2014 summer

Membrane News Twente

News magazine of the Membrane Science and Technology Group

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Welcome

On behalf of all members of the Membrane Science and Technology group and the European Membrane Institute Twente of the University of Twente, I would like to invite you to read our newsletter.

The last six months we celebrated several important academic highlights. In May part-time Professor Erik Roesink gave his inaugural lecture on the next generation membranes for aqueous applications. Furthermore we had 4 PhD defenses. In this newsletter, you can read a summary of all this. In this newsletter, you will also find a summary of another remarkable occurrence. After 22 years as secretary of the Membrane Science and Technology Group, Greet decided to retire from the University of Twente. I think there are many people in the membrane community that in one way or another were in contact with Greet during these 22 years.

Every time we try to give you some insight in a selection of equipment we have in our lab. This time we selected a number of optical techniques that allow investigating interactions at the membrane interface, e.g. fouling on a membrane, but also interactions between membrane and solute or solvent. Equipment is available for academic research, but also for contract research projects through the European Membrane Institute.

We hope you will enjoy reading this newsletter. In case you have additional questions or you would like to receive further information or publications, please feel free to contact us at msttnw@utwente.nl or +31 53 489 2950.

On behalf of all members of the group, I wish you pleasant summer season and we hope to meet many of you at ICOM 2014.

Prof. Dr. Kitty Nijmeijer

Inaugural lecture of Prof. Erik Roesink

Erik Roesink was appointed part-time professor of Advanced Membranes for Aqueous Applications in the Membrane Technology Group of the University of Twente on 1 October 2012. In addition, Roesink recently set up his own business, SOMUT, developing new membrane concepts in collaboration with the University of Twente and research institute Wetsus. Until last year, Roesink was director of the successful UT spin-off X-Flow.

On May 15th Prof. Erik Roesink gave his inaugural speech entitled Porous Plastic and Pure Water. The presentation is available online at: www.somut.nl/oratie.

Figure 1: Prof. Erik Roesink at the start of his inaugural speech

Prof. Erik Roesink started his presentation with a historical overview of synthetic (reverse osmosis) membranes. In this overview he emphasized the contribution of the Membrane Science and Technology Group that started already in the early seventies of the last century the research on membrane formation. Prof. Kees Smolders started this group, which is now headed by Prof. Kitty Nijmeijer.

Figure 2: Drinking dirty surface water through a membrane

To explain the working principle of reverse osmosis (RO) and microfiltration membranes he demonstrated during his speech how pure, safe water can simply be made from dirty surface water. He also demonstrated how porous plastic (membranes) can be made starting from a polymer solution. Due to the increasing amount of contaminants in surface water, so-called micro-pollutants such as hormones and medicine residues, it is increasingly difficult to produce clean drinking water in the Netherlands but also on a global scale. This requires a new generation of water treatment membranes.

The key message of his inaugural speech was that existing membranes are not designed for and thus not optimal for removing these micro-pollutants. The commercial available reverse osmosis membranes are meanwhile close to perfect to remove salt, e.g. in sea water desalination processes (see Figure 3).

Although commercial available RO membranes can remove often > 90 % of the large family of micro-pollutants, they have some disadvantages for treating fresh water:

• Chlorine resistance

• Relatively high operating pressure

The next generation membranes should therefore have a high retention for micro-pollutants, and a high water permeability, but also should have a higher chemical resistance towards harsh cleaning methods and/or disinfection. Furthermore, Prof. Roesink emphasized that there should be a focus on more green chemistry in the production of the membranes, since new legislation (REACH) will probably forbid all kind of polymer chemicals that are no used for membrane production.

In his presentation Erik Roesink was focussing on the use of the layer-by layer (LbL) concept. With LbL, water-soluble poly-electrolytes are used to build ultra thin composite layers. This

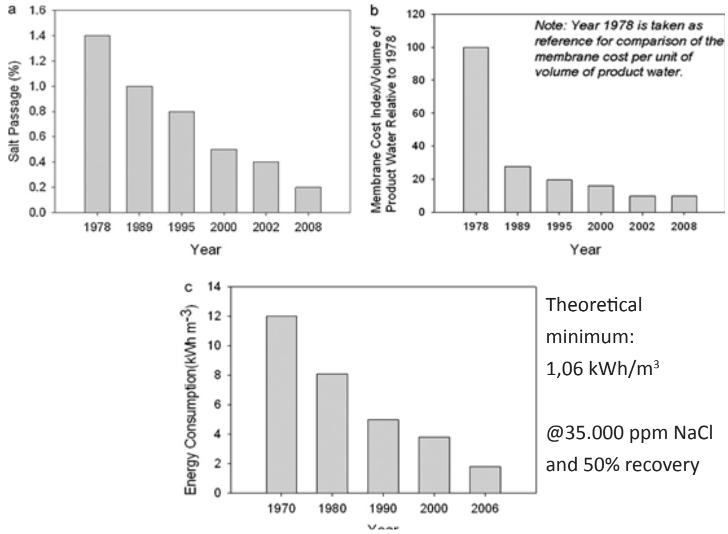


*Figure 3: development of RO membranes from: Kah Peng Lee, Tom C. Arnot, Davide Mattia**

represents a new toolbox for membrane scientists to build ultra-thin selective layers for all kind of applications.

He also explained that this concept can be combined with nano-particles. These can be combined with the thin selective layer in order to obtain required extra functionality. As an example Erik Roesink gave the combination of a LbL formed layer combined with silver nanoparticles to develop a membrane that both can retain viruses but also inactivate them.

This latter membrane type (Figure 4) will be used for a novel household water treatment and storage system to be used in third world countries.

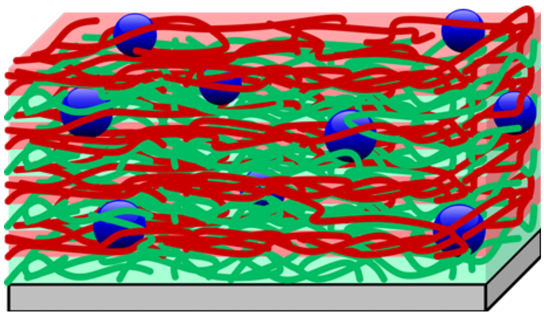


Figure 4: Schematic picture of a LbL toplayer with nano-particles

For both new concepts, virus inactivation and removal of micro-pollutants, Prof. Roesink has set himself the goal of realizing a working pilot plant within five years. In order to meet this tight deadline, Roesink is working very closely with the business community (drinking water utility Oasen) and other research institutions (University of Delft, WetSus, etc.). For more information please contact Prof. Erik Roesink (h.d.w.roesink@utwente.nl)

An integrated MBR-NF Concept with Concentrate Recirculation for Wastewater Treatment & Nutrient Recovery

Christina Kappel

Increasing water shortages drive the need for sustainable water treatment and especially the reuse of water. Membrane technology is very suitable for the treatment and purification of wastewater. Permeate resulting from secondary wastewater treatment using a membrane bioreactor (MBR) can be followed by nanofiltration (NF) for tertiary polishing, allowing the production of high quality water. The produced NF concentrate is a potential environmental hazard, which nevertheless is often discharged in the environment. To decrease this environmental impact of wastewater treatment, it is suggested to recirculate the NF concentrate back to the MBR reactor (Figure 1). Additionally, the production of more concentrated waste streams allows the recovery of valuable components (e.g. minerals) from the waste streams.

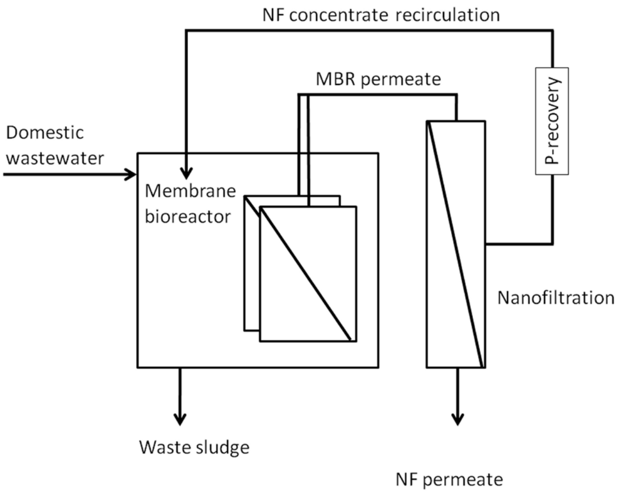


Figure 1: MBR NF concept with NF concentrate recirculation to MBR.

In this thesis, the impact of NF concentrate recirculation and the recovery of phosphorous on an MBR process for the treatment of wastewater are considered. In more detail, especially the impact of concentrate recirculation on the biology in the MBR, as well as the MBR and NF membrane performance are assessed. The possibility to recover valuable phosphorous electrochemically, but also the implementation of a phosphorous recovery step into such a continuous MBR NF system are presented.

Firstly, the consequences of NF concentrate recirculation to the MBR for the microbiology in an MBR NF process is described. A comparison of the results with a reference MBR without concentrate recirculation indicates that the biological performance (COD removal and nitrification) of the MBR is not drastically affected by concentrate recirculation. No improvement in biodegradation was found. The NF concentrate reduces the sludge production by 21% and with that also the sludge disposal costs. Recirculation improves the quality of the sludge flocs in terms of compactness and settleability (shear stress). A main drawback of the concentrate recirculation is the increased fouling of the MBR membranes with recirculation, compared to the reference MBR without. Recirculation of non-biodegradable (soluble) organics is found to be a major issue regarding MBR fouling.

Following, also the impact on membrane operation of both the MBR as well as the NF membranes in an MBR NF process with NF concentrate recirculation is highlighted. A long-term investigation (1 year) showed that the NF permeate quality is not impacted by the recirculation, which shows the potential of the process for reusable water production. Fouling of the MBR membranes was observed and is caused by the MBR supernatant due to colloidal and dissolved organics (Fig. 2).

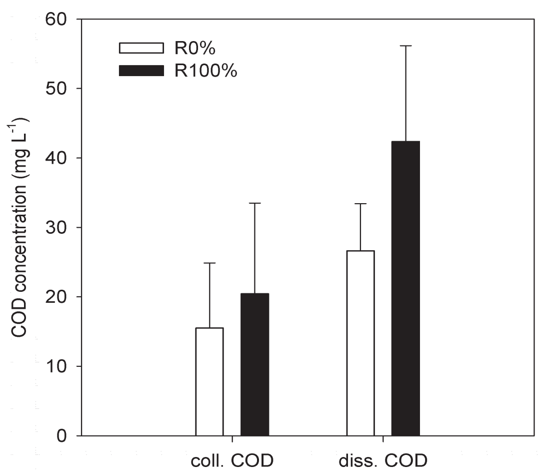


Figure 2: Colloidal and dissolved material in the MBR without (R0%) and with (R100%) NF concentrate recirculation.

Consequently more frequent membrane cleaning is required for the recirculation reactor. Also NF membrane fouling was observed and mostly consists of inorganics (calcium and phosphate), while organics (e.g. humic acids) do not have a major impact on the NF fouling. In fact, the elevated concentrations of humic acids even enhance the flux of the NF. Simultaneous phosphorous recovery from the NF concentrate recirculation in an MBR NF process has the potential to decrease NF scaling. An electrochemical system to recover phosphorous is presented using an electrochemical cell divided into an anode and a cathode compartment separated by a cation exchange membrane (Figure 3).

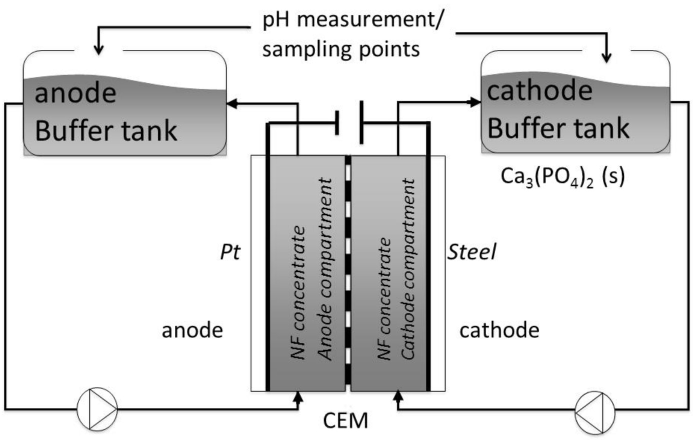


Figure 3: Electrochemical system for phosphate recovery from and MBR NF concept with NF concentrate recirculation.

The precipitation of phosphorous is performed using real nanofiltration concentrate by locally increasing the pH at the cathode surface due to water electrolysis creating supersaturated conditions. 70 - 95% of the total orthophosphate is recovered (at pH 8 - 10). Further analysis by ICP, XRD and ATR-FTIR indicates the presence of amorphous calcium phosphate (ACP). Depending on the pH also minor parts of amorphous calcium carbonate (ACC) are precipitated. Performance losses of the electrochemical system for instance by scaling at the cathode surface are not found. Scaling possibly is prevented by H_2 gas formation at the cathode.

Nutrient (phosphorous) recovery implemented in an integrated MBR NF process with NF concentrate recirculation is discussed. The performance of two laboratory-scale MBR NF processes with NF concentrate recirculation, one with and one without P recovery from the MBR permeate, operated for 200 days. The experiments also include a third “blank” MBR, neither with NF concentrate recirculation nor P recovery. The recovery step results in NF permeate with a sufficiently low P level that allows discharge or reuse as for instance cooling water in power plants (Figure 4).

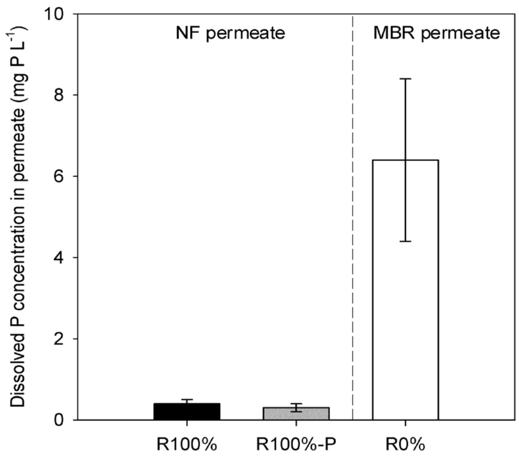


Figure 4: Dissolved phosphorous concentrations in final discharged MBR and NF permeate concentrations.

Scaling especially on the NF membrane is reduced by the addition of the P recovery step, which in consequence also improved the NF filterability of the MBR permeate (decrease of the NF filtration resistance) in comparison to the full concentrate recirculation (Figure 5).

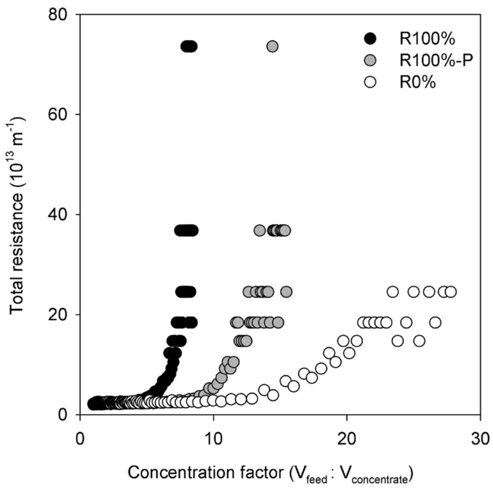


Figure 5: Comparison of NF filterabilities of the MBR NF system without NF concentrate recirculation (R0%), the system with full recirculation (R100%) and the system with concentrate recirculation and intermediate P recovery (R100%-P).

To conclude this thesis, this process produces high quality, reusable water as the NF permeate, and at the same time reduces the amount of concentrated waste and even allows the recovery of valuable (e.g. phosphorous) components. Nevertheless, the use of two membrane systems can be energy and especially maintenance intensive. Also, the decreased sludge production and increased membrane fouling raise some challenges. Although not experimentally investigated in this thesis, the concept is very attractive for micropollutant removal, although more detailed research on the behavior of specific emerging micropollutants in the MBR NF process with concentrate recirculation is important.

Advanced Optical Techniques for Membrane Characterization

Introduction

Light can be a very powerful tool to characterize membranes. This is not limited to simple visual inspections of membranes, or even inspection by optical microscopy. At MST we have a number of more advanced light based measurement techniques, that are capable of characterizing a membrane, or a model membrane, on length scales ranging from nanometers to micrometers. These advanced techniques do not rely solely on the wavelength and intensity of light, but also take into account the light polarization or study the interference between a light beam that passed through a sample with an identical light beam that did not pass through the sample. By using this range of tools we can for example study how a membrane surface fouls by a 1-2 nm thick layer of a model protein, and on the same surface observe and study in detail the subsequent formation of a millimeters thick bio-film. Here we will discuss the working priciple and applications of a number of such advanced optical techniques available in our group.

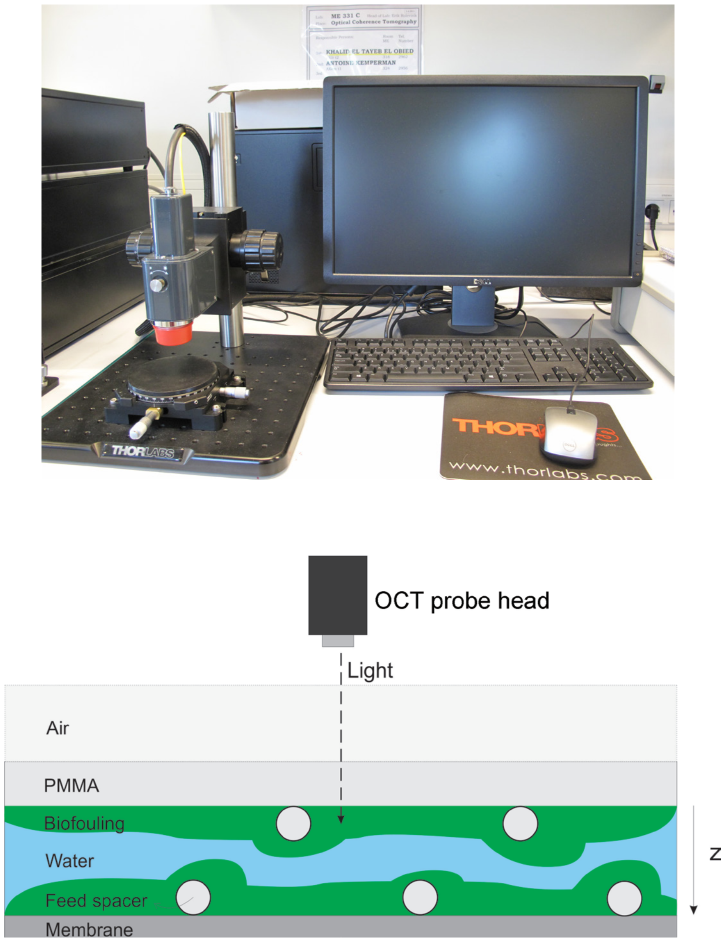


Figure 1: Photograph of the OCT equipment in our lab (upper picture) and schematic representation of the principle of OCT (lower picture). Illustration of a horizontally positioned sample in cross-section: light passes through air (refractive index=1), a 10-mm-thick PMMA plate, the actual biofouling (partly) and a layer of water, and finally is reflected by the shiny nanofiltration membrane sheet (Figure Yusuf Wibisono).

Optical Coherence Tomography (OCT)

Key membrane applications: The non-invasive, in situ monitoring of bio-film growth on flat sheet and capillary membranes, measuring the efficacy of cleaning methods and the subsequent removal of the biofilm.

Optical Coherence Tomography (OCT) is a noninvasive optical imaging technique that provides real-time, 1D depth, 2D cross-sectional, and 3D volumetric images with micron-level resolution and millimeters of imaging depth (Figure 1).

OCT images provide structural information of a sample, based on light scattered from different layers of material within that sample. OCT imaging is considered to be the optical analog to ultrasound. OCT, however, achieves higher resolution through the use of near infrared wavelengths, although at the cost of decreased penetration depth. In addition to high resolution, the non-contact, noninvasive advantage of OCT makes it well suited for imaging samples such as biological tissue and industrial materials. For membranes, it has proven a powerful tool to study the formation and growth of thicker fouling layers such as biofilms in situ during formation. Also the effect of different cleaning strategies can be investigated and the biofilm removal process can be visualized in situ. As the technique is non-invasive the membrane is not disturbed during the measurements, and when taking into account its penetration depth, it even becomes possible to study the inside of certain capillary membranes under process conditions.

As an example, Figure 2 shows the OCT image of a clean membrane before use (R), the formation of a biofilm on the membrane and especially the spacer elements (A1-3), and the effect of two different cleaning approaches (B1-3, C1-3) on the biofilm removal.

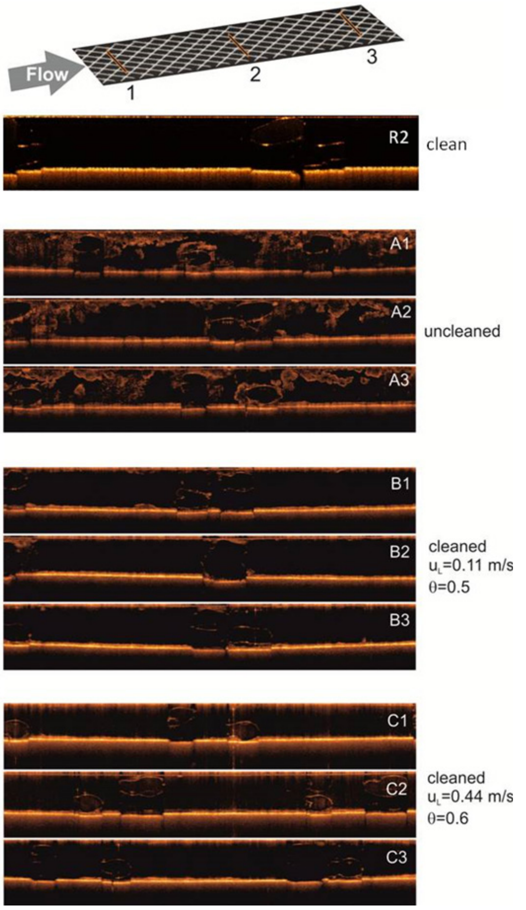


Figure 2: OCT cross sectional image of a clean membrane and spacer (upper picture) and a number of fouled membranes and spacer (lower pictures) in a flat flow-cell geometry (Figures Yusuf Wibisono). Series of equidistant OCT B-scans (7 mm x 1.131 mm, measured in air (refractive index=1) of biofouled feed channels in three regions: (1) adjacent to the inlet (A1, B1, C1), (2) in the middle of the channel (A2, B2, C2), and (3) adjacent to the outlet (A3, B3, C3). Flow cell A is the biofouled feed channel before cleaning, flow cell B was cleaned at a liquid velocity of uL=0.11 m/s and a gas/liquid ratio θ=0.5, and flow cell C was cleaned at a liquid velocity of uL=0.44 m/s and a gas/liquid ratio θ=0.6 (slightly higher ratio, but bubble distribution is identical to θ=0.5). R2 is the clean feed channel before the start of the experiment, as reference, captured in the middle of the flow cell. The intensity of the orange is proportional to the intensity of the detected reflection of the raw signal (Wibisono et al., manuscript submitted to Desalination (2014)).

Ellipsometry

Key membrane applications: Characterization of membrane thin films for NF, RO, and gas separation, determining the interaction of a membrane thin film with a liquid, solute or gas.

In ellipsometry, the sample under investigation is irradiated with a light source, and the change in the polarization state of this light beam when it reflects on and/or transmits from a thin layer of material is measured (Figure 3). This polarization change is represented as an amplitude ratio, Ψ, and the phase difference, Δ, two parameters that are strongly connected to the thickness and the optical properties of the thin layer under investigation. As such, using this principle, ellipsometry can, with great accuracy, be used to determine both the thickness and the refractive index of a thin film. It is a non-destructive technique. For membranes, this technique is especially powerful to characterize thin layers of materials that could be used for nanofiltration, reverse osmosis and gas separation properties in situ. Not only does the ellipsometry provide information on layer thickness, but it is also possible to observe uptake of solutes and liquids, but also gases into the layer (and subsequent swelling) to obtain detailed information on the interaction of the solutes with the membrane. Finally it is a powerful technique to characterize coatings such as polymer brushes and polyelectrolyte multilayers for their use to create e.g. anti-fouling layers and stimuli responsive membranes.

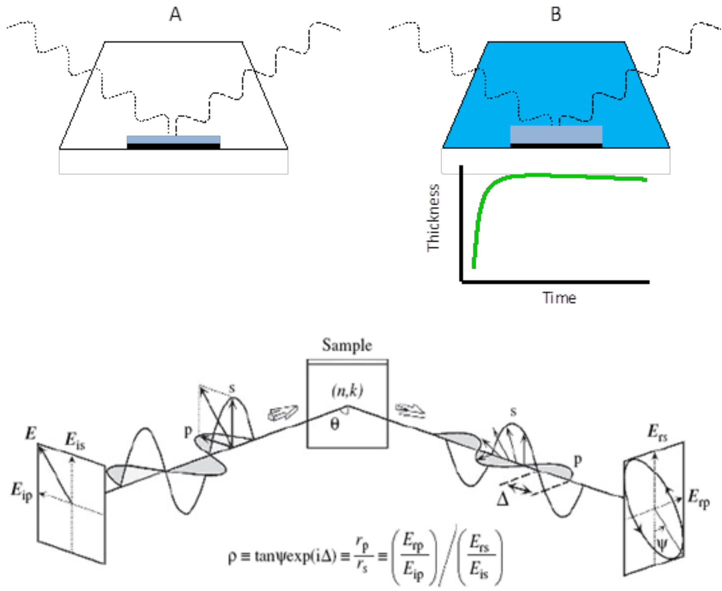


Figure 3: Principle of ellipsometry. Upper picture: A) A sample is irradiated with a light beam; B) As soon as the sample comes into contact with e.g. a liquid, it starts to swell, which is monitored as a change in the polarization state of the light (Figure Joris de Grooth). Lower picture: detailed principle of ellipsometry. Ψ and Δ parameters are converted into useful film properties such as its thickness, refractive index, etc.

Figure 4. Photograph of the ellipsometer in our lab.

Figure 5 shows for example the swelling behavior of the zwitterionic copolymer PSBMA-PA upon exposure to different salt solutions, monitored with ellipsometry. Upon exposure, in time the thickness gradually increases. The different responses to the various anions show the swelling of the film (SD) upon exposure to these solutions and the potential of this co-polymer layer as e.g. ion-selective membrane. Figure 5A clearly shows the strong effect of only small concentrations of the zwitterionic moiety in the polymer on the swelling behavior. Also the type and concentration of the solution used show distinct differences in swelling response (Figure 5A-C). Ellipsometry clearly reveals the anomalous effect of especially lithium salts (Figure 5C). Often, the results obtained in ellipsometry can to a large extent be translated to permeation behavior of the corresponding membranes.

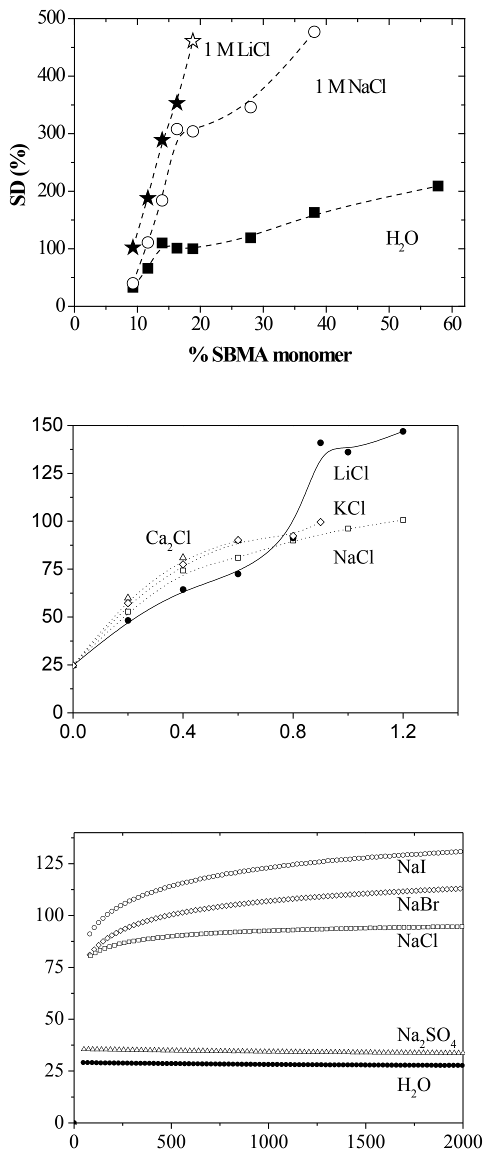
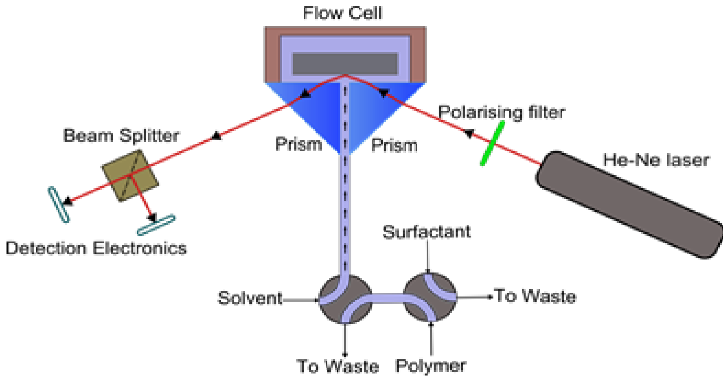


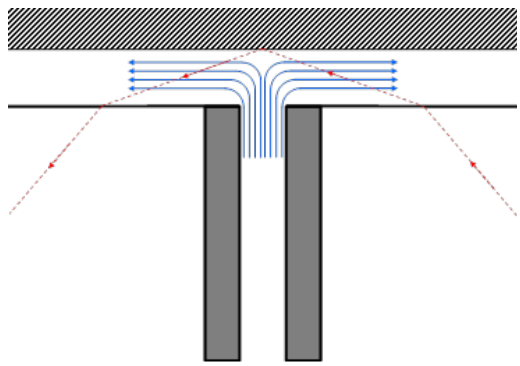
Figure 5: An ellipsometry study into the swelling of a thin film of the zwitterionic copolymer PSBMA-PA, when exposed to different aqueous salt solutions as indicated (de Grooth et al., EPJ 55 (2014) 57–65).

Reflectometery

Key membrane applications: Fouling experiments on model membranes, investigation of e.g anti-fouling coatings, monitoring the deposition of membrane coatings on a model membrane surfaces.

Reflectometry is a technique that relies on the same principles as ellipsometry, but is fully optimized towards the study of the adsorption of for example thin layers of polymers, proteins, humic acids etc. to model surfaces (Figure 6). Especially important in the setup is the flow-cell geometry that in this case is a stagnation point flow. Because of the use of stagnation point flow, the transport of molecules to the surface is very well defined and controlled by diffusion.





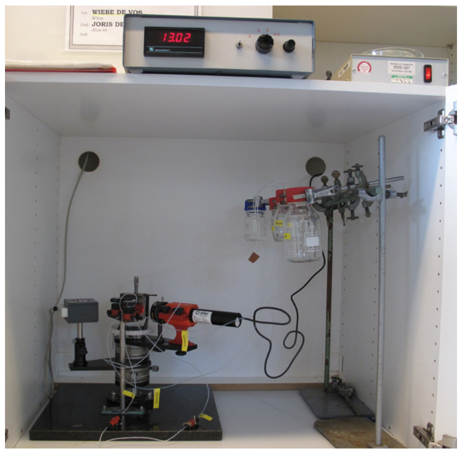


Figure 6: A schematic representation of reflectometry. Note especially the well-defined flow geometry (stagnation point flow) and the use of polarized light. Upper picture: schematic of the full system; Middle picture: representation of the well-defined flow profile in the measurement cell; Lower picture: photograph of the system available in our lab.

The basic surface used for reflectometry is always a highly reflective silicon wafer, but this can easily be coated with a layer of for example cellulose, PVDF, PES to act as a model membrane surface. The technique is especially powerful to predict how membranes will foul when exposed to e.g. particles/proteins/humic acids, but also to subsequently test various methods of cleaning or to test anti-fouling approaches. Furthermore it is an excellent technique to monitor the build-up of one or multiple membrane coatings, such as polyelectrolyte multilayers, on a membrane surface. Figure 7 shows a typical plot of the increase in weight of a sample upon the addition of subsequent oppositely charged (+, -, +, -,..) polyelectrolyte layers on a sample surface as monitored by reflectometry.

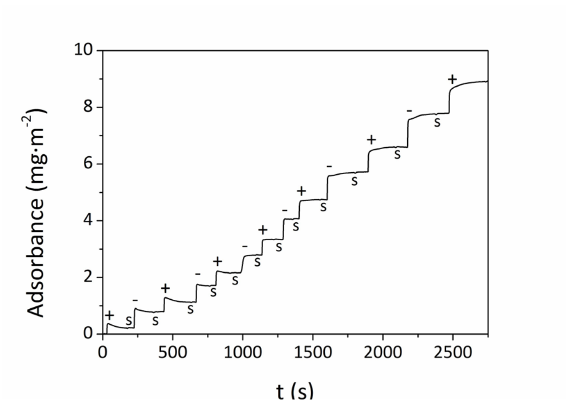


Figure 7: Typical result of the weight increase obtained after subsequent addition of multiple polyelectrolyte layers on a surface.

Figure 8A shows the same type of plot, i.e. the amount of polymer deposited on a model sample surface upon coating this surface with alternating a positively charged electrolyte layer (pDADMAC) and a negatively charged (PSS) polyelectrolyte layer at different salt concentrations. A clear weight increase is observed after every additional layer. This amount can be tailored by the salt concentration of the solution, giving higher mass increase at higher concentrations. Figure 8B shows the corresponding membrane resistance plot as obtained from membrane filtration experiments using membranes coated with exactly the same alternating polyelectrolyte layers and salt concentrations as the model surfaces used for reflectometry. The similarity between both plots is excellent and both data show exactly the same behavior. The obvious advantage of using reflectometry instead of a full membrane preparation and characterization, is its ease of use and simplicity, while providing the same basic information. As such, reflectometry is an excellent technique for e.g. fast and simple screening of a series of possible interesting membrane materials.

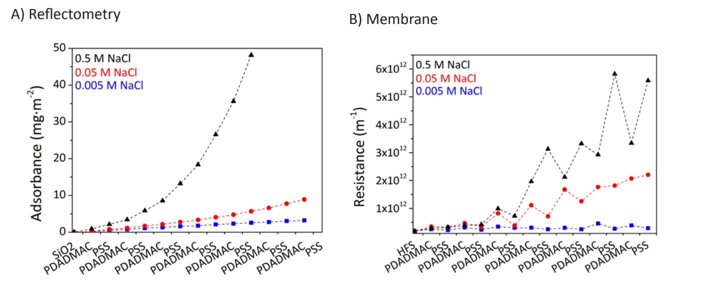


Figure 8: Obvious similarity between A) A plot of the weight increase obtained after subsequent addition of multiple polyelectrolyte layers on a model surface and B) The graph of the corresponding membrane resistance as obtained from permeation measurements for a real membrane coated with the same series of polyelectrolyte layers.

Reflectometry cannot only be used to monitor the deposition of e.g. coating layers on surfaces, it can also be applied to measure the fouling behavior of a (membrane) surface, Figure 9 shows an example of this. The left part of the figure (Figure 9A) shows the reflectometry data on model surfaces and the right part (Figure 9B) shows the corresponding membrane resistance data as obtained from permeation measurements. Both the model surface and the membrane are coated. In the upper graphs, this is a positively charged layer (pDADMAC), in the middle graphs this is a zwitterionic (both positive and negative charges) layer (pDADMAC-pSBMA), and in the bottom graphs this is a zwitterionic layer with additional negative charges (pDADMAC-pSBMA-AA). After that, both the coated model surface and the corresponding coated membrane are contacted with a BSA solution as model foulant. The obvious similarity between the model surface and the real membrane is again striking. Clear information on the fouling potential of the corresponding membrane can be obtained from the much easier and faster to perform reflectometry measurements. A positive surface obviously causes BSA fouling, visible as a weight increase in the reflectometry data and a permeability decline in the membrane permeation data. When a zwitterionic layer is used, fouling seems not to occur, as the permeability remains more or less constant in time. However, the amount of absorbed material decreases, as visualized in the reflectometry data. This is clearly the consequence of the gradual washing away of the applied layers. When a negatively charged zwitterionic layer is applied on the other hand, BSA fouling does not occur and also the applied layers remain on the surface. Also this example shows the benefit and additional value of using optical techniques as a valuable tool for membrane characterization.

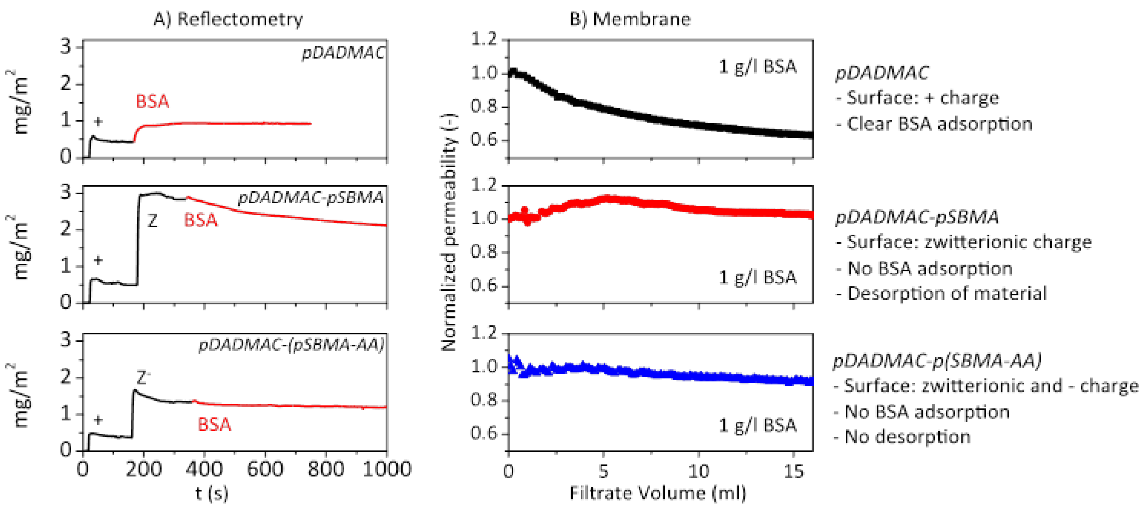


Figure 9: Obvious similarity between A) Reflectometry plots of the weight increase obtained after addition of a positively (upper picture), a zwitterionic (middle picture) or a negatively charged zwitterionic (bottom picture) layer and subsequent BSA (foulant) adsorption on a model surface and B) Corresponding membrane permeability as obtained from permeation measurements.

For more information about optical techniques for membrane characterization, please contact Dr. Wiebe de Vos (phone: +31 53 489 4495 or e-mail: w.m.devos@utwente.nl).

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Two-phase flow for fouling control in membranes

Yusuf Wibisono

The real challenge of the use of NF/RO spiral-wound membrane modules in water treatment is membrane fouling. Fouling problems in NF/RO systems are more complicated than in low pressure membrane processes. Fouling usually is a nanoscale phenomenon, but the extend and type of fouling is also determined by the complex geometry of spiral-wound membrane modules. Reducing membrane fouling is a must during operation of NF/RO membranes in order to minimize product loss and operational costs. Periodical cleaning is needed to relieve unwanted materials from the membrane surface and the feed channel. Physical reversible fouling in NF/RO processes is preferably prevented by a proper pretreatment (MF/UF/ozonation or activated carbon) and is traditionally removed by flushing (backflush, forward flush, reverse flush). Physical irreversible fouling (especially biofouling) needs to be tackled by a chemical cleaning. Yet, chemical agents are found to be ineffective to control biofouling and many studies revealed the survival of microbial cells after chemical cleaning.

Technical and economical analyses demonstrated that gas/liquid two-phase flow cleaning is a promising technology to keep the membrane resistance at sufficiently low levels and to increase the membrane flux for many types of membrane processes: (i) microfiltration (MF), (ii) ultrafiltration (UF), (iii) nanofiltration (NF), (iv) reverse osmosis (RO), (v) membrane distillation (MD), (vi) electrodialysis (ED), and (vii) membrane bioreactors (MBR) [1]. Also it is applicable in a multitude of membrane module types: (i) flat/planar (Fig. 1), (ii) tubular/

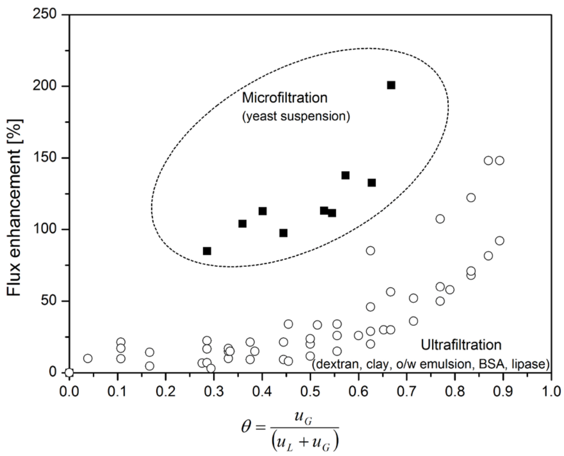

Figure 1: Effect of gas/liquid ratio and feed type on flux enhancement (vertically positioned flat sheet membrane module).

capillary, (iii) hollow fiber and (iv) spiral wound membranes. The research presented in the PhD thesis of Yusuf Wibisono is aimed at understanding and optimizing two-phase flow cleaning in spacer-filled membrane channels used as a model for spiral-wound membrane elements (Fig. 2).

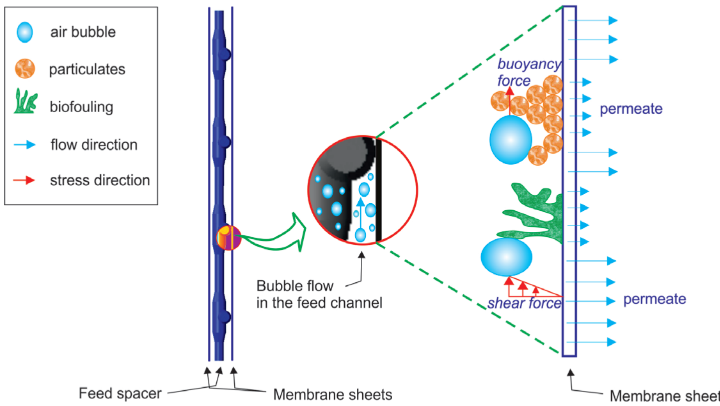

Figure 2: Schematic diagram of two-phase flow cleaning for fouling removal in spiral-wound membrane feed channels.

The following parameters are investigated: (i) feed type and concentration; (ii) feed spacer geometry and orientation; (iii) feed pressure and velocity; (iv) gas/liquid ratio; and (v) feed spacer surface properties.

Efficiency of two-phase flow cleaning in spiral-wound membrane elements

The first experimental study in this thesis is the investigation of the key factors that control the effectiveness of two-phase flow cleaning. In this chapter the importance of several factors (i.e. feed spacer geometry (thickness and orientation), gas/liquid ratio, liquid velocity, and feed type) to control the efficiency of two-phase flow cleaning is investigated

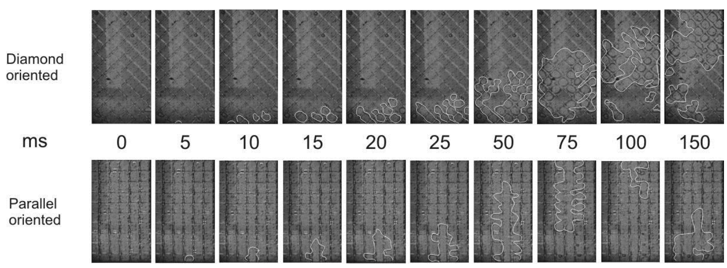

Figure 3: Bubble trajectory in narrow spacer-filled membrane channel with spacer 0.5 mm thickness in diamond orientation (top) and parallel orientation (bottom), with uL=0.07 m/s and gas/liquid ratio=0.629 (elapsed time in milliseconds).

[2]. The results show that although the channel porosity and the hydraulic diameter of spacer-filled channels are important factors in terms of efficiency, the bubble velocity, as determined by high speed camera, is far more important in improving the two-phase flow cleaning efficiency (Fig. 3). The gas/liquid ratio should be maintained in such a way that a slug-like flow pattern is formed, so as to generate a good bubble distribution. Channel coverage strongly depends on the geometry of the spacer-filled channel; maintaining full channel coverage by the bubbles is crucial.

Biofouling removal in spiral-wound nanofiltration elements using two-phase flow cleaning

Biofouling control in spiral wound nanofiltration elements using two-phase flow cleaning was investigated as well. The role of feed spacer geometry, feed pressure, gas/liquid ratio, cleaning duration, and liquid velocity are investigated [3]. The results indicate that bubble flow and bubble size, which are critical for the efficiency of the process, are controlled by the structure of the feed spacer. An increase in the liquid velocity during two-phase flow cleaning was responsible for increasing bubble velocity and this was most effective in improving the recovery of the mass transfer coefficient (MTC). Mesoscale visual inspections using optical coherence tomography (OCT) clearly showed a significant increase in biomass removed from the membrane surface with increasing velocity (Fig. 4). Finally, the use of the FCP (feed channel pressure drop) only as an indicator for biofouling removal was found to be insufficient. For example, the short cleaning duration required (about 5 min) for FCP recovery is misleading since it does not take into account the biomass present on the membrane surface. The information provided by the MTC before and after two-phase flow cleaning gave a better indication about the biofilms present directly on the membrane surface, thus providing more insight in actual removal rates.

Hydrogel-coated feed spacers in two-phase flow cleaning in spiral-wound membrane elements: a novel platform for eco-friendly biofouling mitigation

The potential of two-phase flow cleaning to control biofouling is tested using modified feed spacers. PolyHEMA-co-PEG10MA (neutral), polyDMAEMA (cationic) and polySPMA (anionic) were successfully coated onto PP feed spacer surfaces via plasma mediated UV-polymerization [4]. These coatings were chemically stable for at least 7 days immersion

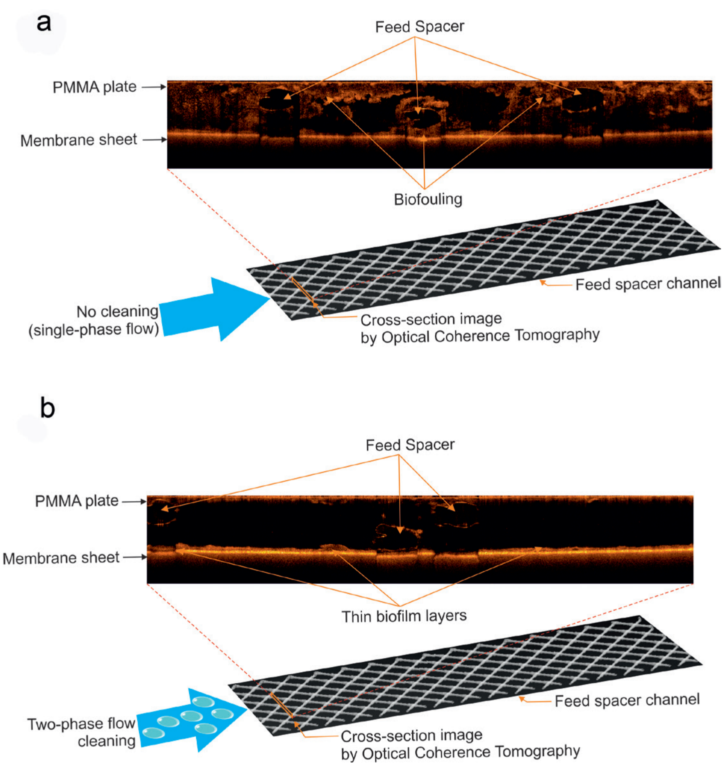

Figure 4: llustration of B-scans (xz-planes) of the biofouled spacer-filled channel, before (a) and after (b) two-phase flow cleaning (uL=0.11 m/s; θ =0.5) at inflow points. The intensity of the orange color is proportional to the intensity of detected reflection of the raw signal. The back-scattered light from the membrane sheet is brighter due to the shiny top layer of the membrane.

into neutral, acidic and basic environment. All hydrogel-coated PP samples showed good anti-biofouling properties during bacterial adhesion tests. During filtration tests, polyDMAEMA showes low anti-biofouling properties due to hydrophobic interactions. The performance of polyHEMA-co-PEG10MA is fairly good. PolySPMA-coated PP feed spacers on the contrary showed significant anti-biofouling properties. Employing these highly hydrophilic surfaces during removal of biofouling by two-phase flow cleaning enhances the cleaning efficiency, feed channel pressure drop and flux recoveries.

Dominant factors controlling the efficiency of two-phase flow cleaning in spiral-wound membrane elements

This study focuses on the experimental optimization of two-phase flow cleaning using a Taguchi Design of Experiment method (L-25 orthogonal arrays) to elucidate the influence of different parameters and to reveal the important factor(s) affecting the cleaning efficiency. All possible combinations of the factors, i.e. feed type, spacer geometry, gas/liquid ratio and liquid velocity, each at five levels, were evaluated. The main effect of each factor on the efficiency of two-phase flow cleaning was measured by determining the performance response and by calculating the mean signal-to-noise ratio. The results showed that the feed type is by far the most essential factor contributing to the cleaning efficiency. The spacer geometry is ranked second, followed by the gas/liquid ratio and the liquid velocity, which both have an only very minor effect. In terms of a practical application, the operator should consider first the type of foulant prior to taking a decision on whether or not two-phase flow cleaning will be effective. Once the feed type is defined, the use of the highest gas/liquid ratio, the highest liquid velocity and the thickest feed spacer (diamond type) are recommended to achieve maximum two-phase flow cleaning efficiency.

Finally, as an outlook, practical studies on the up-scaling of two-phase flow cleaning on NF/RO processes for water purification, waste water treatment or desalination optimized for long-term operation is essential. Key factors affecting two-phase flow cleaning as identified in this study, should be tested at larger scales to elucidate their effect on full scale NF/RO installations using real feed waters. In addition also an extensive economic evaluation needs to be performed.

For more information about this work, please contact Dr. Ir. Antoine Kemperman (a.j.b.kemperman@utwente.nl; phone: +31 (0)53 489 2956).

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[1] Y. Wibisono, E.R. Cornelissen, A.J.B. Kemperman, W.G.J. van der Meer, K. Nijmeijer, Two-phase flow in membrane processes: A technology with a future, Journal of Membrane Science, 453 (2014) 566-602.

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Farewell party Greet

After 22 years as secretary of the Membrane Science and Technology Group, Greet retired from the University of Twente. To thank Greet for everything she did for each of us personally and for the group as a whole, a goodbye party was organized on May 21, 2014. More than 175 people used this opportunity to thank Greet and to wish her all the best for the future.

Greet kamminga

There are only very few people that visited or were in contact with our group during these 22 years that do not know Greet. Of course she performed all tasks that one expects a secretary to do. And she did that with a lot of dedication and accuracy. But she did much more than that. New people in the group always first went to Greet. For all questions, whether it was related to housing, administrative forms for health insurance, visa or a bicycle repairer, she knew a solution. She was always willing to help, independent of how

difficult the question. But also for the people that work in the group, she was able to solve, at first sight impossible-to-solve problems. Always with a lot of enthusiasm and dedication. Her very long experience at the University of Twente and the fact that she was always in the office made that many people in- and outside the university consulted her for questions or advice.

We would like to take this opportunity to sincerely thank Greet once more for everything she did. We will miss her. We wish her together with her family a wonderful future.

Ph.D. Defenses

Cum Laude Ph.D. Defense David Vermaas

On Friday January 17, 2014, Dr. David Vermaas defended his Ph.D thesis on Blue Energy. His thesis is entitled: 'Energy generation from mixing salt water and fresh water: Smart flow strategies for reverse electrodialysis'. The Ph.D. evaluation committee was highly impressed by the excellent quality of the work of David both in terms of scientific excellence, depth, broadness and applicability of the research as well as scientific and societal output and awarded him the degree of Doctor with distinction ('cum laude').

Reverse electrodialysis (RED) is a technology to capture renewable energy from mixing water with different salinities, for example from mixing seawater and river water. The salinity difference between seawater and river water induces a potential difference when both waters are separated by an ion exchange membrane, selective for cations (cation exchange membrane, CEM) or anions (anion exchange membrane, AEM). In a RED stack of alternating CEMs and AEMs, with seawater and river water in compartments between these membranes, the voltage over each membrane is accumulated and this voltage can be used as a power source, using e.g. electrodes and a reversible redox reaction that convert the ionic current into an electrical current.

The Ph.D. thesis of David evaluates the current limitations and future opportunities of reverse electrodialysis and investigates the use of novel flow strategies. Such flow strategies include the use of membranes with integrated spacer functionality (microstructured membranes), mixing promoters, periodical switching to enable a novel electrode system and the introduction of anti-fouling strategies in RED. The obtained knowledge regarding these issues contributes substantially to the realistic potential of reverse electrodialysis as a renewable power source.

David published more than 15 scientific papers, of which one in Energy and Environmental Science (impact factor: 11.653). For more information, please contact Prof. Kitty Nijmeijer (d.c.nijmeijer@utwente.nl).

PhD Defense Enver Guler

On Friday January 31, 2014, Dr. Enver Güler defended his Ph.D thesis entitled: 'Anion exchange membrane design for reverse electrodialysis'. Reverse electrodialysis (RED) is a clean, sustainable, potentially attractive technology for the generation of energy from the mixing of solutions with different salinity. It utilizes the free energy of mixing these solutions (e.g. river water and seawater) to generate power. In RED, a concentrated salt solution and a less concentrated salt solution are brought into contact through ion selective membranes (anion exchange membranes, AEMs, and cation exchange membranes, CEMs) that are alternately patterned in a stack. Anion exchange membranes allow only anions to pass through towards an anode and cation exchange membranes allow only cations to pass through towards a cathode. In his PhD work, Enver investigated the design and development of the RED process, with a special focus on fabrication, characterization and optimization of ion exchange membranes.

With his work, Enver was the first one constructing a RED stack with only tailor made membranes. He obtained the highest power output measured so far at that time. Evaluation of membrane properties of multiple different membrane pairs in relation to performance revealed that especially the membrane resistance dominates the power output. Additionally he developed monovalent selective membranes to mitigate fouling and control the effect of multivalent ions (e.g. Mg^{2+} & SO_4^{2-}), which are present in natural waters and on the short term reduce the power output. Finally he worked on the design and fabrication of microstructured membranes that integrate the membrane and spacer functionality, having the microstructures on the membrane surface functioning as ion conductive spacers. He specifically investigated the influence of structure geometry (pillars, waves or ridges) on power output. Especially the pillar-structured membranes exhibited a more uniform flow distribution compared to the other types. 21% lower ohmic resistance was obtained resulting in 38% higher gross power density and 20% higher net power density for the pillared structures compared to the flat membranes with spacers.

For more information, please contact Prof. Kitty Nijmeijer (d.c.nijmeijer@utwente.nl).

New people

Behavior and adhesion of stabilized oil droplets in produced water on membrane surfaces

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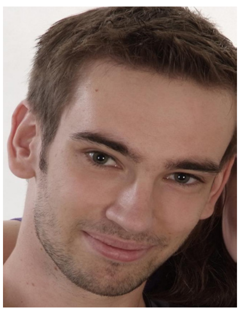
Janneke Dickhout obtained her Bachelors degree in Natural Sciences (physical chemistry profile) at the Radboud University Nijmegen. During her Master at the same university, she did two internships at different departments. The first internship, titled 'The study of two molybdenum polyoxometalate clusters using Kelvin Probe Force Microscopy' was performed at the SPM group. This research project focused on investigating the electrostatic properties of monolayers of polyoxometalate clusters on graphite. These clusters might be used as molecular switches in the future. Her second Master internship took place at the Solid State Chemistry department and was titled 'The effects of additives on Viedma ripening'. This internship was part of a bigger research project, which aims at explaining the enantiopurity of life on earth. After obtaining her master's degree, she joined the Membrane Science and Technology group at the University of Twente as a Phd candidate under supervision of Prof. Kitty Nijmeijer and Dr. Wiebe de Vos. She is located at the research centre of Wetsus in Leeuwarden. Her project focuses on studying the behavior and adhesion of stabilized oil droplets in produced water on membrane surfaces. Produced water is the biggest waste stream in the recovery of oil, and contains dispersed and dissolved hydrocarbons, surfactants, salts and clay particles. To make this water suitable for re-use, these compounds should be removed. Membrane technology is a viable technique to deal with the smallest and most stable oil droplets, but the membranes suffer from fouling and scaling by the compounds in the produced water. This research aims at understanding the fouling behavior of the oil droplets and other compounds on the membrane surface, with the eventual goal of improving the membranes used in produced water treatment.

Mass transport characterization of smoke aroma ingredients through blown films in food packaging



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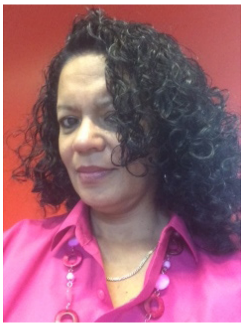
Bjoern Heidrich studied at the local high school of Stadtlohn, Germany from 1999 to 2008. After he gained his university-entrance diploma, he moved to Muenster to study Chemical Engineering at the University of Applied Sciences Muenster. In 2010 he performed an internship at RWE Technology in Essen, Germany. He developed and implemented an optimized control of oxygen supply within a flue gas desulfurization plant at a lignite fired power plant. He completed his Bachelor's degree in 2011 with a thesis in the above mentioned field.
Afterwards, Bjoern went on studying Chemical Engineering with a specialization in Chemical Processing at the University of Muenster. He completed his MSc degree and a second internship at Henkel in Düsseldorf, Germany in 2013. Within his Master's thesis, he focused on various surface preparation techniques to optimize later on bonding with epoxy adhesives of aluminum alloys in the aerospace branch. In June 2013 he joined the group of Professor Norbert Ebeling at the University

of Muenster, to start his doctoral studies. His research aims to characterize the mass transport of different smoke aroma ingredients in the application field of food packaging, especially of sausage casings. His studies involve an extensive literature research to identify key components of smoke and liquid smoke. Furthermore, he will perform various solubility and permeability test from both, liquid and gaseous phase. Bjoern is a member in the group of Food Packaging Technology at the Technical University of Munich as well as in the group of MST at the University of Twente. Within his PhD, he will move between all three mentioned universities.
Along the way, Bjoern is still studying Macroeconomics at the University of Duisburg-Essen since 2012 and Industrial Engineering at the University of Muenster since 2013. He will complete his additional studies with a second MSc degree in 2015. Moreover, he exercises an honorary office in the Association of German Engineers, organizing every year's ChemCar competition. The aim of this international contest is the construction of a vehicle, driven by an innovative (bio-) chemical reaction only.

Group Secretary



Name
Audrey

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Audrey, is working as a secretary for many years and supported the department of Tissue Regeneration (prof. dr. Clemens van Blitterswijk, UT) for the past eight years. Since the group is moving to Maastricht (end of 2014) she transferred to the MST group. with Prof. Dr. Kitty Nijmeijer.
Audrey has been working for several commercial companies like ACNielsen, KLM, Pink Roccade, CSM and Honeywell, all located in- and around Amsterdam. The depts. 'Antropogenetica' and 'Eerste Harthulp' of the AMC as well as 'Bureau Studenten Administratie' of the University of Amsterdam have also been her working area.
Audrey and her family moved from Diemen to Gronau in 2006 and she has joined the UT since then.

Technician

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Patrick Goossens studied chemistry at 'saxion Hogeschool' in Deventer. After his study he worked for 4 years at Akzo Nobel in Arnhem. He worked for the business unit Car Refinishes, and the main goal in his work was the development of a binder (polymer) for a water based transparent clear coat for car repair applications. The main topic he worked on was synthesis of polyesters with different molecular weight and OH functionalities. These binders were subsequently cross linked with Isocyanates to form the final clear coat.
After this he worked for DSM where he also synthesized binders for the coating industry, however this time for UV curable systems. The main binders which were synthesized were polyesters with a relative low molecular weight to keep the viscosity low. To obtain UV curing the binders need to have an double bond. This is built in by reaction with acrylic acid.
Subsequently he worked for 5 years for Unipro in Haaksbergen. Unipro is a producer of waterborne adhesives for the carpet industry. Here he worked on the R7D deparment where he developed different adhesives for different kind of carpets. In contrast to DSM and Akzo Nobel, where he synthesized of all kind of polymers, he formulated adhesives.
In our group, Patrick is the new Technician. He will be working for the MST group and for the EMI. For MST he will participate in projects of the PhD's. For EMI he will participate in projects requested by industrial partners.

It all started in Twente

What is your name?
Katrin Ebert

What are your date of birth and your place of birth?
September 17, 1965 in Dresden

What is your marital status and do you have children?
Not married, no children…

Where are you currently employed and what is your position (please provide a short description of your current job)?
GMT Membrantechnik GmbH in Rheinfelden (Baden) working as Head of Development with the focus mainly on membrane development and optimization.

Where is your company located and where do you live?
GMT is located in Rheinfelden (Germany), very close to the border with Switzerland.

When did you start your PhD and when did you receive your PhD degree?
I started in 1991 and finished in 1995.

On which topic did you do your PhD?
Composite membranes for gas separation

Do you still have contacts with your former PhD students from that time?
Now and then, mainly at conferences

What was your first job after your PhD?
Post-Doc at GKSS working within a European Project in the field of organophilic nanofiltration

How did your career develop?
Already during my PostDoc period at GKSS I was involved in different (industrial) projects related to membrane development for vapour permeation, gas separation and organophilic nanofiltration. Gradually, I had the opportunity to lead project groups. This helped me later when I had to build up a new department within the institute. Besides proceeding with hollow fiber spinning, our group established electrospinning for filtration applications in the institute.
In 2010 I started my current position at GMT Membrantechnik.

How do you relate your career to the experience you gained during your PhD?
I am still working in the membrane business. So, for me very clearly my PhD work in Twente was the basis for my professional career.

How did you experience your time in Twente?
I very much enjoyed the Twente time. Working in an open and friendly atmosphere with PhD-students, students and PostDocs from many countries was a great experience for me.

What important things did you learn during your PhD?
It makes (working) life much easier and much more efficient if the working environment is open and pleasant as I experienced it in Twente. How important that is I just realized later.

What was the biggest challenge during your PhD?
I started my PhD work with a literature study. Reading a bunch of patents and scientific publications left me quite confused since obviously all problems in the field of thin film composite membranes were already solved. Finding a way through that jungle was probably one of the biggest challenges for me.

Do you maybe remember an anecdote or a specific moment of that time?

There are many such moments: the PhD and wedding party's, volleyball and table tennis during the lunch breaks. Some of these moments are related to "cultural" differences, which can be significantly even although countries like The Netherlands and Germany are geographically so close together.

I still remember my first day in Twente when Prof. Smolders welcomed me with the words: "Hello Katrin, I am Cees." For me, with my German education, it was absolutely impossible to call him by his first name.

(I will not stress the orange garlands decorating the room after some highly paid guys dressed in orange played with a ball… Thanks for taking care, Jeroen!)

What was the best moment of your PhD (except the graduation)?

I did not have a "wow, that's it" experience during my PhD. But I remember that I was very proud and at the same time looked a bit incredulously when I held the thesis in my hands for the first time.

What would you have done differently if you could do your PhD again?

Probably, I would and should take more freedom to arrange the work. In the first period of my PhD there were some problems related to the materials provided within the project. Looking back I spent too much time on these issues because I did not dare to switch to other materials.

Which advice do you have for the current generation PhD students?

Enjoy your PhD time!

What is your precious memory of the group?

I very much appreciated (and still do) to work in an open atmosphere with support, trust and clear rules. The social activities outside the work really represented the group's spirit. Later I very strongly realized that this is highly precious and a strong basis for the scientific/professional performance of a group.

To my very precious memories of the Twente membrane group at that time certainly belongs Marcel Mulder.

What could be different in our research group?

I do not have an answer for that question since, unfortunately, I do not know the present Twente membrane group.

What did you miss while working in the group?

That is a difficult question. After that long time you only remember the good and the very bad things. Obviously, I do not have such bad memories that I can recall them.

PhD Defenses

Yusuf Wibisono

Two-phase flow for fouling control in membranes

September 11, 2014, 14.45 h, University of Twente

Salman Shahid

Molecular organic frame work (MOF)-polymer membranes for gas separation applications

February 05, 2015, 14.45 h, University of Twente

Follow us on Twitter: The Membrane Science and Technology group has his own Twitter account!

Follow @MST_UTwente for the latest news of the MST group in a nutshell!

The Faculty of Science and Technology at the University of Twente represents a multidisciplinary environment for higher education and frontier research at the interfaces of applied physics, chemical technology and biomedical engineering. Key research topics include nanotechnology, sustainable energy, biomedical technology and technical medicine.
One of the important research themes of the faculty is Membrane Science & Technology. The group is the only academic polymer membrane group in The Netherlands and internationally leading in the field of membranes for Energy and Water Applications. Knowledge valorization occurs through the European Membrane Institute Twente (EMI Twente), which is a separate entity within the research group.

Within the research group Membrane Science and Technology of the University of Twente, we have a vacancy for a Ph.D. position.

Membrane, module and process design for super critical CO_2 dehydration

Within the research group Membrane Science and Technology of the University of Twente, we have a vacancy for a Ph.D. position.

Ph.D. position: "Membrane, module and process design for super critical CO_2 dehydration"
(location: TTIW Wetsus, Leeuwarden, NL)

There exists a strong interest in the drying of supercritical CO_2 gas streams with gas separation membranes. Current state of the art is the use of zeolite columns for the selective adsorption of water vapor. This process has several disadvantages, like large and heavy equipment and the discontinuity of the process (regeneration of the zeolite). The recirculation of compressed gas is very expensive and hard to defend economically as the removal of the water is done thermally. In this project the possibilities of membranes for dehydration of supercritical CO_2 will be explored. Such membranes transport water vapor preferably over CO_2 and offer an alternative route for the drying of such streams. The project involves membrane design, module construction and process and performance evaluation.

The research will be conducted at Wetsus in Leeuwarden, NL (www.wetsus.nl) under the supervision of the Membrane Science and Technology group, faculty of Science and Technology of the University of Twente (www.utwente.nl/tnw/mst).

We are looking for highly motivated and enthusiastic researchers with an MSc degree in chemical engineering or a related topic, with excellent experimental and theoretical skills.

We prefer candidates with a good team spirit, who like to work in an internationally oriented environment. Fluency in English is a requirement. An interview and a scientific presentation will be part of the selection procedure.

We offer you a PhD position for 4 years. Your starting salary will be € 2083, - gross per month in the first year and up to € 2664, - gross per month in the last year.
Interested candidates are invited to send, by email, a motivation letter, curriculum vitae (including references) and a list of BSc and MSc courses and grades to Prof. Dr. Ir. Kitty Nijmeijer (d.c.nijmeijer@utwente.nl; phone: +31 53 489 4185).

Dynamic gel-layer membranes for (waste) water filtration

Wetsus, the research groups Environmental Technology of Wageningen University and the research group Membrane Science and Technology of the University of Twente have a vacancy for a PhD position.

Ph.D. position: "Dynamic gel-layer membranes for (waste) water filtration" (location: TTIW Wetsus, Leeuwarden, NL)

Separation of particles is very important in (waste)water treatment. Particle separation by micro- and ultrafiltration (MF and UF) offers the advantage that 100% separation efficiency can be achieved. However, these membranes are expensive (typically 50-100 €/m2) and suffer from fouling. This proposal aims to develop an alternative by using a cheap supporting material for a dynamic gel-layer, which acts as the actual separation layer for small (colloid sized) particles (alternative for MF/UF membranes), and later on also for removal of specific dissolved substances (alternative for NF/RO membranes). The project involves membrane design and development, characterization and application. Due to (biological) degradation, fouling, compaction or other mechanisms, performance of the gel-layer will deteriorate in time. To address this aspect, also long term stability and removal and replacement mechanisms will be investigated. For more NF or even RO related applications it is possible to embed specific constituents in the gel layers that selectively remove e.g. organic micropollutants or specific ions. Additionally, to evaluate membrane performance under real conditions, larger scale experiments with realistic waste waters will be performed.

The research will be conducted at Wetsus in Leeuwarden (www.wetsus.nl), NL under the supervision of the research groups Environmental Technology of Wageningen University (http://www.wageningenur.nl/en/Expertise-Services/Chair-groups/Agrotechnology-and-Food-Sciences/Subdepartment-of-Environmental-Technology.htm) and the research group Membrane Science and Technology of the University of Twente (www.utwente.nl/tnw/mtg). Wetsus, centre of excellence for sustainable water technology, is a facilitating intermediary for frontier water research. The multidisciplinary collaboration between companies and universities from all over Europe in Wetsus results in innovations that contribute significantly to solutions for the global water problems. The sub-department of Environmental Technology of Wageningen University performs research in the field of Reusable Water, Renewable Energy and Recyclable Matter including soils and sediments. In cooperation with other research groups ETE addresses cleaner production issues and sustainable material chains. The Membrane Science & Technology group of the University of Twente is the only academic polymer membrane group in The Netherlands and internationally leading in the field of membranes for Energy and Water Applications. Research ranges from molecule to process and comprises the complete knowledge chain from membrane design and development, membrane characterization and application.

We are looking for highly motivated and enthusiastic researchers with an MSc degree in chemical engineering, bioengineering or a related topic, with excellent experimental and theoretical skills and an affinity for (micro)biological processes.

We prefer candidates with a good team spirit, who like to work in an internationally oriented environment. Fluency in English is a requirement. An interview and a scientific presentation will be part of the selection procedure.

We offer you a PhD position for 4 years. Your starting salary will be € 2083, - gross per month in the first year and up to € 2664, - gross per month in the last year.

Interested candidates are invited to send, by email, a motivation letter, curriculum vitae (including references) and a list of BSc and MSc courses and grades to Dr. Hardy Temmink (hardy.temmink@wur.nl; phone: +31 317 484 805; Wageningen University) or Dr. Ir. Antoine Kemperman (a.j.b.kemperman@utwente.nl; phone: +31 53 489 2956; University of Twente).

Follow MST on Facebook!

Interested in the latest news of our Membrane Science and Technology group? Follow us and like us on Facebook (www.facebook.com/membranetechnology). There you will find all our most recent publications, PhD defenses, and MSC colloquia, as well as the more social aspects of our group. Enjoy!

Membrane Science and Technology

Vision

The research group Membrane Science and Technology of the University of Twente, headed by Prof. Kitty Nijmeijer, focuses on the multidisciplinary topic of polymer membranes to control mass transfer through interfaces.

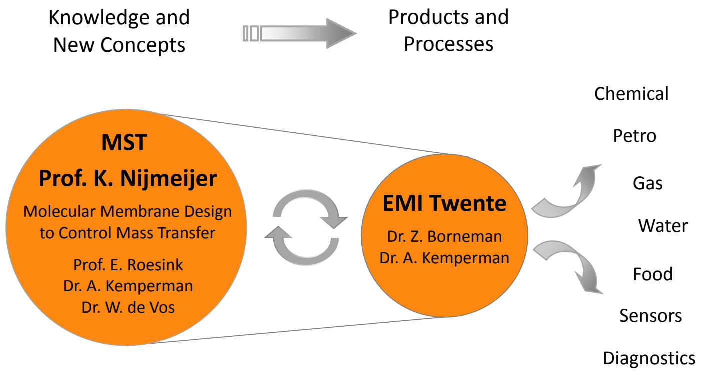

Figure 1 - Organizational structure research group.

The group consists of two separate entities (Figure 1): the academic research group Membrane Science and Technology (MST) and the European Membrane Institute Twente (EMI), which performs confidential research directly with the industry.

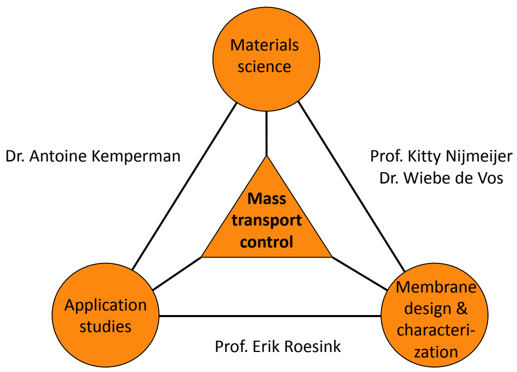

Figure 2 - Membrane Science & Technology.

Research within the group is dedicated to the design, development, characterization and application of polymer membranes for Energy, Water and Life Sciences. We aim at tailoring membrane design, morphology and characteristics on a molecular level to control mass transport in applications (Figure 2). More specifically, our research focuses on the separation of molecular mixtures and achieving selective mass transport. We consider our expertise as a multidisciplinary knowledge chain ranging from molecular design towards process applications.

Most of our research is dedicated towards specific applications. We distinguish three main application clusters, i.e. Energy, Water and Life Sciences (Figure 3).

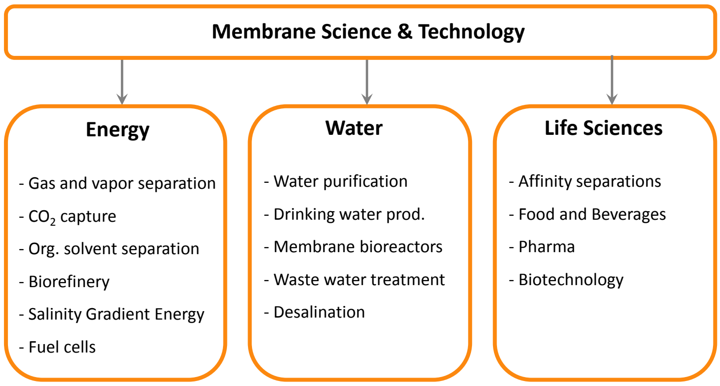

Figure 3 - Major application clusters Membrane Science & Technology.

Energy

The research cluster Energy is dedicated to the molecular design and synthesis of polymer membranes for e.g. gas and vapor separations (CO_2 capture, olefin/paraffin separation, water vapor removal), biorefinery applications, fuel cells and the generation of energy from the mixing of salt and fresh water ('salinity gradient energy' or Blue Energy). Relevant research aspects are control of structure-properties relationships, ultimate selectivity, molecular recognition, and separation of complex, multi-component mixtures.

Water

Within the application cluster Water, research addresses the development of membranes and the application of membrane technology for water treatment, e.g. water purification, desalination, membrane bioreactors and waste water treatment. In particular it investigates the relation between membrane design, morphology and membrane properties in relation to performance, selectivity and causes, consequences and control of fouling.

Life sciences

The cluster Life Sciences focuses on the design of porous membranes to separate complex multicomponent mixtures in pharmaceutical, food, beverage and biotech applications. Important subjects are the tuning of the material properties and structure (e.g. pore morphology and porosity), the development of functional materials (e.g. affinity separations of biomolecules) and the creation of new and/or improved processes (e.g. faster processes, higher yields, less fouling). In addition, aspects related to process design and industrial implementation, such as scale-up of novel membrane fabrication methods, are investigated. The research group consists of 30-35 people among which approximately 15-20 Ph.D. students, three permanent researchers, five B.Sc. and M.Sc. students and five academic staff members. Next to the head of the group, Prof. Kitty Nijmeijer, the staff consists of Prof. Erik Roesink, Dr. Wiebe de Vos, Dr. Antoine Kemperman and Dr. Zandrie Borneman, who is responsible for the EMI Twente. Next to extensive, general knowledge on polymer membrane science and technology, each of the staff members has his/her own specific field of dedicated expertise (Table 1).

Table 1 - Specific expertise of the staff members of MST.

Name	Specific expertise
Prof. Kitty Nijmeijer	Membrane design and characterization, molecular selectivity, molecular recognition, dense membranes, Energy and Water
Prof. Erik Roesink	Membrane formation, porous systems, phase inversion, solvent-free membranes, biomimetic membranes, Water and Life Sciences
Dr. Antoine Kemperman	Causes, consequences, cleaning and control of membrane fouling, interactions at the interface, Water European Membrane Institute (EMI) Twente: Confidential contract research directly with the industry
Dr. Wiebe de Vos	Membrane surface science, surface modification, multilayers, polymer brushes, Water and Energy.
Dr. Zandrie Borneman	European Membrane Institute (EMI) Twente: Confidential contract research directly with the industry

Knowledge valorization

Our group has decided to establish a significant effort in the valorization of its knowledge. The European Membrane Institute Twente (EMI Twente) was established in 1995 and performs confidential contract research directly with the industry and public organizations. Research is governed by questions from stakeholders. To guarantee confidentially, we work with highly skilled researchers with longstanding experience in membrane technology in our group. Students are not involved. EMI Twente creates, transfers and translates (fundamental) scientific knowledge into products, processes and applications. Projects can last from only a few days up to three years and can involve membrane development and synthesis, membrane characterization, and/or membrane application studies. The EMI Twente acts as the interface between the academic research and the industrial needs.

Services

The EMI Twente provides the following services:

- Membrane development
- Membrane characterization
- Membrane application studies
- Desktop studies
- Consultancy
- Selling of equipment (e.g. test cells for gas separation, UF and MF, casting knives, cloud point meters, hollow fiber spinning lines and spinnerets

More information

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MNT- Information

Membrane News Twente is published two times per year and aims to inform the membrane community about the activities of the Membrane Technology Group of the University of Twente (membrane@utwente.nl www.utwente.nl/tnw/mtg).

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