A Comparison of Laboratory and Pilot Plant Experiments on the Combination of Flocculation/Ultrafiltration for Direct Potable Water Treatment of River Water

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ABSTRACT

A direct treatment of river waters with ultrafiltration (UF) is not yet realised in larger scales due to considerable fouling and scaling effects caused by water contaminants on the membranes surface under those circumstances. Therefore, the deposits on the membrane cannot be eliminated extensively by conventional backwashing. An extensively detachment of the formed layers while backwashing is desired to achieve cost advantages when using the process combination flocculation/ultrafiltration for the direct treatment of surface waters. Hence, pilot and laboratory plant experiments were carried out while dosing different coagulants at different pH-values with different concentrations of the coagulant to investigate their influence on the build-up of the coating layers. The experiments described here were focused on the following questions.
Firstly, how do coagulation and flocculation conditions influence the performance of the treatment combination flocculation/ultrafiltration and which coagulant is best? Secondly, does a good operational performance of the combination flocculation/ultrafiltration at laboratory scale coincide with good operational performances at the pilot plant or does the presence of dissolved organic carbon (DOC) in the raw water will decrease the performance significantly? Thirdly, does a good operational performance coincide with an extensively reduction of DOC, or humic substances respectively?

KEY WORDS

Fouling, Coagulation, Flocculation/Ultrafiltration, Direct Water Treatment

INTRODUCTION

Earlier research projects, undertaken by the WdKA Wasserwerk des Kreises Aachen in Roetgen/Germany and the IWW have shown that ultrafiltration can be fundamentally used for direct reservoir water treatment after flocculation [1, 2]. Hence, the combination of flocculation/ultrafiltration is investigated for direct treatment of river waters in laboratory and pilot scale. It is considered that dosing coagulants (e.g. iron or aluminium salts) into

the raw water stream can be of high advantage for the ultrafiltration process, because undesired fouling causing water contaminants (particles, humic substances etc.) can be partly embedded into the formed flocs and therefore, it is assumed that they cannot adsorb onto the membranes surface. These substances should then be able to be eliminated extensively from the membrane surface together with the flocs using an optimised backwashing procedure. The HEW HofEnergie+Wasser GmbH in Martinlamitz/Germany operates with financial help of the German Ministry for Education and Research and scientific support of the IWW in Mülheim/Germany different ultrafiltration pilot plants (Stork (now X-Flow) and Zenon) in the Martinlamitz water works for the direct treatment of river waters by UF after flocculation. The raw water, which can temporally be contaminated with high amounts of turbidity and natural organic matter especially after rainfalls, is taken from two different creeks (Goldbach and Steinbach).
Accompanying to the pilot plant experiments at the Martinlamitz water works, laboratory experiments were performed on a small laboratory plant of the company X-Flow to investigate the influence of coagulation and flocculation conditions on the combination flocculation/ultrafiltration more detailed. The performance of the pilot and laboratory plants was investigated while dosing different coagulants, i.e. polyaluminum-chloride (PACl) or iron-chloride (FeCl), at different pH-values and with different concentrations of the coagulant. An extensively detachment of the coating layers while backwashing, possibly without using enhanced backwashing, i.e. without using chemicals, is desired to achieve cost advantages when using the process combination flocculation/ultrafiltration for the direct treatment of surface waters.

EXPERIMENTAL SETUP

Laboratory Plant

The laboratory experiments were undertaken on a small laboratory scale plant called ‘Quickscan’ of X-Flow (see Figure 1). The laboratory plant was extended with different water tanks, i.e. raw water tank, permeate tank and backwash water tank, one dosing station for dosing different coagulants as well as acid and base to adjust different pH-values, an in-line coagulation to provide a sufficient floc build-up and a dosing station for dosing chemicals if a chemical cleaning of the membrane was necessary.

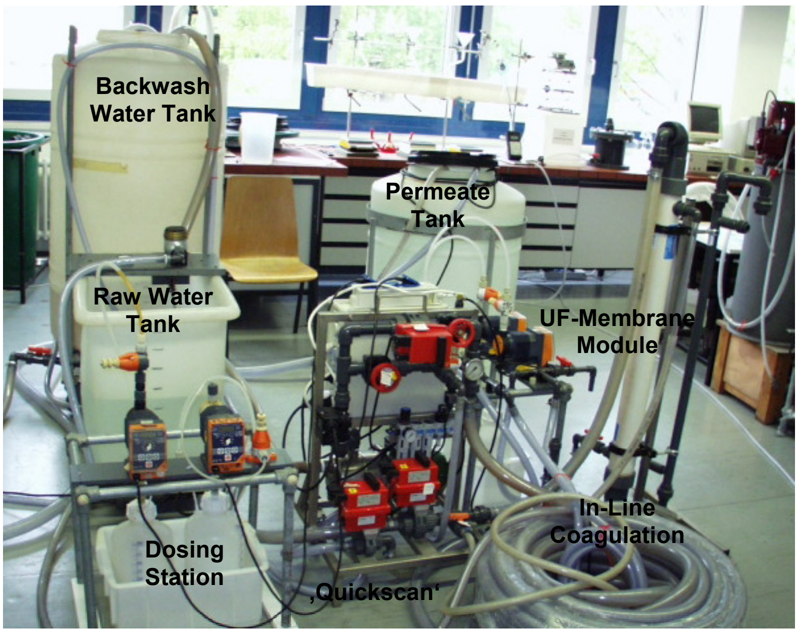

Figure 1: Experimental Setup of the laboratory plant ‚Quickscan‘

PACl or FeCl was dosed into tap water which was used as raw water source and sodium hydroxide (NaOH) or hydrochloric acid (HCl) was dosed into the raw water stream to adjust the desired and investigated pH-value. Sufficient and rapid mixing was provided by the centrifugal pump of the laboratory plant. Floc formation took place in the following in-line coagulation before the water entered the membrane module, which was operated in dead-end mode. The membrane was the same as used in the pilot plant at the Martinlamitz water works, whereas the module of the laboratory plant had a total filtration area of 3.6 m².
To investigate adverse effects on the membrane performance caused by the used coagulant at different coagulation and filtration conditions (see Table 1), the loss in flux, or permeability respectively, was determined by measuring the permeate flow at a constant transmembrane pressure (TMP).

Table 1: Used coagulation and filtration conditions

	Low	High
Coagulant Dosage in [mmol (Me^{3+})/L]	0,1	0,5
pH-Value	5,25	6,75
TMP in [bar]	0,4	0,8

Each trial of the laboratory experiment was operated for about 4 hours with 8 filtration cycles, whereas each filtration cycle lasts 30 minutes. After each filtration cycle a combined back-flow and forward-flush (without dosing coagulant) was performed, like it was done at the Stork/X-Flow pilot plant in the Martinlamitz water works.

Pilot Plant

Two pilot plants (Stork (now X-Flow) and Zenon) were operated in the Martinlamitz water works. The Zenon ZeeWeed® G11 was an immersed UF membrane, operating in OUT/IN-mode, type 500 C, with a MWCO of about 100,000 Dalton. This module provided a filtration area of about 30 m². The pilot plant of Stork was equipped with an UF capillary module, operating in IN/OUT-mode. The membrane material was Polyethersulfon (PES) with a Molecular Weight Cut-Off (MWCO) of about 150,000 Dalton. The capillaries inner hydraulic diameter was 0.7 mm and the module provided a total filtration area of about 23 m².

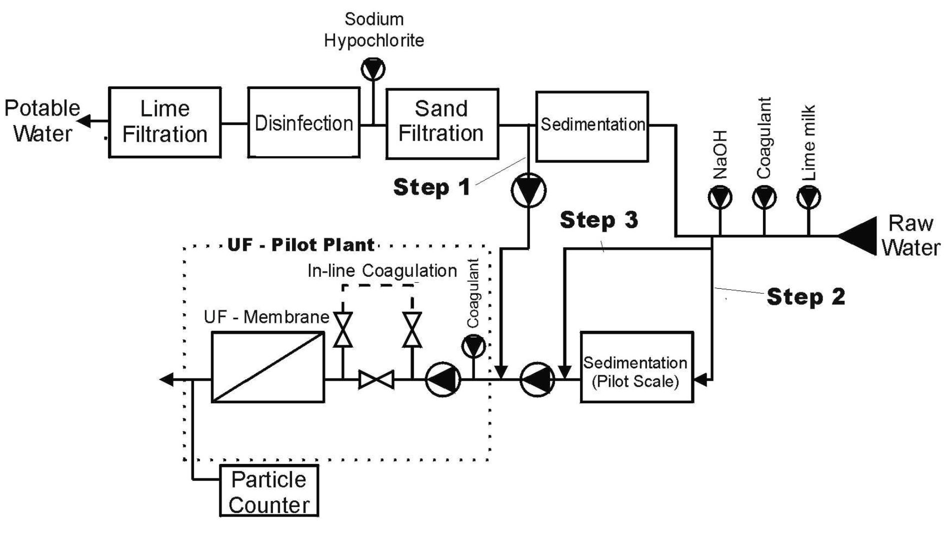

Figure 2: The process scheme of the Martinlamitz waterworks and integration of the UF pilot plants

The water works is treating the raw water in the way that Lime milk, PACl and NaOH is dosed into the raw water stream when entering the water works (compare Figure 2).

Sufficient and rapid mixing is provided by a static mixer. The floc formation takes place in the following chamber, where the main part of the formed flocs are retained by sedimentation. Remaining particles and micro-flocs in the water stream are eliminated when the flow passes a sand filter. Before the water enters the disinfection chamber, sodium-hypochlorite is dosed and finally the water passes a lime filter to adjust the pH-value.
The raw water flow of the pilot plants (about 2-3 m³/h) could be taken out of the raw water stream of the water works at three different locations (see Figure 2). Using location 1 the water was taken out of the water flow of the operating water work right after sedimentation. Location 2 and 3 were independent from the water flow of the water works, giving the advantage that different coagulants, different concentrations and flocculation conditions, i.e. pH-values, could be investigated. Taking the water at location 2, a sedimentation tank was used to eliminate most of the formed flocs before entering the membranes. Water from location 3 provided the possibility to load the membranes with flocculated raw water. Furthermore an in-line coagulation with separate dosing points was designated to provide sufficient residence time.

RESULTS AND DISCUSSION

Laboratory plant experiments

Figures 3 and 4 show the relative flux, which is the ratio of the measured and the initial flux, vs. filter run time in minutes when PACl was used as coagulant at different coagulation and filtration conditions. It is visible that coagulating with PACl at low pH-values (about pH 5.25) will lead to a decreasing permeability by time not only within each filtration cycle but also within the total trial run time, i.e. over all filtration cycles. This effect was true for high coagulant dosages as well as for low coagulant dosages, but it was much more pronounced if 0.5 mmol/l aluminum was dosed, rather than 0.1 mmol/L.

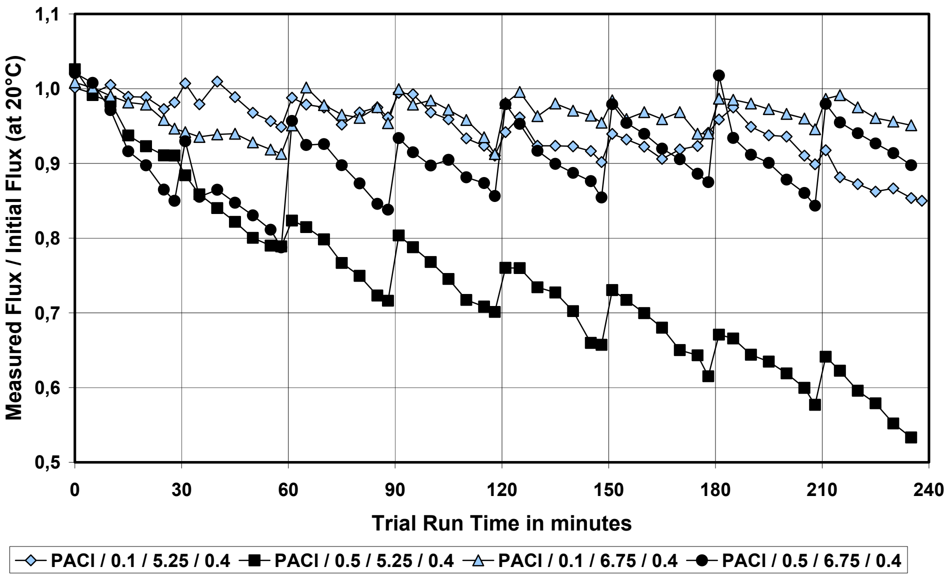

Figure 3: Measured Flux / Initial Flux at 20°C vs. filter run time in minutes. Trial set-up is indicated as: used coagulant / coagulant dosage in [mmol Me^{3+}/L] / pH-value / TMP in [bar].

This means that the backwashing procedure could not clean the membranes surface sufficiently enough to regenerate the permeability of the membrane completely. If coagulation was performed at higher pH-values (about pH 6.75), which is in the optimum range for an aluminum-hydroxide floc build-up due to the solubility of hydrolysis products of aluminum, almost a complete regeneration of the permeability could be observed after backwashing, even if high amounts of the coagulant were dosed. This is, because a good

removable coating layer could have been built by the flocs on the membranes surface under these circumstances.
Furthermore, Figure 3 shows a distinctive saw tooth pattern of the relative flux vs. time curves, especially for the trials when the higher amount of the coagulant was dosed, but also for the lower coagulant dosage. This pattern indicates a flux decline within filtration cycles on the one hand but also an effective backwashing procedure on the other hand, which means that the backwashing could regenerate the flux to a certain extend, not necessarily completely. Hence, it can not be chosen as an indicator of flux decline over the whole trial run time. This distinctive saw tooth pattern of the curves could not longer be observed for the trials at low pH-values when the TMP was further increased to 0.8 bar. For these trials no significant effect of the backwashing procedure was identifiable as one can see in Figure 4, which means that the formed coating layers could not, or only to little extend, be removed from the membranes surface.

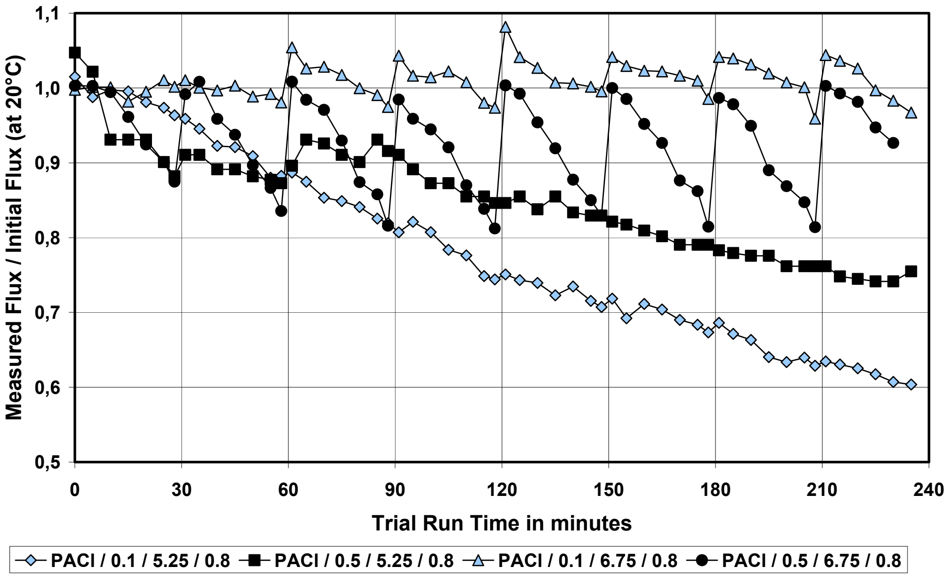

Figure 4: Measured Flux / Initial Flux at 20°C vs. filter run time in minutes. Trial set-up is indicated as: used coagulant / coagulant dosage in [mmol Me^{3+}/L] / pH-value / TMP in [bar].

The described impact of doubling the TMP, which is initially also a duplication of the flux, is due to several occurring effects. When doubling the initial flux while using PACl at low pH-values the mass loading of coagulant will be also doubled. Furthermore, the increased initial flux will lead to higher adhesive forces acting between the flocs and the membranes surface and probably to a higher compression of the formed coating layers. Further experiments at the pilot plants have also shown that the condition of the coating layer seems to be more slimy like a gel layer and less porous at lower pH-values for this coagulant [3], which could explain the worse detachment behaviour of the formed layer on an increasing TMP. A further explanation for this behaviour at low pH ranges can be that dissolved aluminum can precipitate due to an exceeded concentration equilibrium within the supporting layer of the membrane, blocking the pores inside successively with each filtration cycle. This effect could explain the permeability decline over total trial run time.

Figures 5 and 6 show the relative flux vs. filter run time when iron-chloride was used as coagulant at different coagulation and filtration conditions. It can be seen that there was not such an impact of the chosen coagulation pH-value if iron was used as coagulant instead of aluminum. This behaviour can be explained by the broader optimum range for an iron-hydroxide floc build-up due to the solubility of hydrolysis products of iron compared to aluminum. Hence, the feasibility of precipitation inside the active layer of the membrane due to an exceeded solubility equilibrium is much smaller.