PRODUCTION OF DRINKING WATER FROM DOMESTIC WASTEWATER USING CAPILLARY NANOFILTRATION

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ABSTRACT

Direct Capillary Nanofiltration (Direct CNF) is a new technique used for surface water and wastewater treatment in one step without pre-treatment. The CNF membrane module combines the favourable cleaning properties of capillary ultrafiltration membranes with the favourable separation properties of nanofiltration membranes in terms of removal of DOC, colour, bacteria, viruses and pesticides.

Direct CNF was applied to Twente Canal surface water to produce high quality permeate in a single step. In this study, Direct CNF has been applied (for the first time) to wastewater treatment under continuous and stable process conditions. The optimum conditions for Direct CNF when applied to domestic wastewater were 15 minutes filtration time, 20 $l/m^2.h$ flux rate with undiluted domestic wastewater during 8 hours and 40 minutes filtration time.

Direct CNF showed high removal for bacteria, heavy metals, COD, BOD_5, DOC and medium removal for manganese, calcium and magnesium while lower removal was detected for mono ions such as sodium and chloride.

The permeate of CNF was high quality water but it was still not drinkable because of high ammonia, total nitrogen concentrations as well as the residues of bacteria. Accordingly, the permeate was treated with granular activated carbon followed by low doses of chlorine for disinfection to produce drinking water.

Keywords: Capillary nanofiltration, domestic wastewater, drinking water, post treatment.

INTRODUCTION

A capillary NF membrane combines the favourable properties of the capillary UF membranes in terms of ease of cleaning with the favourable properties of the NF membrane in terms of the removal of bacteria, viruses, pesticides and heavy metals. The capillary NF membrane is presently available in the well-known 8 inch modules which are also being used successfully for capillary UF (**Fig. 1**).

(a) **(b)**

Fig. (1) Capillary 4 inch NF module: (a) front view; (b) mounted with endcap.

The capillary NF module is operated in the same way as semi dead-end UF. During the production run the concentrate valve is closed and all the feed supplied to the system is withdrawn as permeate. In order to stabilise the flux and rejections at an acceptable level a small cross-flow velocity is applied over the module. If the rejection drops too much, the concentrate valve is opened and the system is flushed by means of air-enhanced forward flushing, a so-called AirFlush®. During this flushing procedure a backflush can also be carried out. Subsequently, the concentrate valve is closed and the production run starts again.

Capillary nanofiltration (CNF) membrane is a type of pressure-driven membrane with properties in between reverse osmosis (RO) and ultrafiltration (UF) membranes. CNF offers several advantages such as low operation pressure, high flux, high retention of multivalent anion salts and an organic molecular above 300, relatively low investment and low operation and maintenance costs. Because of these advantages, the applications of NF worldwide have increased **[1]**.

Membrane technology is widely accepted as a mean of producing various qualities of water from surface water, well water, brackish water and seawater. Membrane technology is also used in industrial processes and in industrial wastewater treatment, and lately membrane technology has moved into the area of treating secondary and tertiary municipal wastewater and oil field produced water **[2]**.

Membrane technology is a treatment method for producing drinking water from surface water and high quality water from domestic wastewater. Capillary nanofiltration (CNF) membrane, for instance, removes bacteria and viruses as well as pesticides, organic matter, heavy metals, and to some degree also salts. The permeate is therefore of a high quality, reliable and can be used as process water for industry or as potable water.

In a previous study **[3]** a new purification concept was introduced: direct CNF and its potential for direct treatment of surface water and effluent of a waste water treatment plant was shown. More recently **[4]**, this CNF membrane was compared with commercial flat sheet NF membranes for the treatment of surface water showing excellent flux behaviour and comparable rejection characteristics.

CNF concept is developed further for surface water treatment by **Dijkstra *et al.*, [5]** focussing on back flushing and chemical cleaning. Next, the removal rates for various components are studied by modelling and sampling the feed and permeate streams. Attention is paid especially to the membrane performance in comparison with the model. The final objective is to determine the operating conditions for a full scale plant. The last part is dedicated to the long term operation experiences of a fully-automated pilot installation with two 8 inch Capillairy NF modules.

CNF was applied for the first time for direct treatment of domestic wastewater **[6]** by our research team and optimum conditions were detected. The optimization of the chemical cleaning regime was made and the recovery was increased from 35% to 65%.

In this paper we represent the efficiency of Direct CNF in removal of organic, inorganic and biological parameters from domestic wastewater in single step to produce high quality permeate which is secondary treated with granular activated carbon (GAC) followed by 2 mg/l chlorine dose to produce drinking water.

EXPERIMENTAL

Capillary Nanofiltration Membrane used was 4 inches **NF50 M10** which was provided by X-Flow company (The Netherlands) is composed of polyamide / polyethersulfone coated with polyamide. The domestic wastewater was passed first through 500 µm screen before going to the membrane.

The optimum conditions applied in this experiment were 15 $l/m^2.h$ flux rate and 20 minutes filtration time with 100 % domestic wastewater. The system was hydraulically cleaned for 4 minutes between each filtration runs and chemically cleaned for 4.5 hours every 9 hours.

The pilot installation receives the domestic wastewater after a 500 µm strainer to avoid particles damaging the membrane surface and/or clogging the membrane fibers themselves. The concentrate is treated in an anaerobic digestion tank as shown in Fig (2).

The chemical and bacteriological analyses were carried out according to Standard Methods for the Examination of Water and Wastewater 20th Edition (1998).

The samples were collected every 10 minutes during the filtration time using autosampler and mixed together to make composed sample which was analyzed after that.

During the experiment, six samples were collected and analyzed. The removal percent of the various compounds were calculated. The permeate was passed through granular activated carbon (GAC) column followed by chlorine dose. The final effluent was compared to Dutch Standard limits of drinking water.

RESULTS

The removal percentages of the inorganic compounds of the wastewater using direct CNF are presented in Table 1. Table 2 shows the removal percentages of the organic and bacteriological compounds of the wastewater.

The retention of organic compounds was affected by some parameters such as molecular size **[7]** and hydrophobicity **[8]**. Since lower molecular size organic micro pollutants have higher retention. While, more hydrophilic compounds has higher retention. On the other hand, temperature, overall pressure and pre-treatment affect the filtration process as well as the retention **[9]**. CNF reduced the organic loading rate in the wastewaters **[6]** and promoted their partial desalination, making water reuse possible. A major problem of the wastewater treatment is the water recovery rate, which should be close to 80 % **[10]**. To achieve this target, many researchers investigated an integrated membrane system as example **Rautenbach and Linn 1996 [11] and Rautenbach *et al.*, 2000 [12]** used a new concept of integrated membranes consisting of RO/NF/high-pressure RO. The integration can achieve water recovery rates of more than 95% in the case of dumpsite leachate, which promises an almost zero discharge process.

In order to have better understanding of retention mechanism of inorganic ions the relative influence of steric, electronic (influenced by affinity of ions for the membrane surface) and dielectric interactions in the retention mechanism of polyamide CNF membrane in the presence of single and mixed inorganic ions must be taken in consideration **[13]**.

Separation by CNF membrane occurs primarily due to size exclusion and charge effect on electrostatic interactions **[14]**. Namely, the rejection of uncharged molecules is dominated by size exclusion, while that of ionic species is influenced by size exclusion and electrostatic interaction. And, electrostatic characteristics of CNF membranes have been known as playing an important role in rejection anions, i.e., negative zeta potential on the membrane surface varies with different pH and concentration of an electrolyte solution **[15]**.

Direct CNF showed very good results in retention of turbidity, nitrate, phosphate, iron, manganese, copper, lead and nitrite (Table 1), total bacterial counts, E-Coli, COD, BOD_5 and TOC (Table 2). It showed also medium retention for calcium and magnesium. On the other hand mono cations and anions such as potassium and chloride showed the lowest retention (Table 1).

Table (1) Removal percents for some physico-chemical parameters after direct CNF

Parameters	**Unit**	**Influent**	**Permeate**	**% of removal**
Turbidity	*FTE*	51	1.3	97.5
Electrical Conductivity	*µS/m*	473	384	18.82
Chloride	*mg/l*	127	110	13.39
Nitrate (NO_3-N)	*mg/l*	1.37	0.103	92.5
Nitrite (NO_2-N)	*mg/l*	0.21	0.073	65.2
Ammonia	*mg/l*	59.3	52	12.3
Total Nitrogen	*mg/l*	72.8	58.4	19.78
Phosphate	*mg/l*	7.65	0.7	90.8
Iron	*mg/l*	1.43	0.02	98.6
Manganese	*mg/l*	0.36	0.082	77.22
Calcium	*mg/l*	58	29	50.00
Magnesium	*mg/l*	12.4	5.3	57.26
Copper	*mg/l*	0.028	0.0045	83.93
Lead	*mg/l*	0.003	0.0005	83.3
Potassium	*mg/l*	36.6	28.2	22.95

Table (2) Removal percents for organic and bacteriological parameters after direct CNF

Parameters	**Unit**	**Influent**	**Permeate**	**% of removal**
Total Organic Carbon	*mg/l*	138	8.4	93.91
Chemical Oxygen demand (COD)	*mgO_2/l*	725	97.5	86.6
Biological Oxygen demand (BOD_5)	*mgO_2/l*	391	54.4	86.1
Total Bacterial Count at 22°C	*Unit /ml*	5.6×10^6	1000	99.98
Total Coliform at 37°C	*Unit/100 ml*	396	1	99.75
E – Coli	*Unit/100 ml*	377	0	100

Accordingly, Direct CNF produces high quality permeate but it is not drinkable because of the traces of COD, BOD_5, total bacterial counts, ammonia and total nitrogen. Accordingly, double barrier for removal of bacteria, viruses, ammonia and organic micropollutant is required. So, a column of 16 mg/l GAC was used as second step treatment.

1- Treatment of the permeate with GAC

The permeate was passed through 16 mg/l GAC with contact time 8 minutes as secondary treatment step. The adsorption step for GAC showed high removal for COD and BOD_5 (92.69 % and 91.30 % respectively) as shown in Table (4). On the other hand, the removal percents of ammonia and total nitrogen were increased to 52.78 % and 58.79 % respectively (Table 3).

According to presence of small number (traces) of bacteria (Table 4), secondary effluent must be disinfected either using low dose of chlorine or using 25 Watt UV lamp for 15 minutes as contact time. But chlorine was preferred to be used because its low cost technology, strong oxidant as well as disinfectant, it has residue in water and also it can react with ammonia to form chloramines which is weak oxidant and weak disinfectant same time and this will enhance oxidation rate as well as increase the disinfection.

Table (3) Removal percents for some physico-chemical parameters after treatment CNF permeate with GAC

Parameters	Unit	Influent	Permeate	% of removal	Permeate + GAC	% of removal
Turbidity	*FTE*	51	1.3	97.5	2.0	96.08
Electrical Conductivity	*µS/m*	473	384	18.82	332	29.81
Chloride	*mg/l*	127	110	13.39	104	18.11
Nitrate (NO_3-N)	*mg/l*	1.37	0.103	92.5	0.44	67.88
Nitrite (NO_2-N)	*mg/l*	0.21	0.073	65.2	0.035	83.33
Ammonia	*mg/l*	59.3	52	12.3	28	52.78
Total Nitrogen	*mg/l*	72.8	58.4	19.78	30	58.79
Iron	*mg/l*	1.43	0.02	98.6	0.006	99.58
Manganese	*mg/l*	0.36	0.082	77.22	0.009	97.50
Calcium	*mg/l*	58	29	50.00	27	53.45
Magnesium	*mg/l*	12.4	5.3	57.26	5.2	58.06
Copper	*mg/l*	0.028	0.0045	83.93	0.003	89.29
Lead	*mg/l*	0.003	0.0005	83.33	0.0005	83.33
Potassium	*mg/l*	36.6	28.2	22.95	28	23.50

Table (4) Removal percents for some organic and bacteriological parameters after treatment of CNF permeate with GAC

Parameters	**Unit**	**Influent**	**Permeate**	**% of removal**	**Permeate + GAC**	**% of removal**
Total Organic Carbon	*mg/l*	138	8.4	93.91	4.0	97.10
COD	*mgO_2/l*	725	97.5	86.6	53	92.69
BOD	*mgO_2/l*	391	54.4	86.1	34	91.30
Total Bacterial Count at 22°C	*Unit /ml*	5.6×10^6	1000	99.98	23	≅ 100
Total Coliform at 37°C	*Unit/100 ml*	396	1	99.75	0	100
E – Coli	*Unit/100 ml*	377	0	100	0	100

2. Treatment of the secondary effluent with chlorine

The GAC effluent was treated with 2 mg/l chlorine and contact time 15 minutes. The analysis of the final effluent showed total removal for bacteria, COD, BOD_5 (table 5 and Fig 3). Also, the residuals of ammonia and total nitrogen (Table 6) are within the Dutch standard limits and their removal percents exceed 99 % (Fig 2).

It is shown in Table (6) and Fig (2) that the concentration of nitrate is increased by 1.58 times and this was attributed to oxidation of ammonia into nitrate. The final concentration of nitrite and nitrate was very low compared with the original ammonia concentration and this may be attributed to incomplete oxidation of ammonia with chlorine to form, the weak oxidant and disinfectant, chloramines that will increase the oxidation rate and increase the disinfection.

Table (5) Removal percents for some organic and bacteriological parameters after treatment of secondary effluent with chlorine.

Parameters	Unit	Influent	Permeate	% of removal	Permeate + GAC + Cl_2	% of removal	Dutch Standard Limits
Total Organic Carbon	*mg/l*	138	8.4	93.91	2.4	98.26	< 5
COD	*mgO_2/l*	725	97.5	86.6	0	100	0
BOD	*mgO_2/l*	391	54.4	86.1	0	100	0
Total Bacterial Count at 22°C	*Unit/ml*	5.6×10^6	1000	99.98	0	100	0
Total Coliform at 37°C	*Unit/100 ml*	396	1	99.75	0	100	0
E – Coli	*Unit/100 ml*	377	0	100	0	100	0

Table (6) Removal percents for some physico-chemical parameters after treatment of secondary effluent with chlorine.

Parameters	Unit	Influent	Permeate	% of removal	Permeate + GAC + Cl_2	% of removal	Dutch Standard Limits
Turbidity	*FTE*	51	1.3	97.5	1.9	96.27	
Electrical Conductivity	*µS/m*	1373	1134	17.41	1140	16.97	
Chloride	*mg/l*	127	110	13.39	112	11.81	< 150
Nitrate (NO_3-N)	*mg/l*	1.37	0.103	92.5	2.16	-	< 50
Nitrite (NO_2-N)	*mg/l*	0.21	0.073	65.2	0.021	90.0	
Ammonia	*mg/l*	59.3	52	12.3	0.09	99.85	0.1
Total Nitrogen	*mg/l*	72.8	58.4	19.78	0.73	99.00	< 1
Iron	*mg/l*	1.43	0.02	98.6	0.006	99.58	< 0.2
Manganese	*mg/l*	0.36	0.082	77.22	0.008	97.78	< 0.05
Calcium	*mg/l*	58	29	50.00	27	53.45	85
Magnesium	*mg/l*	12.4	5.3	57.26	5.2	58.06	85
Copper	*mg/l*	0.028	0.0045	83.93	0.003	89.29	
Lead	*mg/l*	0.003	0.0005	83.33	0.0005	83.33	
Potassium	*mg/l*	36.6	28.2	22.95	28	23.50	

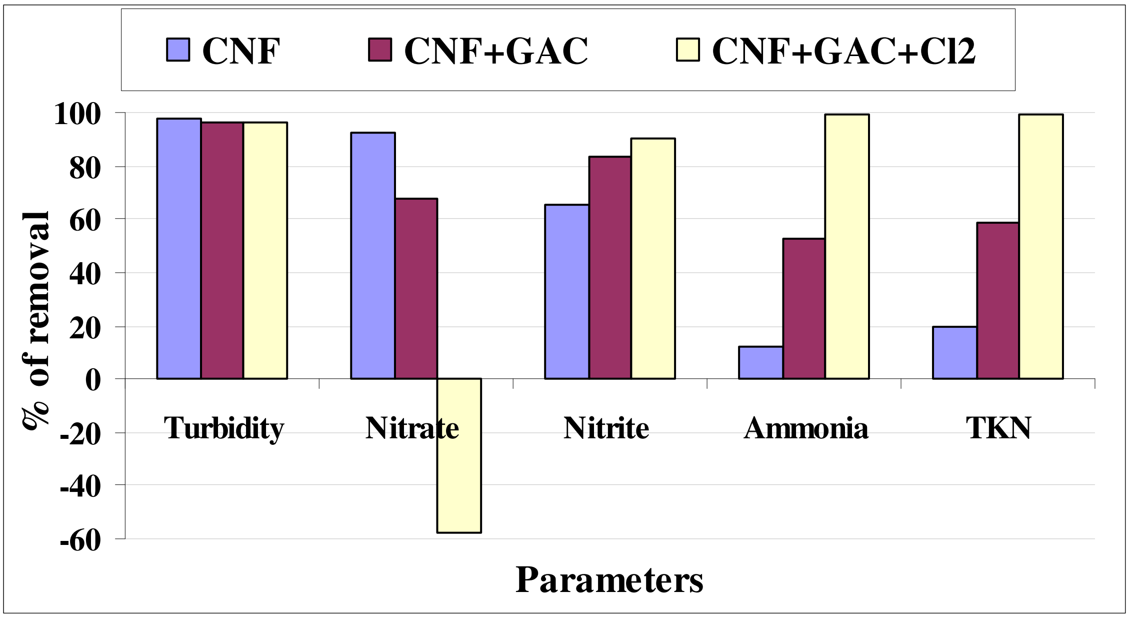

Fig. (2) removal of physico-chemical parameters during treatment steps

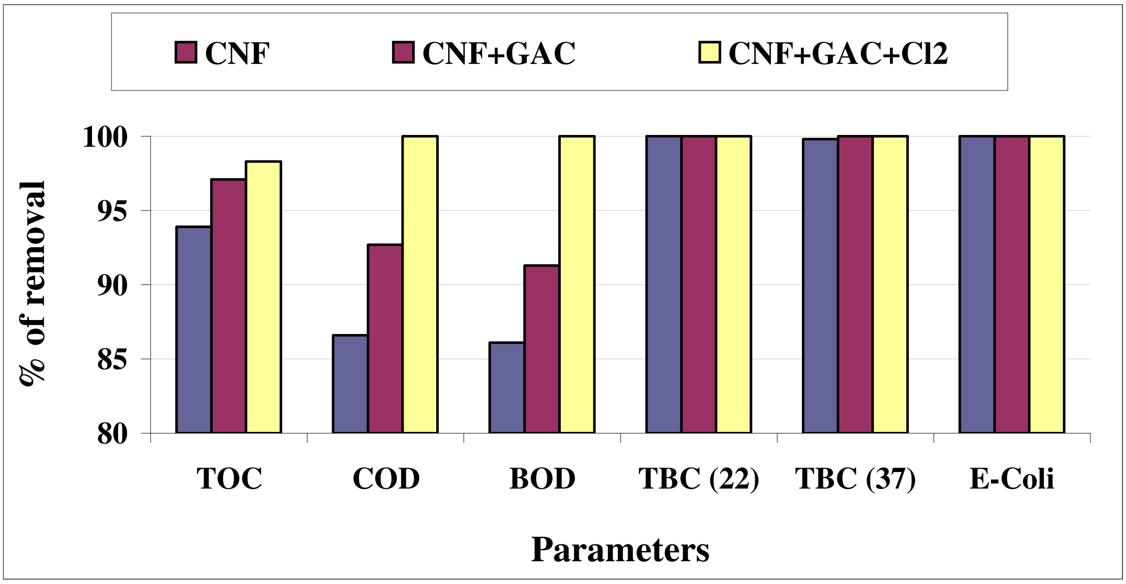

Fig. (3) removal of organic and bacteriological parameters during treatment steps

Finally, we can conclude that domestic wastewater can be treated to produce drinking water using direct CNF by treatment of the permeate with 16 mg/l GAC and 2 mg/l chlorine. The schematic diagram of the system will be as shown in Fig. 4.

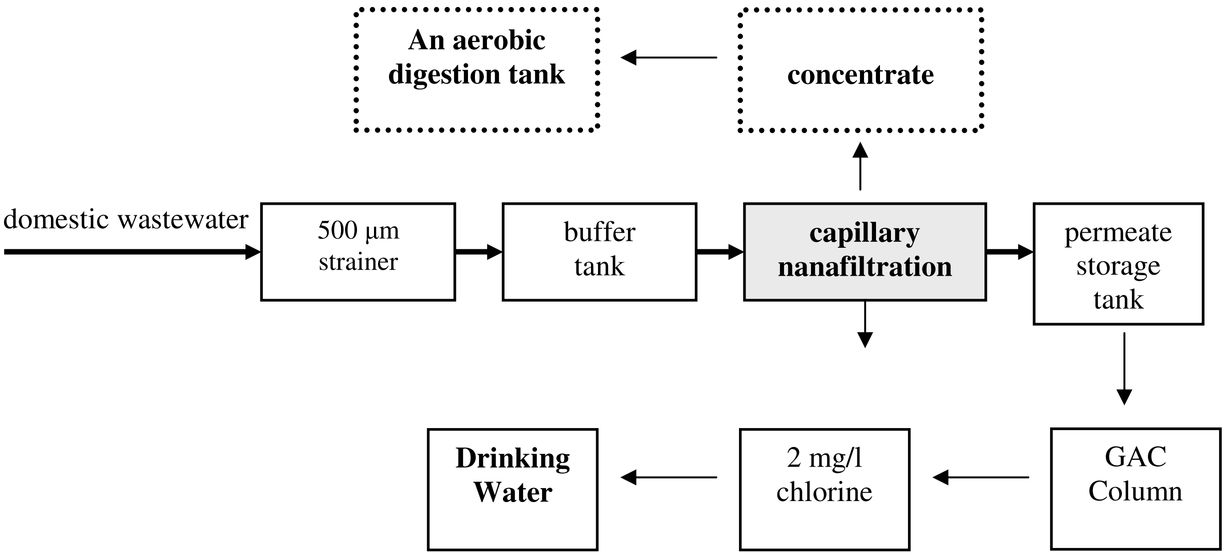

Fig. (4) Schematic diagram for CNF pilot installation

This applied system for wastewater treatment will help in solution of water shortage problem especially arid areas. This bench scale will be enlarged to pilot plant scale soon and we wish that it will be applied in full scale in the future.

FUTURE PROSPECTIVES

The future perspectives for CNF and wastewater treatment are:

- Application of more effective chemical agents in the chemical cleaning regime of CNF.
- Achievement of stable filtration operation with longer filtration runs(time between chemical cleaning).
- Increasing the recovery up to 80 %.
- Explanation of the relation between the composition of domestic wastewater and the effect of (bio)fouling on the membrane**.**
- Economic feasibility for CNF depending on application.

CONCLUSION

Direct CNF was successfully applied for domestic wastewater process to produce high quality water in continous process. the permeate can be drinkable according to Dutch standard limits by further treatment using 16 mg/l GAC column with 8 minutes contact time followed by oxidation and disinfection using 2 mg/l chlorine with 15 minutes reaction time.

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