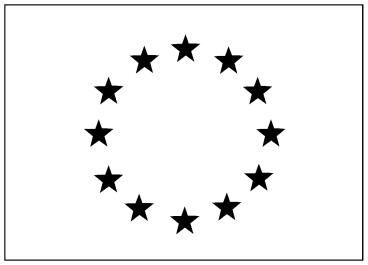

IMPROVED ENERGY EFFICIENCY IN MEMBRANE PROCESSES -WATER DESALINATION AND PURIFICATION

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ABSTRACT

Membrane processes such as Microfiltration, Ultrafiltraion, Nanofiltration and Reverse-Osmosis are relatively new technologies in water treatment and considered as single process, these technologies are limited in their application to a wide variety of source waters because of membrane fouling. To face with these major challenges, a project on membrane technologies was undertaken in the framework of the Non Nuclear Energy programme JOULE III funded by the European Commission.

The primary objective of this project was to increase the applicability of membrane processes for a variety of feed waters and therefore to develop methods to improve design and operation of membrane water-treatment facilities. This project has included the development of advanced feed pretreatment facilities based on the use of an ultrafiltration membrane pretreatment process, the development of improved fouling control techniques based on dosage of anti-scalants and, the development of criteria for selecting optimal pretreatment facilities depending on the types of raw water and membrane.

Results of this project showed that the selection of optimal pretreatment is based on a good definition of the water composition and the treatment objectives (RO feed for example). The water analyses are the primary tool in the complex task of estimating the raw water-fouling propensity. It should be stressed that collection of information on the nature and concentration of contaminants in the raw water is an essential first step in the selection of pretreatment scheme but is by no means sufficient for characterising the rate and severity of the anticipated fouling. Several novel laboratory techniques have been developed for coping with various scaling categories.

Also, the product usage may play a role in the determination of the type of pre-treatment. Finally, operation and capital costs also contribute to the selection of pretreatment. These costs concern the pretreatment and also the impact of the pretreatment on the RO systems.

Keywords: Membrane processes, desalination, purification, fouling, scaling

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PROJECT OBJECTIVES

The most advanced and promising processes in water desalination and purification involve the use of membranes, with various performance characteristics determined mainly by the size of species separated. These processes, which include Reverse Osmosis (RO), Nanofiltration (NF), Ultrafiltration (UF) and Microfiltration (MF) have a potential for tremendous energy savings and overall cost effectiveness. For example, the specific work energy requirement for a moderate salinity RO brackish water desalination plant can be approximately 25% of that required in a single purpose thermal desalination process and the unit cost of water produced in a RO facility can be approximately 30 % of that for a thermal desalination plant. However, considered as single processes for treatment, membrane technologies have been limited in their application to a wide variety of source waters because of membrane fouling. To get full advantage of these benefits, the membrane performance must be protected against rapid degradation (mainly due to fouling), thus avoiding either frequent and expensive membrane cleaning, or costly replacement. Thus, the need for further investigation into pretreatment processes for membranes to retard/prevent fouling has been a recent area of increased interest to the water industry.

Therefore, the objective of the project was to develop methods to improve design and operation of membrane water-treatment facilities (UF, MF, NF, RO), coping successfully with fouling for various feed waters.

This was achieved by the development of advanced feed pretreatment facilities based on the use of an ultrafiltration membrane pretreatment process, the development of improved fouling control techniques based on dosage of anti-scalants and, the development of criteria for selecting optimal pretreatment facilities depending on the types of raw water and membrane.

To achieve the above general objective, the following technical targets were:

- Development of advanced feed pretreatment facilities based on the use of a UF pretreatment process alone or coupled with an additional pretreatment step, such as a load relieving dynamic membrane process.
- Development of improved fouling control techniques (for specific types of membranes) based on dosage of anti-scalants and optimisation of operating conditions.
- Development of guidelines for selecting optimal pretreatment facilities depending on the type of raw water.

TECHNICAL DESCRIPTION

The approach adopted for pursuing the above objectives was by performing the following tasks by joint efforts of partner teams, organised according to their respective expertise.

1. Laboratory Investigations. The main objectives on membrane colloidal and organic fouling was to clarify the main factors involved in colloidal and organic membrane fouling, through laboratory experiments. Therefore, study on membrane scaling including antiscalant testing was carried out in order to develop and test laboratory techniques that could greatly simplify laborious field efforts by providing reliable guiding data. A point of major importance is the reliability of the simplified laboratory techniques developed in this project in predicting scaling propensity and anti-scalant effectiveness of a real plant. In the framework of this task, it was investigated the possible benefit of integrating dynamic membranes (DM) in RO pre-treatment processes using UF/MF membranes for removing organic foulants of polluted surface waters, thereby relieving the fouling load of the more expensive UF/MF units. The benefits of DM lie in the possibility to form them in situ by simple processes and that, once a membrane is too severely fouled, the layer can be removed and a new layer deposited on the same porous support.

2. Pilot Scale Tests. The overall objective of this task was to evaluate Ultrafiltration (UF) and Coupled Membrane Separation Processes on a variety of raw water sources through out pilot testing. The use of integrated membrane processes for water treatment of various sources is a relatively new concept in the water industry, which has traditionally matched a single type of membrane process for removal of a specific type of compounds. Within the research framework, many long-term experiments on UF and coupled membrane processes were carried out. These experiments covered broadly the following investigation issues: the raw water type, the pilot-plant configuration, the type of UF and/or RO membranes and the antiscaling methods. The three water sources employed during this study were:
    - Low-salinity surface water from the Seine River in France
    - Brackish polluted water from the Nahal Taninim River in Israel
    - Sea water from the Atlantic ocean in Fuerteventura, Canary islands

3. Development of Standard Characterisation Methods. This task consists to define the preliminary information required to design a membrane system. The objective of this activity was to help to better define the real conditions under which these characterisation methods will be applied, as well as the desired flexibility of pretreatment processes. Recommendations and possible improvements were made.

4. Formulation of Criteria for Pretreatment Selection Performances. This task provides a guideline for utility personnel on optimal pretreatment in terms of hydraulic performances for membrane operation using the data collected the previous tasks.

5. Recommendation and dissemination. The objectives was to carry out a critical appraisal of the results obtained and provide recommendations on pretreatment selection, characterisation methods and fouling mitigation measures. This activity is aimed at

providing concise recommendations on the potential of advanced membrane processes for pretreating a wide variety of waters in terms of source and pollution load, on the potential of new mitigation methods such as dynamic membranes, on the adequacy of characterisation methods, and on the potential of the recycle technique for reliable characterisation of raw waters and the efficiency of antiscalants.

RESULTS AND CONCLUSIONS

Criteria for selection and design membrane process for fouling water treatment

Result owners: Lyonnaise des Eaux, Mekorot, AGBAR

Foreground information coming from the pilot testing are the criteria for the design and operation of membrane processes for high fouling waters. Result provides information about the capabilities of several types of membranes and membrane processes, particularly as pertains to combined systems, so that they may be able to make more informed decision about selecting the technology without requiring extensive pilot testing efforts. These criteria concerns all the information requested from the set-up of membrane processes from the hydraulic purpose to water quality objectives considering the economical aspects.

Studies by partners suggest that optimised design and operation of seawater desalination can lead to reduced specific energy consumption (to ~4 kWh/m^3) with a total water cost ~0.5 EURO/m^3. Regarding problematic water sources, such as polluted river and brackish waters, and the effluent from municipal treatment plants, the results indicate a cost figure of approx. 0.4 EURO/m^3 but with a specific energy consumption of only ~1.5 kWh/m^3. Treatment of other types of water (not requiring desalination) may be even more energy and cost efficient (0.1 kWh/m^3, 0.25 EURO/m^3.

Novel processing trains promoted by this research were established in the treatment of such polluted feedwater to achieve:

- Maximum Product Safety; application of reliable technologies capable of removing biological hazards while minimising or avoiding the formation of dangerous disinfection by-products (e.g. THM) and of other hazardous chemical compounds.

- Cost Effectiveness; development of novel designs insuring high water recovery under modest energy expenditure; selection of appropriate pre-treatment methods in connection with near-optimum overall process conditions is necessary to mitigate fouling and scaling problems thus improving process efficiency.

- Environmental Friendliness; pretreatment methods to remove hazardous compounds and to mitigate fouling/scaling should be implemented with the minimum of additives; RO desalination should be applied at reduced specific energy usage.

Laboratory techniques for assessing water recovery limitations and antiscalant effectiveness in RO purification of feed waters containing scaling species

Result owners: Technion and Lyonnaise des Eaux

Detection of a scaling threshold limit by flux decline measurements and evaluation of anti-scalant effectiveness by a recycle technique require precipitation of sufficient material on the membrane. An overriding consideration is, therefore, the inventory of scaling material in the recycling solution.

Four different laboratory techniques have being developed for characterisation of scaling propensity and anti-scalant effectiveness: a batch recycle technique, a once through technique and an intermittent recycle technique. The simplest technique is the batch recycle technique in which the onset of scaling is simply determined by detecting the water recovery level at which there is a sharp permeability decline. This technique is suitable for a relatively more soluble scaling species such as $CaSO_4$. With very sparingly soluble salts such as $CaCO_3$, the very low inventory of $CaCO_3$ forming species in the recycling solution cannot provide sufficient material to clog the membrane and enable convenient detection of scaling threshold limits in a practical laboratory system.

Two procedures were developed for overcoming the inventory limitation of sparingly soluble salts. In the once-through technique the membrane is continuously fed with water having a specified scaling potential. There are no inventory limitations at all and scale propensity at different levels of the scaling potential, without and with anti-scalants, can be readily evaluated by both the rate of permeability decline and the rate of scale precipitation. In the less demanding intermittent recycle technique, scaling propensity is characterised by evaluating scale deposition rates from changes in the composition of a recycling solution. The solution is periodically replenished to increasing super-saturation levels by adding fresh feed and bleeding permeate.

The above techniques determine an upper limit of the water recovery at which scale precipitation will occur immediately. A technique was also developed for determining the lower water recovery limit at which scaling is prevented or at least delayed for a long period of time. The technique is based on a fundamentally based method for correlating induction time measurements with the water recovery level.

Results leading to the development of improved fouling indices for RO feed waters

Result owner: CPERI

Experimental results covering a wide range of important parameters in membrane colloidal fouling have been obtained. Moreover, a review and evaluation of the literature on colloidal fouling and its modelling has been performed. Based on these, the improved understanding gained on the key factors, such as fluid shear, permeation flux and physicochemical interactions, has motivated an effort to develop better tools for assessing the colloidal fouling propensity of RO feed waters. Such improved testing equipment and procedures that will better simulate the hydrodynamic and physicochemical conditions prevailing in actual RO membrane operations are needed to overcome the drawbacks of the existing empirical fouling indices.

Test section for optical microscopy observations during membrane filtration

Result owner: CPERI

A special test section has been constructed which allows on line optical microscopic observations to be performed during membrane filtration or back-washing. The section is of a narrow channel configuration and employs flat sheet membrane pieces. Optical observations are conducted through a glass window that forms part of the channel. The pressure and hydrodynamic conditions cover practical microfiltration or ultrafiltration applications. Any type of polymeric MF or UF membrane can be employed. Such a test section is considered a useful tool for simulating membrane filtration applications and performing fundamental studies of membrane fouling since, in addition to membrane flux measurements, information about the development of fouling deposits is obtained.

EXPLOITATION PLANS AND ANTICIPATED BENEFITS

The present project brings together one of the largest and most experienced European water treatment companies (Lyonnaise des Eaux and AGBAR) with a water supply company renowned for its expertise in applying successfully advanced desalination technologies (Mekorot) and with well qualified academic researchers from prominent Institutes (CPERI and TECHNION). All participants are familiar with the increased need for water in their countries and abroad and are aware of the need for increasing the search for industrial means needed to solve the water shortage and pollution problems.

At the moment to prepare this publishable report, the following potential applications are identified:

- In December 1998, the new European Directive (ED) was published. The ED has reduced the number of parameters but has introduced more stringent regulations for the main parameters, which guarantee the quality and the potability of the water. This legislation requires to **implement more effective processes**, such as membrane filtration for the majority of **surface water treatment** facilities for the purpose of removing natural organic matter (NOM), the primary precursor to DBPs. Therefore, this study is able to provide regulators with information about the capabilities of several types of membranes and membrane processes, particularly as pertains to combined systems, so that they may be able to make more informed decision about approving the technology without requiring extensive pilot testing efforts.
- The need for drinking water of best quality and at lowest costs is confronting many countries and will no doubt preoccupy Europe in the not too distant future. Already there are pressing needs in Europe for better and cheaper techniques for **treating polluted water for reuse** at higher quality and at a lower energy consumption. Improvement in energy efficiency and cost will benefit water industries and communities all over the European Union and elsewhere in terms of water supply and quality, and environmental impact.
- The results of this study will provide an answer for utility personnel of **seawater treatment** plant concerning the interest of pretreatment to RO and the selection of appropriate chemicals to prevent/reduce RO fouling.

Successful completion of the proposed research lead to **improvements in the cost and energy efficiency** of water purification and desalination processes and increase the potential of reuse of resources that are presently untreatable. For cases where current conventional pretreatment technologies present a viable option reduction of cost is expected through the lower capital and operating cost of advanced pretreatment processes (due to energy efficiency, compactness, minimisation of chemical dosing), through better selection of antiscalants and novel fouling mitigation measures, and through the increased productivity and extension of RO membrane lifetime (due to better pretreated water quality).

Direct beneficiaries of this research program include public and private drinking water supply companies, water treatment companies, membrane and module manufacturers, as well as cleaning chemical and antiscalant manufacturers. The potential of exploiting currently untreatable water resources is likely to benefit a host of other industrial sectors, such as the

agricultural and food industry etc. Nevertheless, the need for drinking water of best quality and at lowest costs is confronting many countries and will no doubt preoccupy Europe in the not too distant future. Already there are pressing needs in Europe for better and cheaper techniques for treating polluted water for reuse at higher quality and at a lower energy consumption.

Industrial opportunities of exploiting advanced technologies are likely to occur in view of the highly optimistic forecasts for the growth of the membrane industries. The foreground information should concern a significant part of the approximately 10 Mm^3/d of RO produced water. Also, the contracted RO capacity world wide for the years 1996 and 1997 was 810.000 m^3/day and 910.000 m^3/day, respectively (Desalting Plants Inventory, Report N°15, Wangnick Consulting, June 1998). It is expected that the world market will continue to grow at a rate above 10%, due to the well-known shortages in many locations including many regions within the European Union. Indeed, according to some experts, when the exploitation rate exceeds 20% of the existing reserves, water management becomes a vital element in that country's economy. It is estimated that about 20-40% of the total additional desalination capacity in Israel, Jordan and the PNA could eventually be obtained from problematic brackish surface and municipal waste water, and by that will reduce both total cost and especially total energy consumption. In Israel alone, approximately 200 million kWh/year could be saved by replacing seawater desalination by the less energy intensive alternative of desalting the not yet exploited 50 million cubic meter per year polluted brackish water sources.

The interest of **integrated membrane processes** in the case of indirect potable reuse was also clearly identified by several huge bids for new facilities all around the world. For example, the Government of the State of Kuwait has decided to construct a wastewater treatment and reclamation plant at Sulaibiyia in the context of privatisation. To meet the water quality guideline, the water reuse train will include combined membrane processes for a total daily capacity of 300,000 m3/day. The city of San Diego is also looking for such treatment to face the water scarcity in the area. In conclusion, successful application of such integrated processes increase European competitiveness in terms of know-how and technology of commercial units marketed by European companies and also for bids such as BOT (build-operate-transfer).

Currently, laborious and time consuming field tests are considered to be the only reliable way for determining water recovery limitations in RO processes, arising from the scaling propensity of the feed water, and for assessing the relative effectiveness of various anti-scalants, used to extend the water recovery limits. There is a clear need for simple and yet reliable laboratory techniques for predicting field results or at least reducing the scope of field tests.

The economic impact of the scale characterisation techniques that have been developed in this project and made free available through open journal publications can take several forms:

1. The desalination industry may improve significantly their scale control efforts and enhance the limits of water recovery by better characterisation of scaling limitations.
2. Organisations providing laboratory services for water characterisation for RO operations could widen the scope of their services by adopting the laboratory techniques developed in this project.
3. Companies, which develop and market anti-scalants, may improve their R&D efforts for more effective anti-scalants by using the developed techniques to test their products.

All the studies carried out during this project, were published by the partners in sixteen papers:

Yiantsios S.G., A.J. Karabelas "The effect of colloid stability on membrane fouling" Desalination, v. 118, pp. 143-152, 1998

Glucina K., J.M. Laîné, L. Durand-Bourlier, "Assessment of filtration mode for ultrafiltration membrane process",. Desalination, Vol 118, 1998, pp. 205-213.

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Yiantsios S.G., A.J. Karabelas "Experimental studies on membrane fouling by colloidal particles" 2nd Panhellenic Congress in Chemical Engineering, Thessaloniki, Greece

Hasson D., R. Semiat, D. Bramson, M. Busch and B. Limoni-Relis, "Suppression of CaCO3 Scale Deposition by Anti-scalants", Desalination, Vol 118, 1998, pp. 285-296.

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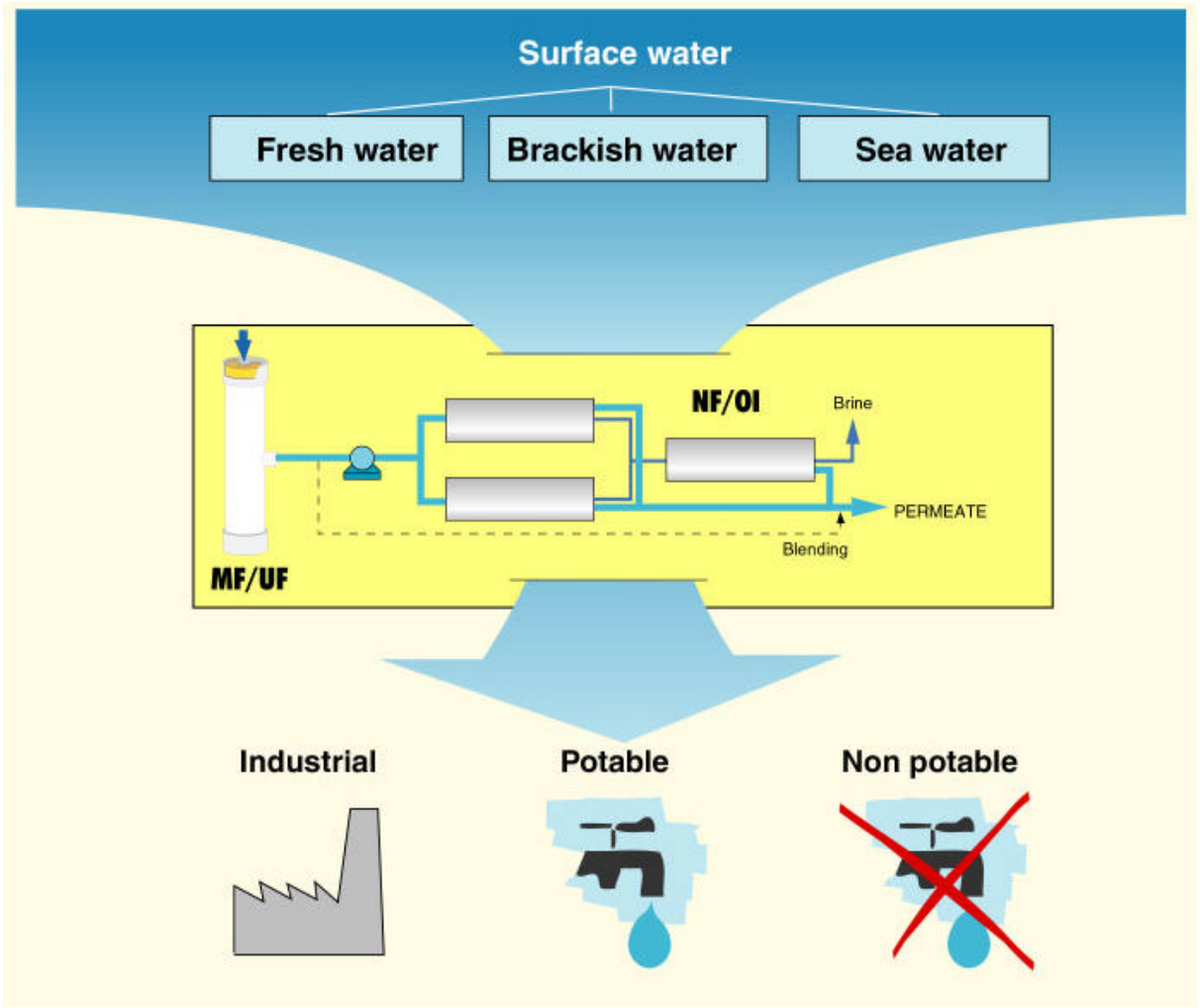
Glucina K., H. Alvarez, J.M. Laîné "Assessment of Integrated Membrane Systems for Surface Water Treatment", Desalination, 132 (2000) pp 73–81

Rumyantsev M., D. Hasson & R. Semia "Removal of humic acid from RO feed waters by dynamic membranes" to be submitted shortly to the J. Collo. Interf. Sc.

Glueckstern P., M. Priel "Experience, Capability and Plans for Erecting Large Seawater Desalination Plants", Large Seawater Desalination Projects – a Timely Solution to Israel's Pressing Water Needs, December 7, 1999 Israel Desalination Society

PHOTOGRAPH TO ILLUSTRATE POTENTIAL APPLICATIONS OF THE PROJECT



Application of combined membrane processes