Executive summary

Introduction
The use of ceramic MF membranes is gaining more interest in water treatment. This is due to the fact that ceramic membranes can withstand high loading pressure, intensive heat and it is chemical stable; and above all the life span of ceramic membranes is longer than polymeric membrane.

However, ceramic MF membranes are not capable of removing pesticides, dissolved organic matter and viruses, because their pore sizes (0.1 µm) are larger than the size of viruses, pesticides and dissolved organic matters. For that reason pre-treatment prior to ceramic MF membrane to overcome these deficiencies is necessary. Processes like coagulation, adsorption and combinations of coagulation/flocculation and adsorption are some of the pre-treatment techniques used in drinking water production.

In this study, super ground powdered activated carbon (S-PAC) pre-coated on channels of a monolith ceramic MF membrane was employed as pre-treatment to meet multiple objectives for NOM, pesticides (atrazine), viruses removal and fouling control. Surface water and secondary waste water effluent treated from Soil Aquifer Treatment (SAT) were used as feed water.

Importance
The typical pore size of the ceramic MF membrane used in this research is 0.1 µm. The membrane module is multi-channels (55 channels) with a length of 1 meter and surface area of 0.4 m^2 that enable high flux operation ranged between 100 – 210 $L/m^2.h$ and in addition very high backwashing flux is used (up to 1,700 L/m^2h). By backwashing, the exhausted pre-coat layer of S-PAC is removed together with reversible fouling.

The S-PAC pre-coat forms a very thin layer resulting in a contact time of less than 1 second during filtration. The layer is introduced at the beginning of filtration cycle in the first few seconds and refreshed after backwashing for the consecutive filtration cycle. Other hybrid processes of ceramic membranes used coagulation-flocculation or inline coagulation that requires specific retention time to provide good removal results of undesired compounds (e.g pesticides, NOM and viruses). Therefore, this approach (pre-coat) aims to reduce the contact time to a minimum, whilst maintaining a high removal efficiency.

Approach
Normal Powder activated carbon (N-PAC) with an effective size of 2 µm was further grounded with a ball mill to produce Super Ground Powder Activated carbon (S-PAC) with an effective size of 0.3 µm. Both S-PAC and N-PAC were used as pre-coats materials in combination with ceramic MF membrane. An average flux of 150 L/m^2h was used for filtration of untreated surface water.

Surface water was used as feed water for virus and atrazine removal experiments. Both S-PAC and N-PAC were used as pre-coat materials and the results were also compared with blanks (no pre-coat on the ceramic MF membrane). The dosing rate of PAC solution (7.5 g/l) was set to 6.7 L/h for a period of between 1 - 3 minutes depending on the pre-coat dose required. Filtration was performed for a period of 1 hour for virus experiments and 2 hours for atrazine experiments. The raw water was spiked with 2 µg/l of atrazine. Backwashing (BW), Air Flushing (AF) and Forward Flushing (FF) were performed before starting another cycle of filtration. The results for atrazine removal were also compared with batch experiments (both with S-PAC & N-PAC) performed with (polymeric) MF PVDF membrane filtration.

The canal water was pre-filtered through 1µm filter and then mixed with 50% of tap water to neutralize and simulate the conditions of most surface water as the DOC level of canal water was high. The filtration cycles of 1 hour up to 4 hours were considered in fouling experiments to investigate the growth of reversible and irreversible fouling. S-PAC pre-coat was used in fouling experiments and the results were compared with blank experiments (without S-PAC).

UV absorbance machine, TOC analyser, Gas chromatography - mass spectrometry (GC-MS) were used to measure UV, DOC and atrazine removal. Liquid Chromatography with Organic Carbon Detection (LC-OCD) tests was carried out by a specialized laboratory (Doc-Labor of Germany) to characterize NOM fractions. TEP measurement includes a series of filters as 0.4 - 0.05 µm was employed for measuring the polysaccharides removed from S-PAC pre-coats. Three-dimensional EEM spectroscopy was applied to characterize the feed and permeate waters MS2 bacteria phages were used as an indicator for viruses as they have the comparable sizes (25 nm).

Results

The ceramic MF membrane pre-coated with equivalent dose of 40 mg/l of S-PAC during one hour filtration can control both reversible and irreversible fouling caused by surface water of DOC level of 5 mg/l. Therefore, membrane cleaning will be limited to large extent as well as minimizing the use of energy caused by TMP increase. Irreversible Fouling was reduced by 42%, 30% and 10% when 20, 13.5 and 10 mg/l of S-PAC pre-coat used respectively. TMP and fouling increases as NOM removal by S-PAC pre-coat (40 layers) deteriorate after 1 hour of filtration.

Pilot experiments with ceramic MF membrane showed 95%, 85% and 43% removal of atrazine when 20 and 10 mg/l of S-PAC pre-coats and 10 mg/l of N-PAC pre-coats used respectively. Batch experiments of schie canal water dosed with 2.1 µg/l of atrazine, and mixed with 15 mg/l of S-& N-PAC for 20 minutes before filtration on 0.1 µm PVDF membranes showed > 98% of atrazine removal for S-PAC and 42% for N-PAC. Therefore S-PAC is robust for micro-pollutants rejection.

Medium DOC surface water (DOC ~ 5 mg/l) showed that DOC removal was at the average of 70%, 60% and 50% when equivalent doses of 56, 28 and 14 mg/l of S-PAC were used respectively. High DOC water from surface water (Schie Canal) showed the averaged DOC removal of 40% when equivalent pre-coat doses of 28 mg/l of S-PAC were used.

Biopolymers and other NOM constituents like humic are well removed to an average of 60% - 70% (based on one hour filtration cycle) when feed water (DOC about 5 mg/l) filtered through 40 layers of S-PAC pre-coated onto MF ceramic membrane and this leads to fouling control. EEM and TEP measurements showed a significant reduction of fluorescence of proteins and removal of polysaccharides (over 90%) and therefore the use of S-PAC with combination with ceramic membrane may be considered as pre-treatment for RO or NF membranes in controlling biofouling. In general, the use S-PAC can meet the multi-objectives of fouling control, NOM reduction, micro pollutants removal but not virus removal. Other pre-treatment techniques should be employed with regard to virus removal.

More information

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TKI Categorisation

Classification									
Supply Chain		Process Chain		Process Chain (cont'd)		Water Quality		Water Quantity (cont'd)	
Source		**Raw water storage**		**Sludge treatment**		**Legislation/regulation**		- Leakage	
- Catchment		- Supply reservoir		- Settlement		- Raw water (source)		- Recycle	
- Groundwater		- Bankside storage		- Thickening		- Treated water			
- Surface water	√	**Pretreatment**		- Dewatering		**Chemical**			
- Spring water		- Screening		- Disposal		- Organic compounds	√		
- Storm water		- Microstraining	√	**Chemical dosing**		- Inorganic compounds			
- Brackish/seawater		**Primary treatment**		- pH adjustment		- Disinfection by-products			
- Wastewater		- Sedimentation		- Coagulant		- Corrosion			
Raw water storage		- Rapid filtration		- Polyelectrolyte		- Scaling			
- Supply reservoir		- Slow sand filtration		- Disinfectant		- Chlorine decay			
- Bankside storage		- Bank filtration		- Lead/plumbosolvency		**Microbiological**			
Water treatment		- Dune infiltration		**Control/instrumentation**		- Viruses		Consumers / Risk	
- Pretreatment	√	**Secondary treatment**		- Flow	√	- Parasites			
- Primary treatment		- Coagulation/flocculation		- Pressure	√	- Bacteria		**Trust**	
- Secondary treatment		- Sedimentation		- pH		- Fungi		- In water safety/quality	
- Sludge treatment		- Filtration		- Chlorine		**Aesthetic**		- In security of supply	
Treated water storage		- Dissolved air flotation(DAF)		- Dosing	√	- Hardness / alkalinity		- In suppliers	
- Service reservoir		- Ion exchange		- Telemetry		- pH		- In regulations and regulators	
Distribution		- Membrane treatment		**Analysis**		- Turbidity		**Willingness-to-pay/acceptance**	
- Pumps		- Adsorption		- Chemical	√	- Colour		- For safety	
- Supply pipe / main		- Disinfection		- Microbiological		- Taste		- For improved taste/odour	
Tap (Customer)		- Dechlorination		- Physical	√	- Odour		- For infrastructure	
- Supply (service) pipe		**Treated water storage**						- For security of supply	
- Internal plumbing		- Service reservoir				Water Quantity		**Risk Communication**	
- Internal storage		**Distribution**						- Communication strategies	
		- Disinfection				**Source**		- Potential pitfalls	
		- Lead/plumbosolvency				- Source management		- Proven techniques	

		- Manganese control				- Alternative source(s)			
		- Biofilm control				**Management**			
		Tap (Customer)				- Water balance			
		- Point-of-entry (POE)				- Demand/supply trend(s)			
		- Point-of-use (POU)				- Demand reduction			

TKI Categorisation (continued)

Contains		Constraints		Meta data					
Report	√	Low cost		*Author(s)*	√				
Database		Simple technology		*Organisation(s)*	√				
Spreadsheet	√	No/low skill requirement		*Contact name*	√				
Model	√	No/low energy requirement	√	*Contact email*	√				
Research	√	No/low chemical requirement	√	*Quality controller name*					
Literature review	√	No/low sludge production		*Quality controller organisation*	√				
Trend analysis		Rural location		Source					
Case study / demonstration		Developing world location		*Date prepared*	√				
Financial / organisational				Date submitted (TKI)	√				
Methodology	√			Date revised (TKI)					
Legislation / regulation									
Benchmarking									