Summary Report

The 2nd Workshop on Innovation of Membrane Technology for Water and Wastewater Treatment (IMTEC Sapporo)

August 27-29, 2007
Gateaux Kingdom Sapporo, Japan

Drinking Water Session
Day1 (Monday 27 August)

Chairpersons:

Markus Boller, EAWAG
Hallvard Ødegaard, NTNU

Reporters:

Gary Amy, UNESCO-IHE
C. Visvanathan, AIT

09:20-10:20 Stefan Panglisch, IWW Rheinisch-Westfaelisches Institut fuer Wasser:

Current Research Acitivities at IWW, Germany – New Challenges for Drinking Water Treatment

Dr. S. Panglisch, made the opening presentation of this session. His presentation focused mainly on the issues related to the "New Challenges for Drinking Water Treatment". In his presentation, he emphasized on 2 major focus areas, namely: Basic Research on MF/UF Fouling Phenomena and Design of new processes and process combination in water treatment.

The major highlights and discussions related to this presentation were:

- Optimization of flocculation is very important in water filtration using MF/UF membranes;
- In order to characterize membrane fouling phenomena, there is a need to develop a standardized - particle/colloidal fractionation technique;
- Definition of colloids cut-off size by water experts is 0.45 um, while the colloidal scientists prefer to use IUPAC definition of 1 um;
- The reported aspect of rapid clogging observed in UF than MF, can not be generalized.
- In general, using ozone as part of the pre-treatment system, basically improved the backwashability of the membranes. However, there is an interest to investigate the

potential of using ozone gas as part of the backwashing process, and its effects, specially for the newly developed membrane based water treatment systems.

- A new technique for isolating large volumes/masses of colloids was presented and validated. The importance of both size and "reactivity" of different fractions was discussed.
- The adverse role of calcium in NOM fouling of MF/UF was demonstrated.
- The importance of both nominal pore size and pore size distribution was discussed.

10:20-11:20 Katsuki Kimura, Hokkaido University:

Physically Irreversible Fouling of Low Pressure Membranes used for Drinking Water Treatment

The second presentation entitled "Physically Irreversible Fouling of Low Pressure Membranes used for Drinking Water Treatment" was presented by Dr. Kimura. In his presentation, he discussed the aspects of total membrane resistance, as part of reversible and irreversible (R_{irr}) resistances. He concluded the importance of the physically irreversible fouling, which could be removed only by chemical cleaning. It was reported that conventional wisdom states that NOM-humic substances plays a significant role in creating this resistance. However, Dr. Kimura, reported not all NOM components cause R_{irr}, and maybe NOM might not play a significant role in creating this resistance. He reported, majority of the earlier studies, were conducted in flat sheet membranes, while, actual membrane units in water treatment uses HF modules. Plus, the synthetic humic substances used in these experiments, behave differently with the natural humic substances.

The major highlights and discussions related to this presentation were:

- Polysaccharides – PS are most important foulants in creating R_{irr}; followed by humic substances and proteins; there was some discussion on the lesser effect of proteins.
- Size of the PS is closer to the size of the membrane pores, which could lead to the pore plugging phenomena. However, there was a suggestion to re-consider this hypothesis, because PS are not necessarily spherical in shape, and its long chain structure could lead to the aspects of creation of "mesh" on the pore openings.
- An AFM technique revealed that PS has a very high affinity towards the membrane surface, which could be a strong chemical reason for PS to attach to membrane surface through hydrogen bonding.
- Greater adhesion forces were found for PVDF than PES membranes, presumably due to the very electronegative fluorine component of PVDF.

- It was indicated that care should be taken in simple interpretation of FTIR spectra, and linking directly PS to membrane fouling mechanisms.
- Why the importance of the "proteinous" compounds are neglected in the R_{irr} discussion.
- Straining method could give better interpretation of importance and role of PS and protein in membrane fouling contribution.
- It is also important to look in to the structure of PS, and link that to membrane fouling issues, specially in water treatment;
- Is the NaOH based extraction of PS used in this study, is universally accepted? There is need to have a further in-depth discussion on this issue.

11:40-12:40 So-Ryong Chae, Hokkaido University:

Comparison of Fouling Characteristics of Two Poly-Vinylidene Fluoride Microfiltration Membranes with Different Structures in a Pilot-Scale Drinking Water Treatment System

Dr. So-Ryong Chae made an interesting and very detailed pilot scale water treatment experimental results related fouling characteristics of 2 different PVDF membranes with symmetric and asymmetric structures. This work reported the importance of pre-chlorination and associated Al, Fe, and Mn oxidation issues in membrane filtration systems. The paper focused on multi-component fouling involving both NOM and inorganics (e.g., Al, Fe, Mn, Ca, Si).

The major highlights and discussions related to this presentation were:

- It might be good to have a pre-chlorination prior to sand filtration, thus the oxidized Mn could be easily removed by sand filtration, than by membrane;
- The critical aspect of the reported research was the pore size of the thin layer used in the asymmetric membranes. By selecting appropriate pore size, the internal pore plugging aspects could be overcomed easily;
- The aspects of chlorine backwashing is not necessarily linked to inorganic fouling only. It is important to link this to the issue of formation of secondary "biofouling" formed within and on the surface on the membrane.
- A difference between symetric and assymetric membranes relates to "depth filtration" (symetric) versus "surface filtration" (assymetric).

14:00-15:00 Gary Amy, UNESCO-IHE

Natural Organic Matter (NOM) Fouling of Membranes: What We Know and What We Need to Know

The forth presentation of this session was made by Prof. Gary Amy, where he discussed the issues of "Understanding Organic Matter Fouling of Membranes". He discussed mainly low pressure (MF & UF) membrane operations, and linking the NOM and EfOM forms of fouling.

The major highlights and discussions related to this presentation were:

- Membrane properties do play a role in affecting fouling. However, soon after filtration operation, the membrane (pore size, MWCO, zeta potential, contact angle, etc), looses its properties, thus plays a very in-significant role in fouling;
- Bacterial peptidoglycan colloids (dead biomass) are the major sources of fouling; These colloids constitutes of mainly PS.
- Addition of Ca^{2+} could increase the fouling created by humic substances. Here change in zeta potential of humic substances/PS could play an important role, for the change in fouling characteristics.
- Various forms of fouling are reported in this workshop namely: physically reversible fouling, physically irreversible fouling; chemically reversible fouling ; physically reversible fouling with aging, etc… there is a need to standardize all these technical terms and its measurement techniques, thus research results could be compared.

15:00-16:00 Dick van der Kooij, KIWA:

Bioassays for Elucidation of Membrane Biofouling Processes

Prof. Dick van der Kooij of Kiwa Water Research presented the concept of "Bioassays for Elucidation of Membrane biofouling Processes". In his presentation, he indicated the multi-barrier concept in water treatment in The Netherlands. It is also interesting to note, that in Netherlands, no residual chlorine was maintained in the distribution systems, as the consumers do not prefer to use chlorinated water. Therefore, extensive biofiltration is applied in water treatment to reduce the AOC in the water to a low concentration (< 10 ug C/l), and developments of more reliable bioassay tests to microbial growth potential of water.

The major highlights and discussions related to this presentation were:

- about 40 % of fouling in RO operation is related to biofouling, which indicated the importance of developing proper pre-treatment in RO to handle this issue;
- ATP measurement and number of cells (micro-organism) count are interlinked;
- The biofilm is defined as the attached growth of micro-organisms, with viable growth of cells, determined with ATP analysis;
- Biofilm concentration in membrane systems can be measured with ATP analysis. Need to develop in-situ measurement technique to monitor biofilm in the membrane systems;
- NF membranes can remove AOC (90%)
- Antiscalants can potentially induce biofouling through either available carbon or overcoming P limitation.
- There was some discussion on the most appropriate measure to predict biofouling, Biofilm Formation Rate (BFR and/or AOC. This depends on whether measurements are made on-site (BFR) versus in a laboratory (AOC).
- There was also some discussion about the composition of biodegradable compounds as they affect AOC and BFR. This depends on "contact time", shorter in BFR (thus more rapidly available compounds) and longer in batch AOC (at least one week).

15:00-16:00 Mark Wiesner, Duke University

Nanomaterial-Based Advances in Membrane Technologies

Prof. Mark Wiesner made the last presentation of the day - Nanomaterial-based advances in membrane technologies. This talk focused on making membranes from nanomaterials including: (i) nano-composites and (ii) templating with nano-materials. Methods discussed included deposition and templating as well as ceramic membranes. Templated membranes can be created by nano-particle deposition, through ballistic or diffusive transport, with chemical association through favorable (sticky) or unfavorable interactions. An attribute of this tracking approach is the rigorous control of pore size. Ceramic membranes can be created with metal oxanes, e.g., ferroxane, through nanodeposits on a surface. Two potential applications were discussed: membrane distillation and fuel cells. In the former, one can attach functionalities to the ceramic material to modify important fundamental surface properties (e.g., hydrophobicity); one example discussed was C-60-fullerenes. Overall, there are many new possible applications of nanomaterial-based membranes in passive diffusion or active transport as well as the possibility nanomaterial membrane reactors.

Wastewater Session

Day 2 (Tuesday 28 August)

Chairpersons:

Kazuo Yamamoto, University of Tokyo
Say-Leong Ong, NUS

Reporters:

Satoshi Okabe,
Hokkaido University
Guang-Hao Chen, HKUST

09:30-10:30 Xia Huang, Tsinghua University

Evaluation of oxidant used for decreasing the fouling potential of mixed liquor in membrane bioreactor

This paper reported a lab-scale trial of dosing ozone to abate membrane fouling in MBR. A membrane filtration setup (hollow-fiber membrane, 3 L) was employed to examine filtration ability of the mixed liquor after exposed to ozone and H2O2 at low dosages (~0.1 g O_3/g-SS and ~1 g H_2O_2/g-SS).

Both oxidants eased the MBR fouling. It was found that part of extra-cellular polymeric substances was removed, while floc size increased and viscosity decreased. The author further conducted a continuous-flow test of MBR with intermittent dosing of ozone at 0.25 mg/g-SS/day for 20 min once 1-2 days. The continuous-flow test clearly confirmed that dosing ozone improved

the fouling control. The author also concluded that the method could be expensive than coagulation-based pretreatment.

Prof. Magara raised question about the impact of the pretreatment with coagulation on the effluent quality for reuse and recycling. The presenter agreed. Prof. Watanabe commented that the pretreatment with coagulants can also reduce F/M ratio, leading to small flocs and low viscosity, thus remedying the fouling. The presenter argued with different purposes and methods for her study. It seems that some more discussions are needed. Prof. Lee C.H. suggested the presenter to further differentiate the EPS fractions in terms of soluble and bounded portions.

10:30-11:30 How Yong Ng, NUS

Influence of Membrane Material on Performance of a Submerged MBR by Ng HY, NUS.

The study was conducted with three different membranes with same pore size (01. micrometer): PTFE, PCTE, PETE. The three modules were immersed in the same reactor.

The main findings are: 1) porous membrane performed better than track-etched membrane in terms of pure water permeability; 2) a low flux is important to sustain a better performance of MBR; 3) after chemical cleanings, both hydrophobicity and membrane surface charge were increased but in a long run they could not be so important. The presenter further reported his other studies on FO, fuel cell, CFD in RO application, and Ferritin membrane and etc.

Dr. Kurihara commented that it is too hard to make FO although the idea has been talked about for 40 years. He also asked for a clear explanation of the hydraulics involved in the feed distribution during RO operation. Dr. Ng explained a large flow with high push could be better to create a suitable flow distribution.

Dr. van der Kooij asked about the pore connectivity and measurement of the contact angle inside the pore. Dr. Ng replied that appropriate methods need to be developed. Prof. Yamamoto pointed out that the permeate ability should be related to the filtration resistance. Dr. Ng replied that the permeate ability in his study should refer to a PWP measured at the end of operation, which is thus different from the definition of conventional permeate ability. Prof. Yamamoto further pointed out that the contribution of the cake layer in the filtration resistance could be more important than the material filtration resistance. Prof. Roger also commented that PWP could not be suitable for MBR application. Prof. Huang questioned the critical flux. Dr. Ng replied that the MBR operation did not involve such a critical flux.

14:00-15:00 Chung Hak Lee, Seoul National University

Biofouling and Biofilm Architecture in MBRs

He presented his recent fundamental research results dealing with biofouling and biofilm architecture in MBRs. First, he summarized current market, trend, and limitations of MBRs in Korea. There are presently 1,800 MBR plants in Korea. He also showed his research approach to solve these problems related to MBRs, he was emphasizing to combine BT (biotechnology), IT(image analysis), ET(environmental technology), and NT(nanotechnology). His presentation was mainly related to control of biofouling in MBRs. He has used several recent powerful analytical tools to characterize biofilm attached on membrane surfaces (he called "Bio-cake). He demonstrated the impact of formation and architecture of Bio-cake on membrane performance.

Several questions

1. In general, is physical cleaning good enough to remove bio-cake? If so bio-cake formation is not so important ? Physically irreversible fouling is more important than bio-cake? Bio-cake includes both reversible and irreversible fouling. Furthermore physical cleaning demands energy consumption which is one of drawbacks of MBR compared with a conventional activated sludge process. So prevention or mitigation of bio-cake formation is very important.
2. Structure of bio-cake is depending upon EPS and cells.
3. What is limiting in the deeper part of biofilms, which promote EPS production? Oxygen as well as substrate is most likely limiting.
4. Bio-cake formation is also depending upon pore size or surface roughness? Yes.

15:00-16:00 Jaap van der Graaf, TU Delft

Direct Ultrafiltration of Municipal Wastewater
Dead-end Ultrafiltration of WWWTP Effluent
The Delft Filtration Characterisation Method

He presented the contribution of TU-Delft to the development of the novel concept " direct ultrafiltration of municipal wastewater". The direct membrane filtration has great potential with regard to water recycling and sanitation because of production of bacteria-free filtrate in one single step. The presentation focused on the influence of operating conditions (TMP and crossflow velocity) and pretreatment (primary sedimentation and coagulation) on fouling

characteristics. He also presented the results of fundamental analyses of the permeate characteristics.
He concluded that the process is technologically feasible with sustainable fluxes, which indicates the application is virtually economically reasonable. The cost of water extraction is below 0.30 Eurocents per m3.

Several questions as below:

1. Why is P-removal rate so low ? Usually, P is associated with particles.
2. It is important to remove pathogens (bacteria, protozoa, and maybe viruses) but simultaneously to leave nutrients (P and N) for irrigation.
3. UFis suitable for direct membrane filtration of municipal wastewater?