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Production of demineralized water out of rainwater: environmentally saving, energy efficient and cost effective

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Abstract

Membrane based processes for conventional production of demineralized water often consist of ion exchange and/or reverse osmosis. An innovative alternative process is using rainwater followed by low-pressure micro-/ultrafiltration offering potential benefits concerning the environment, energy consumption and costs. A project is carried out to determine the benefits of the alternative process for the production facility of S.Search b.v., a company that develops and produces membranes. The project is partially funded by Novem b.v., the Dutch organization for energy and environment. Data of rainfall is collected and attuned to water consumption using a in-house developed spread sheet. It appears that at average annual rain fall of 850 mm there is no shortage of demineralized water at a water consumption of 1 m^3/d discontinuous. Membrane performance on rainwater is currently tested, but is expected to show high flux together with low frequency of flushing and cleaning. Rainwater quality after treatment by micro-/ultrafiltration seems sufficient for S.Search b.v. Flexibility of the process using rain water in terms of water quality and quantity however is less compared to the conventional process. Therefore a cost calculation and comparison is carried out to determine when use of rainwater followed by micro-/ultrafiltration is attractive compared to processes using reverse osmosis and ion exchange.

Keywords: Micro-/ultrafiltration; Rainwater; Demineralized water; Cost comparison

1. Introduction

General processes world wide for production of boiler feed water or demineralized water consist of (multi stage flash) evaporation, ion exchange, reverse osmosis in combination with ion exchange or double pass reverse osmosis. With either of these processes dissolved solids are removed until required water quality guidelines are reached. Pretreatment is often necessary to

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prevent fouling of equipment or membranes by removal of suspended solids and colloids. In some applications, for example in the case of boiler feed water, very strict demineralized water quality requirements have to be reached as is shown in Table 1.

Other applications might need less stringent water quality requirements as is the case in the membrane production facility of S.Search b.v., where demineralized water is used during membrane production as well as for rinsing and testing of membranes. S.Search b.v., located in Dedemsvaart, the Netherlands, is a young and innovative company that develops and produces membranes for various applications, mainly for water purification and (waste) water treatment. As usually hot water is used during the production processes of S.Search b.v., one of the major items concerning water here is that no scaling of calcium carbonate or other components occurs. From the point of view of product purity use of demineralized water is also desirable. Finally because of implementation of wastewater reuse it is also necessary that the wastewater has low contents of dissolved solids. Estimated demineralized water quality guidelines for S.Search b.v. are also given in Table 1.

Table 1
Demineralized water quality requirements [1]

Parameter	Boiler feed water (medium pressure)	Demineralized water S.Search b.v.
Temperature, °C	>30	50–85
pH	6–9	6–9
Conductivity @ 25°C, μS/cm	<5	max. 50, preferably <25
Total dissolved solids (TDS), mg/l	<3	<25
Hardness, mmol/l	<0.108	no scaling
Silica (SiO_2), mg/l	<0.03	no scaling
NH_4, mg/l	<1	—
Cu, μg/l	<50	—
Fe, mg/l	<0.05	—

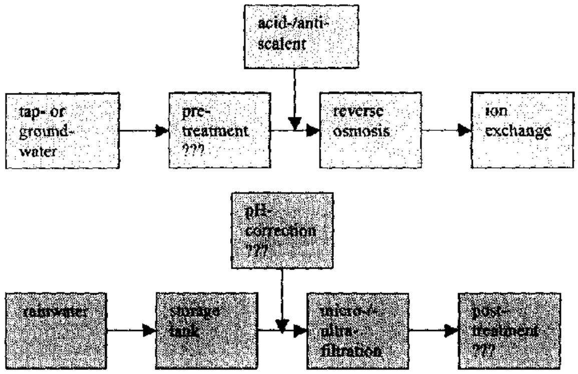

Fig. 1. Conventional and alternative process for demineral-ized water production.

2. Membrane based processes for demineralized water production

Two membrane based processes for demineralized water production, a conventional as well as an alternative process, are given in Fig. 1.

When reverse osmosis is used as a process step for production of demineralized water the overall process generally consists of intake of tap water or treated (ground) water followed by reverse osmosis and post treatment by mixed bed ion exchange. Additional pretreatment of the feed water is usually necessary to meet criteria for SDI (silt density index) or MFI (membrane filtration index) to prevent fast fouling of reverse osmosis membranes. Acid and/or anti-scalant dosage is often necessary as well to prevent scaling. Potential scaling components with reverse osmosis are calcium carbonate or barium sulphate. Finally mixed bed ion exchange or a second reverse osmosis process step will be applied for total salt removal before desired demineralized water criteria are reached. Surface water can also be used as feed water, but extensive pretreatment is definitely necessary due to high amounts of suspended solids and colloids present in surface water. There is a much higher risk of fouling of reverse osmosis membranes when surface water is used and therefore pretreatment needs to be more extensive. Possible pretreatment steps are flocculation–sedimentation–rapid sand filtration or low pressure membrane filtration (micro-/ ultrafiltration).

In an alternative process rain water followed by micro-/ultrafiltration is used offering an innovative alternative for production of demineralized water for S.Search b.v. Rainwater has low contents of dissolved solids and therefore salt removal by reverse osmosis and/or ion exchange seems not necessary. Scaling potential of rainwater is minimal due to the fact that almost no dissolved solids are present. This also implies that there is no acid and/or anti-scalant dosage and there is no use of chemicals for regeneration of ion exchange resins. Both aspects lower environmental impacts compared to processes using reverse osmosis and/or ion exchange. Rainwater can easily be collected in a storage tank that acts as a buffer tank as well. Data on the amount of rainfall is collected. In the Netherlands average annual rainfall is about 800–850 mm a year. The minimum size of the storage tank is calculated using a spreadsheet in order to produce the desired demineralized water capacity and to guarantee that there is enough water for the membrane production facility of S.Search b.v. Chemical analysis of rainwater indicates the water quality. Analysis also determines if an additional correction of pH is necessary, especially at low pH (acid rain). If this is the case only a small dosage of base (i.e. NaOH) is needed, because rainwater in not buffered. By applying micro-/ultrafiltration on rainwater, removal of suspended solids and colloids as well as desinfection is obtained. Dependent on the desired water quality for specific applications additional post-treatment may be necessary before using rainwater as demineralized water. For the membrane production process of S.Search b.v. additional post-treatment seems not necessary.

3. Potential benefits alternative process: environment, energy and costs

Although very stringent water quality can be reached (i.e. for boiler feed water), the production process of demineralized water using reverse osmosis and mixed bed ion exchange has some potential disadvantages compared to the alternative process based on rain water followed by micro-/ultrafiltration. The potential disadvantages concern impact on the environment, energy consumption and costs. The main items are:

- frequent and high use of chemicals (i.e. strong acid such as HCl or H_2SO_4 and strong base such as NaOH) for regeneration of ion exchange resins,
- acid and/or anti-scalent dosage for scaling prevention with reverse osmosis (mainly for prevention of calcium carbonate scaling),
- use of chemicals for temporarily cleaning of reverse osmosis membranes,
- energy consumption due to operating pressure needed for reverse osmosis,
- pretreatment to improve feed water quality to prevent fouling of reverse osmosis membranes by lowering MFI or SDI,
- costs for intake of tapwater and/or use of groundwater,
- wastewater disposal due to high dissolved solids contents (reduction of wastewater).

When using rainwater for demineralized water production intake of rainwater is free. A buffer tank is used to store rainwater, causing costs for the tank, but these costs are relatively low. Cleaning chemicals are also temporarily used for micro-/ultrafiltration, however cleaning frequency is expected to be low(er) in comparison with reverse osmosis due to the water quality of rain water (i.e. low suspended solids and colloids). Micro-/ultrafiltration will easily work at a pressure <1 bar, substantially lowering the energy consumption in comparison with reverse osmosis. Even for low-pressure reverse osmosis membranes a working pressure of minimum 10 bars is needed. Therefore energy consumption for reverse osmosis is at least 10 times higher in comparison with micro-/ultrafiltration. Overall costs for equipment are also expected to be lower for the process using rainwater compared to the process using reverse osmosis and ion exchange because of less stringent equipment requirements. A cost comparison for both processes for the production facility of S.Search b.v. will be shown during the oral presentation. The process with reverse osmosis and ion exchange however is more flexible in the production capacity of demineralized water (no limits by the amount of rainfall). It also is capable to produce a more strict water quality when needed.

4. Project description

In this article use of rainwater (followed by micro-/ultrafiltration) as demineralized water for the membrane production processes of S.Search b.v. in Dedemsvaart, the Netherlands is described. The project is partially funded by the Dutch Organization for Energy and Environment, NOVEM b.v., in Utrecht, the Netherlands [2]. The project consists of a theoretical part (considerations on rainfall and cost calculations) and a practical part (pilot research and chemical analysis). The project is carried out by S.Search b.v. in cooperation with SepeQ b.v., an equipment manufacturer specialized in membrane equipment. The laboratory of the Water Supply Company Overijssel (WMO) in Zwolle, the Netherlands, carried out chemical analysis to determine water quality. The project consists of the following items (based on the situation of S.Search b.v.):

- characterization of the amount of rain fall and the size of the storage tank in relation to the desired demineralized water production capacity,
- design data of micro-/ultrafiltration membrane parameters (i.e. flux, operating pressure, recovery, frequency and efficiency of backwash/forward flush and frequency and efficiency of chemical cleaning),
- analysis of rainwater quality and treated water quality in relation to the desired demineralized water quality,
- cost analysis of the conventional process and the alternative process for production of demineralized water.

5. Rainwater quantity

Use of rainwater as demineralized water is only possible in areas or countries where enough rainfall occurs. In the Netherlands average annual rainfall is about 800–850 mm. Annual data of rainfall per day in the Netherlands during three characteristic years is collected from the KNMI (the Royal Dutch Meteorological Institute). It appears that 1984 was an average year concerning rainfall, 1996 was an extremely dry year and 1998 was an extremely wet year. Annual rainfall in those years is given in Table 2. Figs. 2a–c show the difference in rainfall per day in the mentioned years. From these figures differences in rain fall during the year can be seen clearly.

Rainwater is collected from the roof of the production facility of S.Search b.v. The roof has a surface area of about 550 m^2. With an average annual rainfall of 800–850 mm, the total volume of rainwater is about 450 m^3 each year. Rainwater is collected in three storage tanks with a capacity of 15m^3 each, i.e. a total volume of the storage tanks of 45 m^3. Water losses for evaporation from the roof and recovery losses from membrane equipment are estimated at about 10% each, i.e. a total loss of 20%. Water consumed for backwash and/or forward flush in membrane equipment however can be (partially) reused further improving water recovery. Demi-

Table 2
Results of calculation on rainfall and water consumption (at S.Search b.v.)

Rain fall			Water shortage at capacity of 1 m³/d	Water shortage at capacity of 1.5 m³/d	Water consumption without water shortage
year	mm	status	days	days	m³/d
1984	819	normal	0	28	1.15
1996	576	dry	15	57	0.85
1998	1231	wet	0	0	1.68

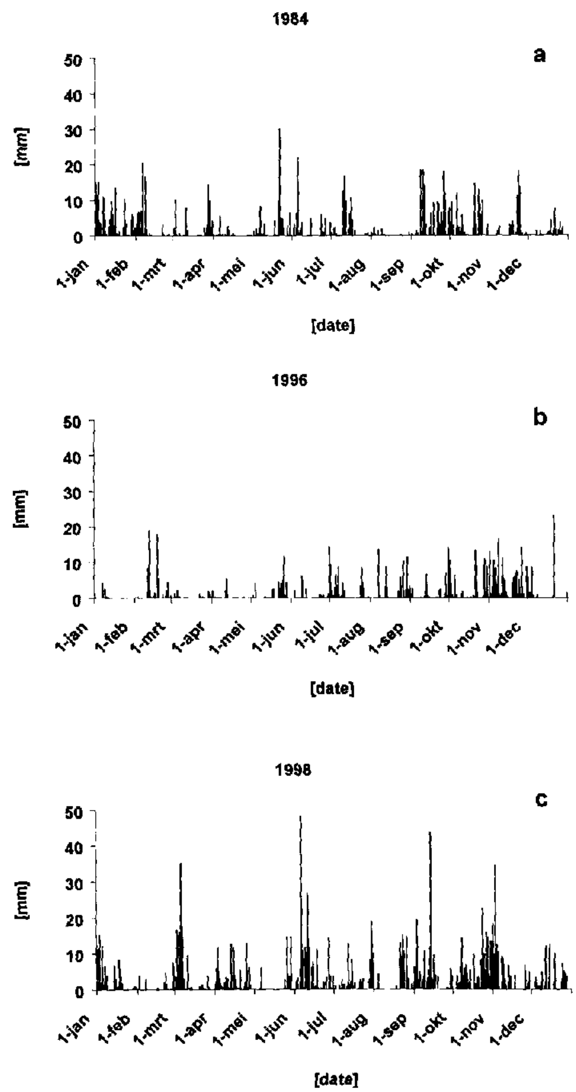

Fig. 2. Annual rainfall in: a, 1984; b, 1996; c, 1998 [3].

neralized water consumption for the most critical processes of S.Search b.v. is estimated at an amount of 1 m³/d discontinuous during working hours, 5 days a week. Using an in-house developed spreadsheet and based on the conditions mentioned above, it is calculated that in years with average annual rainfall like in the year 1984, there will be no shortage of process water for S.Search b.v. on any (working) day. However in extremely dry years the number of (working) days with water shortage increases towards 15. The same estimations and calculations are used for a larger water consumption of about 1.5 m³/d. This causes in general an overall increases in the number of (working) days with water shortage. The maximum water consumption for each of the mentioned years without any (working) days with water shortage is also calculated based on the spreadsheet. The results show a discrepancy of factor 2 between the lowest and highest possible production capacity dependent on minimum or maximum rainfall during the year. All results are presented in Table 2.

6. Rainwater quality

In literature and research in the Netherlands it is reported that the contents of rainwater can show variations in water quality dependent on local circumstances and area [4]. The impurities in rainwater mainly originate from materials in contact with rainwater or contact of rainwater with air. Components that are present in air are dependent on local air pollution originating from for example industry, agriculture, (heavy) traffic transport by road or railways. The production facility of S.Search is located in rural area and therefore has low contents due to contact with air. During the project several measurements of the water quality of rainwater will be taken. The material in contact with rainwater at S.Search b.v. consists of synthetics (both roof and down-pipe) and concrete (storage tanks). The building has no gutters of zinc or copper and therefore rainwater has low contents of heavy metals. The water quality of rain water, also estimated to be valid for the production facility of S.Search b.v., is given in Table 3.

Table 3
Water quality of rain water [4,5,6,7]

Conductivity @ 25°C, µS/cm	28.4
pH	5.29
NH_4^+, µmol/l	86
NO_3, µmol/l	43
SO_4, µmol/l	29
PO_4, µmol/l	0.3
F, µmol/l	0.6
Cl, µmol/l	78
Na, µmol/l	68
K, µmol/l	4.3
Mg, µmol/l	8
Ca, µmol/l	5
Fe, µmol/l	0.5
Cu, µmol/l	0.02
Zn, µmol/l	0.1
Cd, µmol/l	0.001
Pb, µmol/l	0.02

7. Pilot study

The process of use of rainwater followed by micro-/ultrafiltration as demineralized water is scheduled for testing on pilot plant scale at the production facility of S.Search b.v. summer 2000. The pilot trial takes several months and predicts the following items [8]:

- the fouling rate of the membranes when using rainwater,
- backwash/forward flush frequency and efficiency,
- chemical cleaning frequency and efficiency,
- rainwater quality and water quality of the permeate.

The pilot research delivers data for design of a full-scale plant. The design data include a constant flux rate at a set operating pressure range and a certain backwash/forward flush/cleaning frequency (including determination of water losses or recovery) together with long term stable performance. The pilot trial has just started and the results will be presented at the oral presentation during the conference. Revolutionary new capillary membranes are used in the pilot trial. In the past few years S.Search b.v. developed and introduced an improved membrane product in the market, based on the patented so called multibore technology. This means that up to 7 capillaries are joined together in one single fiber resulting in improved strength of the membrane fiber. The structure of the proprietary multibore capillary membrane fiber is shown in Fig. 3.

A typical example of the inner structure of a (multibore) membrane is shown in Fig. 4a by the cross section of a membrane (open foam structure), Fig. 4b the outer surface skin of a membrane (porous structure, large pores) and Fig. 4c the inner surface skin of a membrane. The photographs in Fig. 4 concern a microfiltration type membrane, where the inner skin acts as a separating layer. In the case of (multibore) capillaries as used in this project the inner skin also acts as separating layer. However in membrane production at S.Search b.v. the separating layer can be adjusted on either side of the capillary fiber at almost any desired pore size. The multibore principle is also used in flat

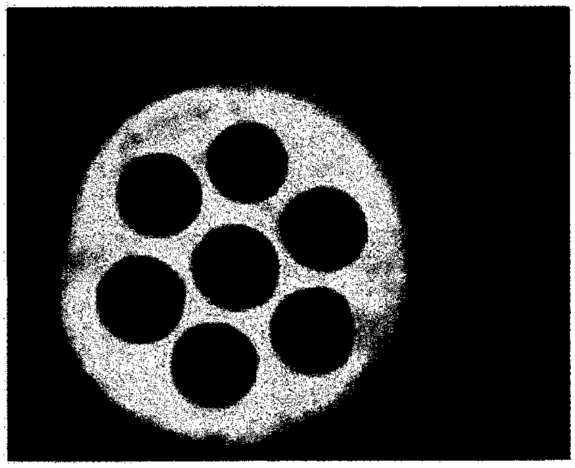

Fig. 3. Multibore capillary structure.

sheet multibore membranes, offering opportunities for outside-in filtration (separating layer on the outside) in for example (waste) water treatment.

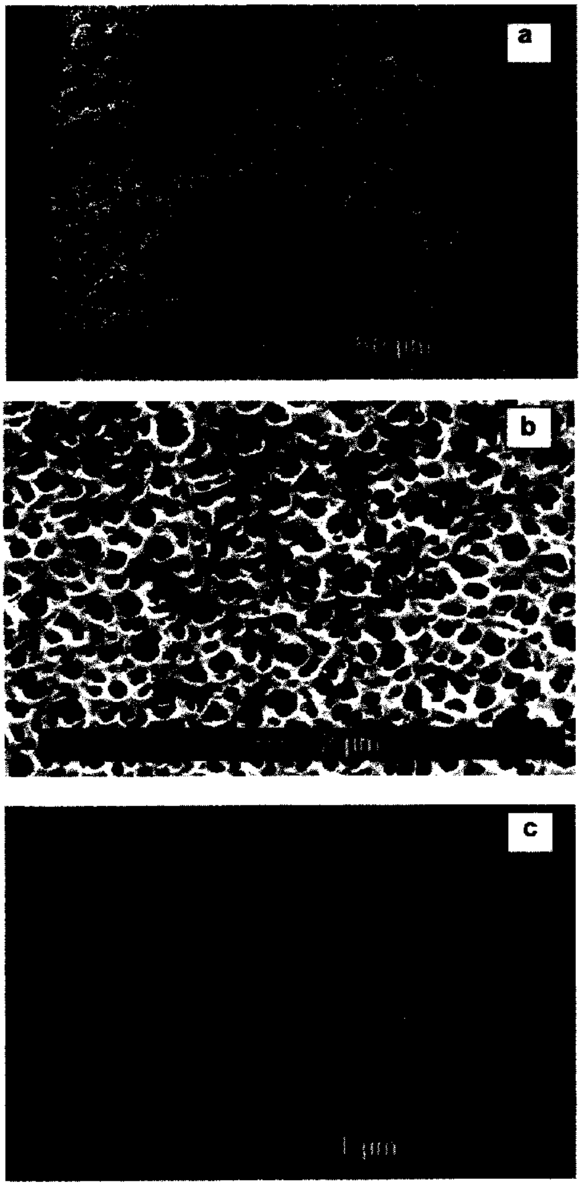

Fig. 4. Membrane fiber structure: a, cross-section; b, outer membrane surface; c, inner membrane surface.

8. Conclusions and remarks

Use of rainwater as demineralized water seems to offer the best opportunities when limited amounts of demineralized water are needed and water quality requirements are not very stringent. Membrane performance on rainwater after a course filtration (strainer) is expected to show high flux in combination with low frequency of flushing and cleaning. In those cases use of rainwater for demineralized water production is cost effective compared to conventional processes using reverse osmosis and ion exchange. When post-treatment of rainwater after micro-/ultrafiltration is necessary to remove residual dissolved solids by reverse osmosis or ion exchange, extra costs are caused. The amount of rainfall is also limited, limiting the total amount of demineralized water. In the above mentioned cases and when reliability of demineralized water production is an issue, additional or other treatment processes may be necessary. The alternative process therefore will be probably less attractive concerning cost in those cases. A further cost calculation and comparison will show where the break-even point lies for various applications. However for S.Search b.v. the rain water quantity and quality seems sufficient for the membrane production processes.

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