Arsenic in the Environment: Bridging Science to Practice for Sustainable Development –
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Removal of low concentration of arsenic by coagulation-ultrafiltration

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ABSTRACT: A In order to reduce arsenic concentrations in drinking water to very low levels (below <μg1/L), we investigated the effect of coagulation with iron(III) prior to ultrafiltration on arsenic removal. It was found that arsenic could be removed to below 1 μg/L, as long as only infiltrated dune water is used as a source. When natural groundwater is also abstracted, removal of arsenic by coagulation – ultrafiltration is not sufficient due to resulting higher concentrations of arsenic and various anions in the feed water. At a dose of 0.4 mg Fe/L and a flux of 55 L m-2 h-1, membrane fouling could be controlled by chemically enhanced backwashing with citric acid and sodium hypochlorite.

1 INTRODUCTION

The World Health Organization (WHO) limit for arsenic (As) in drinking water is 10 μg/L. However, the Dutch drinking water sector has voluntarily agreed to reduce arsenic concentrations in drinking water to below 1 μg/L. Here, we investigate the option to use coagulation with ferric chloride (FeCl3) in combination with an ultrafiltration (UF) treatment step at a drinking water treatment plant (DWTP) to reduce arsenic concentrations from 3 μg/L to below 1 μg/L.

2 MATERIALS AND METHODS

2.1 *DWTP Ouddorp*

The main raw water source of DWTP Ouddorp is surface water which is pre-treated and subsequently infiltrated into the dunes. In addition, a limited amount of natural groundwater is used as a source. During dune infiltration arsenic is mobilized.

DWTP Ouddorp consists of aeration – rapid sand filtration (RSF), granular activated carbon filtration (GAC) and ultrafiltration (UF). Prior to the RSF iron chloride ($FeCl_3$) is dosed in order to partly remove As by means of coprecipitation with in situ formed Fe(III) precipitates. The predominant form of As in the raw water is arsenite. The remaining As in the RSF effluent is completely oxidized from arsenite to arsenate. The latter is considered to be easier removable at neutral pH (6-8) (Dixit & Hering 2003).

2.2 *Pilot description*

For the execution of the pilot research one pressure vessel, containing four Norit S-225 35 m^2 polyether-sulfone hollow fibre membranes, was isolated from one of the full scale UF skids. Subsequently, the isolated pressure vessel was attached to a fully automated pilot installation which included an inline Fe(III) dosing at the feed side of the membranes. Iron was dosed in the range of 0.1 – 1.0 mg Fe/L. Periodically, the membranes were cleaned with backwashes and chemical enhanced backwashes (CEB's). The applied CEB's were citric acid (2.000 or 4.000 mg/L) and sodium hypochlorite (100 mg/L). In order to achieve a stable membrane performance, a combination of different operational parameters were varied throughout the study (e.g. flux, backwash interval, CEB regime).

UF feedwater both pre- and post Fe(III) dosing and UF permeate was sampled. The samples were analyzed for arsenic, iron, ortho-P, Si and dissolved organic carbon (DOC). All analyses were executed at Aqualab Zuid, an accredited laboratory. Table 1 provides details of infiltrated dune

Table 1. Average quality parameters ($N \geq 17$) of the raw water sources, RSF effluent and UF feed of DWTP Ouddorp.

Parameter	Unit	Infiltrated dune water	Natural groundwater	RSF effluent	UF Feed
pH (-)	–	7.6 ± 0.2	7.5 ± 0.0	7.7 ± 0.1	7.6 ± 0.1
As	μg/L	10 ± 2.5	<0.5	3.0 ± 1.1	3.0 ± 1.1
Dissolved Fe,	mg/L	0.78 ± 0.17	0.50 ± 0.40	0.01 ± 0.01	<0.005
Dissolved Si	mg/L	4.6 ± 2.9	24 ± 1	4.4 ± 2.7	4.4 ± 2.7
Ortho-P	mg/L	n.b.	0.36 ± 0.1	<0.02	<0.02
DOC	mg/L	3.8 ± 0.7	6.7 ± 1.1	2.8 ± 0.5	2.2 ± 0.5

DOI: 10.1201/9781003317395-170

water, natural groundwater, RSF effluent and UF feed water for the aforementioned parameters.

3 RESULTS AND DISCUSSION

3.1 *Arsenic removal*

In Figure 1, the concentration of As in the coagulation-ultrafiltration (C-UF) permeate at different applied Fe(III) dosages is displayed. Independently of the operational settings an As concentration of lower than 1 µg/L could be reached with a Fe(III) dosage of $0.3 \geq Fe \leq 0.5$ mg/L, but only in the absence of natural groundwater (red triangles; September, October, December). It is evident that during admixture of natural groundwater in July, August and November, As could not be lowered below 1 µg/L by C-UF. The worsened As removal can be attributed either to a higher concentration of arsenic in the feed water of the C-UF, or changes in water quality of the raw water, for example higher concentrations of silica, phosphate and/or DOC (Ahmad *et al.*, 2019).

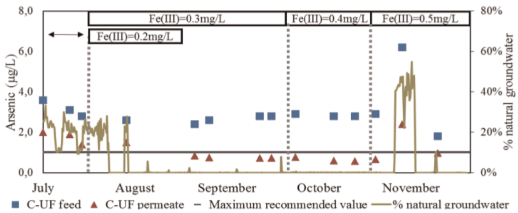

Figure 1. Effect of coagulation dose and percentage natural groundwater on arsenic removal by C-UF.

3.2 *Fouling control*

During coagulation, the membrane resistance (R) increases due to buildup of a layer of iron precipitates. Figure 2 shows the increase in R over ten filtration cycles, including one CEB per cycle, with a dose of 0.4 mg Fe/L and a flux of 55 L/m^2/h. The CEB is shown to be effective as R does not increase in time. R^2 is low and this shows that irreversible fouling is either absent or small using the above-mentioned settings. At higher fluxes or lower citric acid soaking times, irreversible fouling occurs (Table 2).

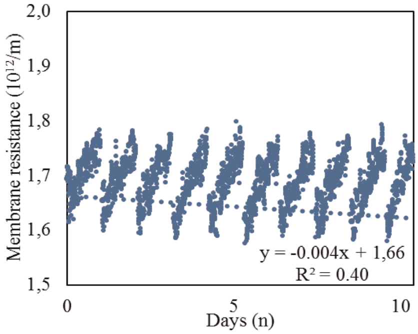

Figure 2. Changes in membrane resistance at 0.4 mg Fe/L, 55 L/m^2/h and citric acid soaking time of 60 min. Ten filtration cycles including the effect of a CEB are shown.

Table 2. Slopes and R^2 of membrane resistance development of C-UF in time with an iron dose of 0.4 mg Fe/L.

Flux (L/m^2/h)	Soaking time citric acid (min)	Slope	R^2
55	60	−0.004x	0.40
55	30	0.011x	0.94
120	60	0.084x	0.96

4 CONCLUSIONS AND RECOMMENDATIONS

C-UF with a dose of 0.4 mg Fe/L and flux 55 L/m^2/h can be successfully applied to remove arsenic concentrations from 3 to below 1 µg/L. In these circumstances, fouling of the UF modules can be controlled if a daily CEB with citric acid followed by sodium hypochlorite is applied.

REFERENCES

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