber, W. H., Hiller, G., & Süßmuth, W. (2005). Entfernung von iodierten Röntgenkontrastmitteln bei der kommunalen Abwasserbehandlung durch den Einsatz von Pulveraktivkohle. *GWF, Wasser - Abwasser*, *146*(9), 638–645.

[5] Oligny, L., Bérubé, P. R., & Barbeau, B. (2016). Impact of PAC Fines in Fouling of Polymeric and Ceramic Low-Pressure Membranes for Drinking Water Treatment. https://doi.org/10.3390/membranes6030038

[6] Schwartz, T. (2019). Kommunale Kläranlagen, Eliminationsverfahren. Abschlussveranstaltung des BMBF-Verbundvorhabens HyReKA: Antibiotikaresistenz im Wasserkreislauf

[7] Zeman, L.J. and Zydney, A.L. (1996). Microfiltration and Ultrafiltration – Principles and Applications, Marcel Dekker Inc., New York.

Paper prepared for: *12th IWA International Conference on Water Reclamation and Reuse; 16 - 20 June 2019 - Berlin, Germany*

DOI: 10.17185/duepublico/49420
URN: urn:nbn:de:hbz:464-20201126-164544-4