Membrane Distillation for the Removal of Fluoride and Pesticides in Remote Areas in India

by

Julia Gabriele Plattner

A Thesis submitted in fulfilment of the requirements for the degree of

Master of Engineering

May, 2017

School of Civil and Environmental Engineering
Faculty of Engineering and Information Technology
University of Technology Sydney (UTS)
New South Wales, Australia

Certificate of original authorship

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Student:
(Julia Plattner)

Date: 11.5.2017

Acknowledgements

I would like to express my wholehearted appreciation to my principle supervisor, Professor S. Vigneswaran and my co-supervisor, Dr. Christian Kazner, for providing me with the opportunity to come to UTS and to work on the research project. Thank you for your valuable guidance and support at all levels during my study at UTS and at FHNW in Switzerland. Special thanks also to Professor Thomas Wintgens who has encouraged and supported me to realize this Master Thesis.

My extended gratitude goes to Dr. Gayathri Naidu, who introduced me to the system operation and offered generous assistance and advice in the progress of this study. In addition, I would like to thank Dr. Md Johir who has taught me to use the analytical instruments in the UTS laboratory and who has supported me in the method development for the pesticide analysis.

My appreciation also goes to Fouzy Lotfi and Laura Chekli from UTS and Kirsten Remmen, Thérèse Krahnstöver and Lena Breitenmoser from FHNW for their friendship and companionship. In addition, I would like to express my sincere thankfulness to Lauren Kolamkanny for proof reading this thesis and for her friendship and support.

The research in this thesis has been funded by the European Commission under the FP7 project Water4India (GA No. 308496). I greatly acknowledge the financial support given by UTS through an International Research Scholarship (UTS IRS 165924) and the opportunity to work at the University of Applied Sciences and Arts Northwestern Switzerland.

Finally, I wish to thank my husband Mathias Plattner for his unconditional love and encouragement throughout the whole journey that he has taken with me. It would not have been possible without you. Furthermore, I would like to thank my parents, my sisters and my in-laws for their support and love.

Journal articles published

- Plattner, J., Naidu, G., Wintgens, T., Vigneswaran, S. & Kazner, C. 2017, 'Fluoride removal from groundwater using direct contact membrane distillation (DCMD) and vacuum enhanced DCMD (VEDCMD)', Separation and Purification Technology, vol. 180, pp. 152-32 DOI: 10.1016/j.seppur.2017.03.003

- Plattner, J., Kazner, C., Naidu, G., Wintgens, T. & Vigneswaran, S. 2017, 'Removal of selected pesticides from groundwater by membrane distillation ', Environmental Science and Pollution Research DOI 10.1007/s11356-017-8929-1

Conference Papers and Presentations

- J. Plattner, G. Naidu, M. Johir, T. Wintgens, S. Vigneswaran, C. Kazner, Fate of Pesticides in Membrane Distillation for Water Supply from Brackish Groundwater, 8th International Conference on Challenges in Environmental Science & Engineering 28. Sept. - 2. Oct., Sydney, Australia
- J. Plattner, G. Naidu, M. Johir, T. Wintgens, S. Vigneswaran, C. Kazner, Fate of Pesticides in Membrane Distillation for Water Supply from Brackish Groundwater, Micropol & Ecohazard Conference 2015, 22-25 November, Singapore
- J. Plattner, G. Naidu, T. Wintgens, C. Kazner, S. Vigneswaran, Treatment of Brackish Groundwater Containing Fluoride and Pesticides with Direct Contact Membrane Distillation (DCMD), 9th International Membrane Science and Technology Conference, 5-8 December 2016, Adelaide, Australia

Table of contents

List of abbreviations

AGMD	Air gap membrane distillation
BB	Building blocks
BP	Biopolymers
BV	Bed volumes
CCD	Charge coupled device
CDI	Capacitive deionisation
CF	Concentration factor
CP	Concentration polarisation
DCMD	Direct contact membrane distillation
DOC	Dissolved organic carbon
DOM	Dissolved organic matter
EBCT	Empty bed contact time
ED	Electrodialysis
EDC	Endocrine disrupting chemicals
EDR	Reverse electrodialysis
EDX	Energy-dispersive x-ray spectroscopy
FE-SEM	Field emission scanning electron microscope
FO	Forward osmosis
GAC	Granulated activated carbon
GC-MS	Gas chromatography-mass spectrometry
HA	Humid acid
HPLC	High pressure liquid chromatography
IAP	Ion activity product
IC	Ion chromatography
LC-OCD	Liquid chromatography-organic carbon detection
MD	Membrane distillation
MED	Multiple-effect distillation
MEMD	Multi-effect membrane distillation
MGMD	Material gap membrane distillation
MP-AES	Microwave plasma-atomic emission spectrometry
MSF	Multi-stage flash
NF	Nanofiltration
NMI	National measurement institute
PAC	Powdered activated carbon

PEDCMD	Pressure enhanced direct contact membrane distillation
POE	Point-of-entry
POU	Point-of-use
PTFE	Polytetrafluorethylene
PVDF	Polyvinylidene fluoride
RO	Reverse osmosis
RR	Recovery ratio
RSSCT	Rapid small scale column test
SEM	Scanning electron microscope
SGMD	Sweep gas membrane distillation
SI	Saturation index
SIM	Selective ion mode
SPE	Solid phase extraction
SSS	Small-scale system
TDS	Total dissolved solids
TOC	Total organic carbon
TP	Temperature polarisation
TROCs	Trace organic compounds
TZW	Technologie Zentrum Wasser
UF	Ultrafiltration
VCF	Volume concentration factor
VE-DCMD	Vacuum enhanced direct contact membrane distillation
VMD	Vacuum membrane distillation
V-MEMD	Vacuum multi effect membrane distillation
WTP	Water treatment plant

List of symbols

A	Area
B_m	Membrane coefficient
c_{inf}	Concentration of the compound in the influent to the column
c_{f0}	Concentration in the feed solution at the beginning of the experiment
c_{fe}	Concentration in the feed solution at the end of the experiment
c_{eff}	Concentration in the effluent to the column
c_p	Concentration in the permeate at the end of the experiment
$\Delta H_{v,i}$	Latent heat of vaporization
ΔP	Delta P, partial pressure difference
Δt	Delta t, temperature difference
E^0	Oxidizing character
H	Global Heat Transfer Coefficient
$h_{w,f}$	Heat Transfer Coefficient in the Feed Boundary Layers
$h_{w,p}$	Heat Transfer Coefficient in the Permeate Boundary Layers
J	Flux [L/(m²·h)]
k_m	Thermal Conductivity of the Membrane
K_{OC}	Carbon-water partitioning coefficient
K_{SP}	Ion activity product
L_c	Concentrate Feed Volume
$L_{f,0}$	Initial Feed Volume
LogD	Distribution coefficient
LogP	Partition coefficient (octanol water partition coefficient)
m_f	Flow rate [L/min]
Nu	Nusselt number
Pr	Prandtl number
R_{ads}	Adsorptive removal
T_f	Feed temperature
T_{fb}	Fluid bulk temperature on the feed side
$T_{filtered}$	Filtration time
T_{fm}	Membrane surface temperature on the feed side
T_{pb}	Fluid bulk temperature on the permeate side
T_{pm}	Membrane surface temperature on the permeate side
T_p	Permeate temperature
v	velocity
vf0	Volume of the feed at the beginning of the experiment
vfe	Volume of the feed at the end of the experiment
vp	Volume of the permeate at the end of the experiment

List of illustrations

Abstract

The world's increasing population, economic development and climate change are driving the demand for more drinking water. In India, more than 100 million people live in areas of poor water quality. It has been reported that more than 33% of India's groundwater resources are unsuitable for consumption. Anthropogenic contaminants, such as microbial contaminants, nitrate, pesticides and industrial discharge, together with geogenic contaminants, such as fluoride, arsenic, iron and saline water, pose a threat to human health. In many rural areas neither a centralized system for drinking water production nor stable electric power supply exists. Decentralized small-scale water treatment systems with independent power supply could be implemented to produce safe drinking water for the communities. Recently, Membrane Distillation (MD) has been identified as a promising technology for drinking water production in situations with off-grid power supply. The objective of this research was to evaluate the application of MD for the production of drinking water in small-scale communities.

It was shown in this study that bulk salinity, as well as fluoride, nitrate and non-volatile pesticides were well removed from a synthetic brackish groundwater solution using a bench scale and a pilot scale MD unit. The application of a vacuum at the permeate side enhanced the permeate production up to 40%. An elevated scaling potential was identified in the presence of fluoride together with calcium. However, only minor traces of loosely deposited solids were observed in this study. The membrane was efficiently cleaned with flushing of Milli Q water.

Fluoride and nitrate were removed at rejection rates higher than 98-99% and 99% respectively in all experiments. The removal of pesticides was shown to be strongly depending on the vapour pressure and the LogD of the target compounds. A low vapour pressure and a low LogD were found to be favourable for a good rejection in MD.

Post-treatment with granulated activated carbon filtration after the MD was tested for removal of any remaining traces of pesticides to safeguard full compliance with drinking water standards. A 2 log unit removal for all selected pesticides was achieved up to 67,600 bed volumes.

The study demonstrates that membrane distillation is a promising alternative for small-scale water supply from brackish groundwater.