MEDRC

R & D Projects

REQUEST FOR PROPOSALS

RFP 2009

Issued: January 2009

MIDDLE EAST DESALINATION RESEARCH CENTER

P.O. Box 21, Al Khuwair, P.C. 133, Muscat, Sultanate of Oman

Tel: (968) 24 415 500; Fax: (968) 24 415 541

Website: www.medrc.org

E-mail: projects@medrc.org.om

CONTENTS

INTRODUCTION AND BACKGROUND

The Middle East Desalination Research Center (MEDRC) is an international non-profit organization, based in Muscat, Oman. The purpose of the Center's research program is to conduct, support and coordinate basic and applied R&D in water desalination and supporting fields, with the overall objective to reduce the cost of desalination. The Center strives to identify appropriate projects, which can help in opening up new areas of research, contribute to the development of new processes or improve the existing technologies and make these processes technically more efficient, implementable, reliable, environmentally friendly and sustainable, and also to collect reference materials in desalination useful not only in learning the current status of that topic, but also to identify the areas that require further research or development and to develop appropriate strategies.

Other program components with a focus on the Middle East and North Africa (MENA) region are devoted to the objectives of capacity building in research and in desalination practice, as well as to technical communication and assistance. In this context the Center is giving priority to research proposals that contain scholarship component. The Center is also seeking to become a source of reference for information and working materials in desalination by developing design tools, software packages etc. The Center is thus giving priority to projects that comprise the development of software packages for design and simulation of desalination processes. Almost everyone engaged in desalination has the need for access to systematic information, which in other technologies, would be collected in comprehensive handbooks and data banks. This applies to researchers, plant and equipment manufacturers, consultants, plant operators, planners and decision makers, students and beginners.

The background, objectives, practices and activities of MEDRC are summarized in the Center's "Program Framework and Profile".

The Center RFPs are based on the recommendations of the Center's Research Advisory Council (RAC) - a group of around 20 experts from around the world, suggestions from members of the Project Advisory Committees and from Technical Representatives of the member countries. It also includes the feedback from many individual researchers and other partners of the Center, and the result of the experience gained in eleven years of organizing and monitoring the Center's research program.

The RFP addresses all individuals, institutions and companies, worldwide, engaged in the different fields of desalination practice, in desalination R&D, in academic teaching or in practical training.

The Center budget for this RFP is in the order of US$ 500,000.

RESEARCH PROJECTS

The titles of research topics covered by this RFP are listed in the **Table of Topics, Annex A**. This table is grouped into the following **Topic Areas**:

(TP) Thermal Processes
(MP) Membrane Processes
(NT) Non-traditional or Alternative Processes
(OM) Operation and Maintenance Issues
(IO) Intakes and Outfalls
(EG) Energy Issues
(EV) Environment Issues
(HP) Hybrid Desalination Processes
(CP) Certification Programs
(AS) Assessment Studies
(SP) Software Packages

The outlines of some of the prioritized projects are given in **Annex B** with different degrees of detail. As a general policy, the Center assumes that the proposing experts know best what tasks and approaches will most effectively contribute to advances in desalination and serve the objectives of the research program. Only a few projects, which need directions, are specified in more detail.

Whereas proposals for all listed topics will be considered, the Center has given them different levels of priority, marked in the table as **Type A, B or C** within the brackets in the project title number, representing the following:

Type **A**: Higher priority projects, considered to fit particularly well into the current research program or to fill a gap in a series of related projects.

Type **B**: Lower priority projects at the present time. However, the Center will accept proposals (preferably as a pre-proposal first) for projects that are exceptionally attractive through importance and quality, or by value of a cooperation scheme, or for the creation of reference materials, or utilizing a special opportunity for a project.

Type **C**: Topics of currently on-going and completed projects. The Center will consider proposals if they suitably supplement these projects or approach the topic with a different, attractive objective. Proposals, preferably as pre-proposal first, should be submitted by new project teams. The reports of the completed projects are available on the Center's web site under "R&D/final reports" and the objectives and the tasks of the on-going projects are included in Annex B.

Self-specified, unsolicited proposals:

The Center also encourages the submission of research proposals for projects other than those specified in the Table of Topics, Annex A. The proposed project must relate to desalination technology or its fundamentals and show merit and value in the context of the research program. Pre-proposals should also be submitted for this type of projects. The requirements, guidelines and evaluation procedures for the unsolicited proposals are the same as for solicited proposals, as described below.

FUNDING ESSENTIALS

Scholarship component proposals

Project proposals with scholarship component (M. Sc. / Ph.D. student from MENA region) will be given high priority since they contribute to the capacity building in the MENA region. The student and the supervisor together submit a research proposal. The research proposals will be dealt with according to the Center procedure for funding regular research projects. Preference will be given to high performance students who obtain tuition waiver from the intended university.

Application in industry

Results of the proposed project that find immediate application in the desalination industry will also be given high priority. The project title can be from the list of prioritized projects in Annex A, or self specified.

Partnership in Research

The Center places a high priority on the formation of research partnerships. The research team must include at least one member from an organization or institution in the MENA region. A long-term objective of the Center is to stimulate capacity building for research in desalination within the region. Further, the Center seeks to supplement and complement the work of the existing organizations and institutions within the region. Proposals that present well-balanced and effective regional partnerships will be encouraged.

If, in the stage of submitting a pre-proposal, the applicant requires assistance in finding a research partner, the Center may be able to help in forming cooperation. The pre-proposal should briefly specify the tasks proposed for the partners.

The requirement of forming research partnership can be exempted for projects dealing with data banks, specific reference materials, or with capacity building.

Cost Sharing

The applicant is expected to provide for cost sharing at least 50 percent of the total cost of the project. Any higher cost sharing will be acknowledged accordingly in the evaluation of a proposal. The cost share component may consist of cash and/or in-kind contributions from the applicant's institution, from donors or from other R&D funding organizations. In-kind contributions can include labor, materials, rent of facilities and equipment, or other similar contributions at their realistic, fair market value.

In specific types of projects, identified as such in this RFP, the Center may consider granting more than 50% of the project costs.

Contracting agreement

Standardized project funding agreement is available on the Center's web site as downloadable document. The Center advises the applicant to go through the terms and conditions of the contract agreement before submitting his pre-proposal.

The Center signs the contracting agreement only with registered institutions and not with individuals.

Creation of Reference Materials

It is the policy of the Center to demand in every project a component that will serve as an advanced source of reference on the topic under investigation. This can be a comprehensive literature survey, review and evaluation. It can also provide other materials of reference that are of value to someone already working or initiating work in the subject area: for instance a comprehensive presentation of design and calculation tools, simulation software packages, an assessment of solutions to a certain problem, or a systematic collection of specific data relevant to the topic under investigation. This contribution is expected to comprise a separate chapter of the final report and should be clearly identified in the proposal.

Intellectual Property

The researcher's intellectual property rights are firmly protected by the Center's research contract in accordance with international law. Patent rights remain with the researcher unless he/she transfers these rights to the Center. The final report of Center funded projects will be published for the benefit of the desalination community. The Center's Technology Management Plan covers all these aspects. It is included in the Guidelines for the Preparation of Proposals.

BUDGET

The total budget of the project should be proportional to the proposed scope of work in the project. The proposal is required to clearly specify the cost components like personnel, equipment, travel etc., and they must be reasonable and realistic. In the proposal review process, the Project Advisory Committee will assess the value and work of the project against the proposed budget.

Since the Center aims to sponsor a greater number of projects with limited budget, maximum contribution of Center's funds in any project will be limited to around US$ 100,000. The MEDRC funds will not completely compensate for researchers time and it is mostly covered under in-kind contributions. In scholarship component projects, living expenses of the student will be completely covered. Thesis supervisor is not eligible for compensation of time spent on supervising the thesis. The Center will not provide funding for building pilot plants, developing general facilities in the laboratories and buying laptops. Only expenses for updating the existing experimental facility (small budget), building small bench scale units, chemicals etc. for conducting research will be provided. Minimum budget is allowed for travel; it is expected that the coordination between the project partners be carried out through communications. The Center's **Guidelines for the Preparation of Proposals** provides details for the presentation of the budget.

Where appropriate, the investigator may suggest that a project be carried out in two phases. The award of successive phases will be at the discretion of the Center.

PRE-PROPOSALS

The Center recognizes that the submission and processing of a full proposal requires considerable commitment of resources and time both on behalf of the applicant and the Center. In order to optimize efforts and time, and to improve the quality of the proposal, the Center encourages the applicant to first submit a pre-proposal for review and comment by the Center, prior to submitting a full formal proposal. A pre-proposal is expected to be less than five pages. It should cover the following:

- project objectives,
- a brief description of the project,
- why the work is important, any novelty,
- identification of the team to work on the project (not mandatory at this stage),
- the main work packages,
- the essentials of an approximate budget.

A CV of the principal investigator and CV of student in scholarship component projects, not more than 3 pages, should be included as an annex.

On the basis of the pre-proposal, the Center with the help of Project Advisory Committee (PAC) members, decide on whether it will accept a full proposal or not. If a full proposal is encouraged, the Center's comments may comprise suggestions such as to include or exclude certain work items, to consider or build on results of previous projects, to consider participation of a certain institution as partner, to adjust the funding requirements, to consider separating a project into two phases, etc. For reasons pertaining to the program policy or the research budget, the Center may also request the full proposal to be submitted at a later date.

The Center's comments on the pre-proposals are purely advisory and will in no way commit the Center to funding the project. The decision whether or not a project is awarded funding will be made entirely on the basis of the formal full proposal.

Pre-proposals are generally evaluated internally by the Center. In some cases, however, the Center may solicit the advice from external experts.

FULL PROPOSALS

Details for the preparation of a full formal proposal together with the regulations and procedures for awarding projects are given in the **Guidelines for the Preparation of a Research Proposal**. This document can be downloaded from the Center's web site, **www.medrc.org**. Alternatively, on request this information can be sent to the proposer in paper format or on a diskette. Low budget project pre-proposals or project pre-proposal dealing, for instance, with the development of a data bank, design tools or other materials for technical reference or training, the Center may advise a simplification of the proposal procedures and contractual conditions.

The full formal proposals are evaluated by the Center and an external PAC of two or three experts in that field. All PAC members are bound by a Confidentiality Agreement with the Center.

The Center reserves the right, in its sole discretion, to award or not award to any contractor under the terms of the RFP.

THERE ARE NO DEADLINES FOR SUBMISSION

Pre-Proposal and Full Proposals may be submitted at any time during this year.

Pre-proposals and proposals preferably be submitted by E-mail to:

projects@medrc.org.om

or in paper format or on diskette, sent to:

Via Mail: The Middle East Desalination Research Center
P.O. Box 21, Al Khuwair
Postal Code 133, Sultanate of Oman

Via Courier: The Middle East Desalination Research Center
Building 3200
North Al-Hail Corniche
Muscat, Sultanate of Oman
(Tel. +968-24 415 541)

Pre-proposals and full proposals should be written with the software "Microsoft Word" for text and "Excel" for spread sheets

MEDRC INFORMATION MATERIAL

The following documents are available from the Center and can be sent on request in paper format or diskette.

Alternatively they can be downloaded from the Center web site.
The Center's home page is **www.medrc.org**

- Guidelines for the Preparation of Research Proposals
- Guidelines for the Preparation of Project Reports
- Guidelines for the Preparation of Progress Reports
- Standard contract agreement
- [This document]
- Research Reports of completed projects
- MEDRC Program Framework and Profile
- MENA University and Research Institutes Directory
- PRIME
- RAC Directory
- PAC Directory
- The latest MEDRC Newsletter

Annex A

TABLE OF TOPICS

S. No.	(Priority)	Title	Center Budget / Project Duration
THERMAL PROCESSES			
1. Multi Stage Flash			
TP-1.1	(A)	Simplification of MSF plant design, including study of once through approach	($50,000 / 1 year)
TP-1.2	(A)	Life extension and upgrading of existing MSF plants	($50,000/1 year)
TP-1.3	(B)	Standardized data collection on existing MSF plants	
TP-1.4	(A)	Nanofiltration process to increase top brine temperature – Demonstration in Al Ghubra MSF plant, Oman	($40,000/1 year)
TP-1.5	(A)	MSF vapor compression	($30,000/1 year)
TP-1.6	(C)	Computational fluid dynamics simulation of MSF condensers: Non-condensable gas effects and design optimization *[On-going project]*	
TP-1.7	(A)	New demister concepts	($50,000/1 year)
TP-1.8	(C)	Performance evaluation and optimization of the Barka MSF desalination plant *[On-going project]*	
TP-1.9	(C)	Reliability modeling and analysis of desalination plant *[On-going project]*	
2. Multi Effect Distillation			
TP-2.1	(A)	MED technology– the current status	($20,000/1 year)
TP-2.2	(A)	MED heat exchanger design improvements	($70,000/1 year)
TP-2.3	(C)	The release of CO_2 in Multiple-Effect Distillers [Completed project]	
3. Scaling and Fouling			
TP-3.1	(A)	Novel scale prevention techniques for thermal desalination	($80,000/ 1 year)
TP-3.2	(A)	New techniques to increase top brine temperature of distillation processes	($80,000 /1 year)
TP-3.3	(B)	Development of a transient fouling model for seawater desalination plants	

TP-3.4	(C)	Development of novel methods for the control and inhibition of scaling in thermal seawater desalination plants [*completed project*]	
4. Other Thermal Processes			
TP-4.1	(C)	Assessment of the innovative freezing / melting process for desalination of seawater [*Completed project*]	
5. General topics			
TP-5.1	(A)	Innovative heat exchanger concepts or design approaches	($50,000/1 year)
TP-5.2	(A)	Optimization of acid cleaning and Taprogge operation	($30,000/1 year)
TP-5.3	(C)	Novel material selection to improve corrosion resistance [*Completed project*]	
TP-5.4	(A)	Use of plastic materials in desalination processes	($30,000/1year)
TP-5.5	(B)	Potabilization of distillate with CO_2 from venting gases	
TP-5.6	(C)	Basic experimental studies of the CO_2 release in the carbonate system in seawater distillation [On-going project]	
MEMBRANE PROCESSES			
1. Understanding Fouling Mechanisms			
MP-1.1	(C)	Critical assessment of fouling indices [*Completed project*]	
MP-1.2	(B)	Development of universal fouling propensity device	
MP-1.3	(A)	Microbial attachment mechanisms	($20,000 /1 year)
MP-1.4	(A)	Surface chemistry modifications to avoid fouling	($70,000/1 year)
MP-1.5	(C)	Identification of critical flux and cross-flow conditions for control of bacterial and organic fouling of seawater RO membranes [*Completed project*]	
MP-1.6	(C)	Review of colloidal fouling in spiral wound Modules [*Completed project*]	

MP-1.7	(C)	Study of the formation and inhibition of silica scales in RO desalting [*Completed project*]	
MP-1.8	(C)	Study of the interactive effects of inorganic and biological fouling in RO desalination units [*On-going project*]	
MP-1.9	(C)	Application of molecular modeling to understand crystallization fouling and the interactive effects [*On-going project*]	
MP-1.10	(C)	Development of a novel approach to the prediction of Nano-filtration membranes performance using Advanced Atomic Force Microscopy (AFM) [*Completed project*]	
MP-1.11	(C)	Improvement of techniques for assessing RO membrane colloidal fouling [*Completed project*]	
MP-1.12	(C)	Preparation of thin film composite RO membrane with reduced fouling for seawater desalination [*On-going project*]	
MP-1.13	(C)	Development of particulate/colloidal fouling indicators in SWRO: Further development of MFI-UF concept [*On-going project*]	
MP-1.14	(C)	Optimization of the membrane sub-layer for development of RO membranes with improved fouling resistance [*On-going project*]	
MP-1.15	(C)	Toward Better Calcite Scaling Understanding in SWRO [*On-going project*]	
2. Pretreatment and Fouling Control			
MP-2.1	(A)	Membrane fouling; its control and removal	($70,000 /1 year)
MP-2.2	(A)	Improved pretreatment techniques, simplifications, alternative disinfectants and impact on RO design	($70,000 / 1 year)
MP-2.3	(A)	Nanofiltration for fouling control	($50,000 /1 year)
MP-2.4	(C)	Development of new technologies for the reduction of fouling and improvement of performance in SWRO systems [*Completed project*]	

MP-2.5	(C)	Combined macromolecular adsorption and coagulation for improving pre-treatment process in desalination plants [*Completed project*]	
MP-2.6	(C)	Novel seawater pre-treatment processes by sorption onto chemically modified bentonite coupled with Ultra-filtration operation in RO plants [*Pre-closed project*]	
MP-2.7	(C)	Minimize the use of chemicals in sea water Reverse Osmosis: Impact on scaling & concentrate disposal [*On-going project*]	
MP-2.8	(C)	Boron pre-treatment for seawater and brackish water desalination [*On-going project*]	
MP-2.9	(C)	Application of Solar Energy in RO Pre-Treatment Process - Phase I [*On-going project*]	
3. Advances in RO membranes and Modules			
MP-3.1	(A)	Advanced reverse osmosis membranes	($100,000/2 years)
MP-3.2	(C)	A novel method to permanently improve the rejection of RO desalination modules to significantly lower the cost of desalination [*Completed project*]	
4. Process and Plant Design			
MP-4.1	(B)	Improved design, including simplification of the reverse osmosis process	
MP-4.2	(B)	Development of reference design package for small and medium size reverse osmosis units	
MP-4.3	(B)	Optimization of HP energy system and train size in seawater RO plants (Large plants)	
MP-4.4	(B)	Material selection for HP piping in SWRO, including state of the art assessment	
MP-4.5	(B)	Design limits and performance projections for SWRO under fouling conditions	
MP-4.6	(A)	Investigating the residence time distribution in a membrane module in order to improve the module and gain better operational understanding	($50,000 /1 year)

MP-4.7	(A)	Using Particle Image Velocimetry (PIV) technique to investigate the flow next to the spacer between membranes in order to increase the turbulence without increasing the pressure drop	($50,000 /1 year)
MP-4.8	(C)	Computational fluid dynamics (CFD) studies for performance enhancement of spiral modules by modifying fluid flow behavior [*Completed project*]	
MP-4.9	(C)	Theoretical and experimental studies of flow through narrow channels with inserts towards membrane module performance optimization [*Completed project*]	
MP-4.10	(C)	New Desalinarion Process for Enhanced Recovery from Brackish Water System Utilizing Ultrasonic Reflectometry & Flow Reversal [*On-going project*]	
5. Other Membrane Separation Systems			
MP-5.1	(C)	A study of the state of the art, commercial potential, and prospects for advancement of desalination by membrane distillation [*Completed project*]	
MP-5.2	(C)	Design of novel membranes for desalination by direct contact membrane distillation [*Completed project*]	
MP-5.3	(C)	Development of polymer nano-fiber, micro-fiber and hollow-fiber membranes for desalination by membrane distillation [*On-going project*]	
6. General topics			
MP-6.1	(B)	Critical assessment of membrane operations for seawater and brackish water desalination; standardized data collection on existing RO plants	
MP-6.2	(B)	Standards (ISO) for membrane properties	
MP-6.3	(B)	Storage and recycle of used membranes	
MP-6.4	(A)	Cleaning of membranes	($50,000 / 1 year)
MP-6.5	(C)	Design and development of a small packaged RO system driven by a hybrid power supply system [*Pre-Closed project*]	

MP-6.6	(A)	Natural organic matter characterization in seawater around the Gulf and its relation to membrane fouling and pretreatment	($70,000 / 1 year)
MP-6.7	(B)	Optimization of novel IMS technology: New types of MF/UF + advanced RO/NF modules for pollutant surface water (including waste water) and for open intake seawater	
MP-6.8	(A)	Development of training program guidelines to develop a training course targeted at plant operators in the Middle East.	($30,000 / 1 year)
MP-6.9	(A)	State of the art of wastewater purification by advanced desalination techniques	($30,000 / 1 year)
MP-6.10	(C)	Study of the AMF hybrid process for removal of Boron from seawater [*Completed project*]	
MP-6.11	(C)	Evaluation of the performance of RO plants in Oman [*Completed project*]	
MP-6.12	(C)	Comparison of NF and RO processes for the treatment of brackish water feeds [*Completed project*]	
MP-6.13	(C)	An integrated membrane operation in desalination of sea and brackish water [*On-going project*]	
MP-6.14	(C)	Study of the AMF hybrid process for removal of Boron from RO pretreatment – Part 2: Evaluation of desorption circuit and advanced MF study [*On-going project*]	
NON-TRADITIONAL OR ALTERNATIVE PROCESSES			
NT-1	(A)	Innovative concepts	
NT-2	(C)	Small solar MED desalination plant [Completed project]	
NT-3	(C)	VARI-RO™ Solar powered desalting study [*Completed project*]	
NT-4	(C)	A comprehensive study of solar desalination with a humidification-dehumidification cycle [*Completed project*]	
NT-5	(C)	Small scale thermal water desalination systems using solar energy or waste heat [*Completed project*]	
NT-6	(C)	Hybrid Fossil/Solar heated Multi-Effect Still [*Completed project*]	

NT-7	(C)	Greenhouse – State of the art review and performance evaluation of dehumidifier [*Completed project*]	
NT-8	(C)	Seawater greenhouse development for Oman : Thermodynamic modeling and economic analysis [*Completed project*]	
NT-9	(C)	Development and analysis of the diffusion driven desalination process [On-going project]	
NT-10	(C)	Experimental and theoretical studies on integration of new PCM-based components in solar desalination [*On-going project*]	
NT-11	(C)	Development of a solar still desalination system with enhanced productivity [*On-going project*]	
OPERATION AND MAINTENANCE ISSUES			
OM-1	(C)	Automation and operation optimization to reduce water costs [*Completed project*]	
OM-2	(B)	Development of standardized form and content for O&M manuals	
OM-3	(A)	Preventive maintenance	($40,000 /1 year)
OM-4	(B)	Best practice for O&M organization to achieve highest level of reliability and availability	
OM-5	(B)	Comparison of design criteria versus operational performance	
INTAKES AND OUTFALLS			
IO-1	(B)	Hybrid intakes	
IO-2	(C)	Beach well intakes for small SWRO plants [*Completed project*]	
IO-3	(A)	Literature survey of intake / outfall systems for desalination of brackish and seawater – including designs and materials of construction	($40,000/6months)
IO-4	(A)	Survey of existing models and development of improved simulation for discharged brine dispersion	($30,000 / 1 year)

		ENERGY ISSUES	
EG-1	(B)	Large scale desalination using renewable energy	
EG-2	(C)	A study of a hybrid fuel cell / desalination systems [*Pre-closed project*]	
EG-3	(B)	Assessment of options and specific features of desalination plants coupled with nuclear power plant	
EG-4	(B)	Municipal solid waste energy utilization for desalination	
EG-5	(A)	Development of robust and energy efficient small desalination systems	($50,000 / 1 year)
EG-6	(C)	PV powered desalination: Matching technology options With market demand [*Completed project*]	
EG-7	(A)	Assessment of integrated energy recovery systems	(50,000 / 1 year)
ENVIRONMENT ISSUES			
EV-1	(C)	Assessment of the composition of desalination plant disposal brines [On-going *project*]	
EV-2	(C)	Investigation on the use of evaporation ponds for brine disposal in inland desalination plants [*Completed project*]	
EV-3	(C)	Enhanced evaporation for treatment of desalination brines [*Completed project*]	
EV-4	(C)	Spirulina culture using brine water from desalination plants [*Pre-closed project*]	
EV-5	(C)	Near field mixing of desalination plumes [*On-going project*]	
EV-6	(C)	Environmental planning, prediction and management of brine discharges from desalination plants [*On-going project*]	
HYBRID DESALINATION PROCESSES			
HP-1	(C)	Hybrid desalination systems	

HP-2	(C)	Hybrid desalination systems – Effectively integration of membrane / Thermal desalination and power technology [*Completed project*]	
HP-3	(A)	Membrane development to meet the requirements of the hybrid systems	($80,000 / 1 year)
HP-4	(A)	Process integration with air conditioning systems	($40,000 / 1 year)
HP-5	(A)	Process integration with waste heat utilization	($40,000 / 1 year)
HP-6	(A)	Energy optimization of dual-purpose power and desalination plants	($50,000 / 1 year)
CERTIFICATION PROGRAMS			
CP-1	(C)	Zero-waste design and development and performance evaluation for small home-use RO units [*Completed project*]	
CP-2	(A)	Development of standards for plant commissioning	($40,000 / 1 year)
CP-3	(B)	Certification procedures for RO membranes	
CP-4	(B)	Compilation and standardization of desalination terminology	
CP-5	(B)	Desalination standards (Specifications, testing, design, etc.)	
CP-6	(A)	Develop standards (ISO) for desalination costs	($30,000 / 1 year)
ASSESSMENT STUDIES			
AS-1	(B)	Critical assessment of state of the art of individual desalination technologies	
AS-2	(B)	Assessment of non-conventional desalination processes	
AS-3	(B)	Assessment of integrated energy systems	
AS-4	(A)	Electrochemistry of seawater	($60,000 / 1 year)
AS-5	(A)	Electrochemistry of corrosion with seawater	($60,000 / 1 year)
AS-6	(A)	Use of aquifers for the storage of desalinated water	($50,000 / 1 year)
AS-7	(C)	Systematic application of exergo-economic methods for the analysis and optimization of desalination processes *[Completed project]*	
AS-8	(C)	Privatization of water desalination in Oman [*On-going project*]	

AS-9	(C)	An Investigation of Total Composition of Sea Water in Oman [*On-going project*]	
SOFTWARE PACKAGES			
SP-1	(C)	Matching renewable energy with small unit desalination plant: Literature review and analysis of the state of the renewable energy and small unit desalination systems [*Completed project*]	
SP-2	(C)	Matching renewable energy with small unit desalination plant: Development of a PC-based decision support system [*Completed project*]	
SP-3	(C)	Data bank for seawater compositions [*Completed project*]	
SP-4	(C)	Development of a logistic model for the design of autonomous desalination systems with renewable energy source [*Completed project*]	
SP-5	(C)	Systems analysis of renewable energy conversion integrated with desalination processes [*Completed project*]	
SP-6	(C)	Development of web based computer package for simulation of thermal and membrane desalination process [*On-going project*]	
RED – DEAD SEAS PROJECT			
1		R&D studies in desalination pertinent to the Red Sea – Dead Sea Project	
2		Reassessment of Red Sea - Dead Sea desalination plant based on new technical plus new cost data.	

Annex B

PROJECT OUTLINES

TABLE OF CONTENTS

THERMAL PROCESSES

TP-1.1 Simplification of MSF plant design, including study of once through approach

Objective

Conduct techno-economic feasibility studies of various MSF configurations; including the once through layout. Develop a new MSF configuration that has simple and efficient layout.

Background

The brine circulation MSF configuration dominates the thermal desalination market. The main feature of this process is the heat rejection section, which absorbs the excess heat added to the system and controls the makeup seawater temperature. As a result, the flow rate of the makeup feed seawater is small, which results in low consumption rate of the chemicals additives for feed water. This also results in adopting a small size deaeration unit. The disadvantages of the brine circulation configuration are associated with the large number of the pumping units. This implies large specific power consumption of electricity. Also, pumps are the main source of down time and require frequent maintenance and parts replacement.

The once through MSF process has a smaller number of pumping units. This would reduce the capital cost, specific power consumption, and down time associated with maintenance and parts replacement of the pumping unit. On the other hand, the once through requires chemical and deaeration of the entire intake seawater stream, which is about four to five times larger than that of brine circulation MSF process. Also, lack of a temperature control on the intake seawater may cause severe problems, especially in cold climate or during winter operation.

Research Approach

- Develop different feasible process configurations of the recycle and once through MSF plants.
- Perform techno-economic feasibility analysis of the proposed configurations. The analysis should take into considerations the cost of chemicals, materials of construction and feed water conditions of the Gulf region.
- Provide the optimum process configuration based on the results of the techno-economic feasibility study.

TP-1.2 Life extension and upgrading of existing MSF plants

Objective

To develop strategy and procedures for upgrading the existing old MSF plants for extending their life and productivity.

Background

There are many MSF plants in the Gulf region operating since last more than 20 years. Most of these old plants are designed to operate at low top brine temperature and low capacity, 90 ^{0}C and 6 mgd, respectively. They need now replacement of corroded tubes in certain stages and linings for stage interiors and also the pumps and motors. Recent MSF plants are operated at top brine temperatures of more than 110^{o}C and have the capacity in the range of 12 mgd. Therefore, the life extension exercise provides an opportunity to upgrade these plants to increase their productivity and performance.

Research Approach

Develop methodology to perform the following tasks.

- Examining the process and equipment designs of the old MSF plants.
- Evaluating the status of all process equipment, piping, pumps and motors with respect to materials of construction.
- Evaluating the performance of the control equipment.
- Upgrading the whole plant

TP-1.4 Nano-filtration process to increase top brine temperature –

Demonstration in Al-Ghubra MSF plant, Oman

Objective

To conduct a techno-economic feasibility study for increasing the top brine temperature of a single train of MSF plant in Al-Ghubra, Oman with the feed water treated by nanofiltration process.

Background

Nanofiltration can be used to remove divalent ions from the feed seawater to reverse osmosis or thermal desalination processes. Literature studies by SWCC, Saudi Arabia, indicate the possibility of increasing the MSF top brine temperature to 160^0C upon removal of the divalent ions by nanofiltration. Adopting this approach results in increasing the flashing range by a factor of two, which implies doubling the plant capacity? However, system operation at high temperatures implies increase in the shell pressure in the brine pre-heater and in the high temperature stages. At 160^0C the pressure exceeds 6 bars; this is instead of 1 bar at 100^0C or vacuum at lower temperatures. Another difficulty in adopting this configuration is the lack of field experience for operating the large capacity nanofiltration pretreatment plant. Moderate rise in the top brine temperature, to a value of 120^0C, might be more feasible. Even at this condition, the system pressure is 2 bars; however, many of the existing plants can withstand this pressure increase.

Research Approach

- Explore the availability of space and facilities to set up a nanofiltration plant in Al-Ghubra, Oman premises to supply the feed water to one train of an existing MSF plant.
- Evaluate the selected MSF train suitable for proposed rise in top brine temperature and system pressure.
- Evaluate the fouling problems of nanofiltration process with the feed water from the existing intake system.
- Design the nanofiltration plant to suit the available space, feed water conditions and other facilities at Al-Ghubra plant.
- Perform techno-economic feasibility of the combined nanofiltration and MSF. Evaluate system performance at high top brine temperature.

TP-1.5 MSF vapor compression

Objective

Develop process schemes for MSF vapor compression. Conduct thermo economic feasibility study of the proposed schemes.

Background

Multiple effect evaporation with mechanical or thermal vapor compression are well-established processes. Operation in the vapor compression mode increases the unit performance ratio by a factor of two. This makes adoption of this technique with the MSF process quiet attractive. Previous literature studies show that MSF with thermal vapor compression increases the thermal performance ratio by 15%. However, development and assessment of new MSF configuration with thermal or mechanical vapor compression is required to achieve higher efficiency.

Research Approach

- Propose schemes for MSF combined with thermal or mechanical vapor compression.
- Evaluate performance ratio enhancement for the proposed schemes. Apply fundamental thermodynamic relations to analyze the performance of the proposed schemes.
- Design and size the required steam jet ejector or mechanical compressor for vapor compression.
- Perform detailed thermo economic analysis of the proposed configurations.
- Propose schemes for adoption of the proposed vapor compression configurations in the existing MSF plants.

TP-1.6 Computational fluid dynamics simulation of MSF condensers: non-condensable gas effects and design optimization

Objectives

Conduct a comprehensive CFD study of the flow, heat and mass transfer characteristics of MSF condensers. Specifically, the characteristics of condensation with non-condensable gas in real MSF condensers will be investigated to provide design improvements that lead to performance enhancements via reducing the adverse effects due to the presence of non-condensables.

TASKS

Phase-I: A Preliminary Study of CFD Modeling of MSF Desalination Condensers

Due to the complexity of mathematical modeling of condensation in condensers used in real MSF desalination plants Phase I is designed to give MEDRC the basis upon which to decide on funding Phase II of the proposed work. Thus, Phase-I represent a fact-finding mission to mathematical modeling of MSF condensers.

Task 1: A review of the literature and manufacturers' information on the design of real MSF condensers and identification of the major design parameters affecting their performance will be carried out. Physical models of the most widely used MSF condensers will be clearly presented to assess in the Tasks 2 and 3.

A review of the field experience data on various tube failures due to tube corrosion problems on the vapor side of MSF condenser. This should aid in investigating possible design improvements to prevent or reduce corrosion problems in MSF condensers

Task 2: A thorough literature review on the CFD modeling of condensation in condensers similar, or nearly similar to MSF condensers will be carried out. The simplifying assumptions used, the boundary layer treatments, the liquid-gas two-phase and multi-component two-phase flow modeling approaches and the auxiliary relations governing the heat and mass transfer will be identified and assessed in view of the physical model outlined in Phase I.

Task 3: Specifying the requirements on the CFD model and providing realistic simplifying assumptions that enable the software providers to gauge their software capabilities against.

Task 4: Review of CFD commercial software capability in modeling condensation in MSF condensers under real-world conditions under the simplifying assumptions in Task 3 above. Contact with commercial CFD software providers will be carried out at this stage which culminates in an assessment of the modeling capabilities of the selected software. Moreover, the cost required for the best suited CFD software can be specified as an input for phase II.

Task 5: Identify a set or sets of experimental data for validation of the models being intensively developed and implemented in Phase II. This is to ensure the success of model validation process, a priori.

TP-1.7 new demister concepts

Objective

To develop new demister configurations and designs for improved performance in MSF plants.

Background

Current mesh type demisters used for preventing the carryover of salts along with the vapors in MSF plants clog more frequently and pressure drops are high. This needs regular cleaning and replacement. Small droplets of brine pass through these demisters increasing the salinity of the distillate and may also contribute to the corrosion in the vapor space of the chamber. There is thus a need for developing a new type of demister, which is less susceptible for clogging, offers less pressure drop and reduce droplets carry over.

Research Approach

- Propose schemes for on-line cleaning systems for existing or new demister designs.
- Evaluate performance of novel materials, such as, composites or plastics versus conventional alloys. Evaluation should provide mechanical and chemical resistance properties, pressure drop, and separation efficiency.
- Apply and test existing or new models for evaluation of pressure drop and separation efficiency as a function of operating conditions.
- Test feasible schemes in prototype units or existing desalination plants. Provide long term performance data for the test schemes.

TP-1.8 Performance evaluation and optimization of the Barka MSF desalination plant

Objective

The main objective of the project is to study the performance of the Barka MSF desalination plant and optimize its operating conditions at various loads using a steady state mathematical model.

Tasks

1. Conduct literature survey for collecting better correlations for physical & thermodynamic properties and heat and mass transfer rates in MSF plants.
2. Develop mathematical models that describe the physical phenomena occurring in the MSF process based on the basic principles of chemistry and physics.
3. Identifying the methods to solve the developed model for simulating and optimizing MSF plant operations.
4. Collect the dimensional parameters of Barka MSF desalination plant, its design conditions, performance test conditions during commissioning and current operating conditions
5. Check the developed model with the design data of the Barka MSF plant and evaluate the design data with the performance runs after commissioning the plant.
6. Evaluate performance of the Barka MSF plant with the present operating data.
7. Identify bottlenecks and optimize the Barka MSF plant operations for various loads and evaluate the economic benefits.

TP-1.9 Reliability modeling and analysis of a desalination plant

Objectives

Develop reliability models on failure and repair of Al Ghubra desalination plant, Muscat Oman and analyze using the mathematical techniques for obtaining important reliability indices.

Tasks

- Review the related literature on the project subject.
- Collection of real maintenance data for Al Ghubra desalination plant.
- Develop and investigate some Reliability models based on real maintenance data for system with finite servers and various types of repair policies.
- Suggest some extended modeling strategies for a good comparison with the existing ones.
- An extensive reliability analysis of the desalination plant / system which in turn is helpful in increasing the uptime of the plant / system.
- Predicting the breakdown and repair possibilities
- Improve the effectiveness of the plant / system.
- An extensive failure analysis of the plant / system.
- Obtaining the important reliability indices numerically.
- An extensive graphical analysis to interpret the results.

TP-2.1 MED Technology – the current status

Objective

To perform a state of the art survey and critical review of the existing MED process technologies.

Background

At present and even more so in the future, MED plants can compete with other thermal desalination processes, such as MSF, and even with membrane processes, such as RO. However, there is no critical survey report on the MED process technologies useful to decision makers. Such information can in understanding of the pros and cons for various seawater desalination processes and as a result in lower the investment costs and consequently lowers water costs. MED plants, whether with or without thermal vapor compression are very simple and therefore well suited for application in developing countries.

Research Approach

A comprehensive literature survey should be conducted in order to collect all the available information on existing MED plants (process, design, materials, economics, and investment costs). The review should include the information from technical journals and also from records of the qualified plant suppliers, plant owners, plant operators and consultants or any other relevant source. In addition, technical specifications of actual tenders should be studied. Problems encountered in the operation and maintenance of these plants should be highlighted.

TP-2.3 MED Heat Exchanger Design Improvements

Objective

To critically review the literature related to the design of MED heat exchangers and to develop new designs for improved performance.

Background

Multi-effect distillation is adapted to desalination for small-scale processes, particularly on ship, many decades ago. Since then many heat exchanger configurations like horizontal tube, vertical tube and fluid contact arrangements such as submerged, wetted wall, spray have been proposed and used for desalination applications on ship and on shore applications. Each configuration has its advantages and drawbacks. Many reviews have been presented about these configurations.

In spite of the better theoretical performance of multi-effect distillation many large-scale commercial plants are not constructed based on this process compared to MSF plants due to operational problems. In order to overcome this problem there is a need to develop/improve the Multi-effect heat exchanger design.

Research Approach

- Review the existing designs.
- Propose new design concepts or suggest improvements to existing designs suitable for large-scale desalination application.
- Provide detailed design procedure including various correlations for the proposed design.

TP-3.1 Novel scale prevention techniques for thermal desalination

Objective

Development or evaluation of new scaling control concepts or improvement of existing scale control methods in thermal desalination processes.

Background

Reliable and effective control of scale formation and fouling continues to be one of the central objectives in the design and operation of thermal desalination plants. Considerable advances have been achieved in the past thirty years. In the case of MSF evaporators this has led to employing top brine temperatures up to 112^{0}C with scale control additives. In large MSF desalination plants the ball cleaning system is an effective method of achieving reasonable asymptotic fouling resistances.

MED plants with horizontal or vertical tube film evaporators are vulnerable to fouling by alkaline scales above 65^{0}C even with anti-scale additives. When designed for 100^{0}C operation with acid treatment, inadequate wetting of the surfaces can initiate sulfate scaling.

We know today that with correct design of an evaporator, the actual fouling factors in operation tend to be lower than the design fouling factors as demanded by all of today's tender specifications. Some experts believe that the efficiency of the MSF plants can be notably improved and the consumption of energy and chemicals can be reduced in these plants by on-line monitoring of the fouling condition and automatically optimizing the operation parameters, the chemical dosing rates, and the ball cleaning cycles.

Decarbonation with acid was ousted by the success of high temperature additives (HTA) and the problems of handling the acid. Years of operation of two plants in Holland and another in Saudi Arabia showed that a combination of HTA and acid, employing modern means of monitoring, can further improve process efficiency and reduce the costs for scale control. Such treatment is of course applicable to MED as well.

In ME distillation, most of the early scaling problems have been overcome by better understanding of the chemistry of scaling and hydrodynamic phenomena, and by the improved brine distribution concepts.

It has been claimed in the literature that for seawater with higher than normal salinity and with top brine temperatures higher than 100^{0}C, HTA consumption is lower in a once-through MSF process than in the conventional brine re-circulation system.

New developments with micro-filtration or nano-filtration have been proposed as an alternative pretreatment process, not only to replace chlorination to control bio-fouling and to reduce particulate fouling, but also to reduce the concentration of scale-forming constituents in the feed.

The need for reducing energy consumption in all industrial thermal processes, and the development of new methods for brine disposal and water re-use in most other technologies have brought forth new approaches to fouling control in general. It is likely that some of these achievements have not yet been acknowledged or tested in desalination technologies.

The above is a summary of examples that have motivated to launch this RFP for the development, testing, or implementation of new approaches for fouling control in thermal desalination.

Research Approach

The scope for potential research topics and approaches on this subject is so broad, that only some of the general requirements are pointed out in the following.

The main goal is to reduce the cost of desalinated water and enhance the availability and life of the desalination plants. In the case of fouling control these objectives may be achieved by

- Development of more effective pre-treatment technologies
- Development of new anti-scale additives
- Improving a desalination process for reduction in fouling
- Achieving higher levels of reliability
- Simplifications or by more sophisticated control methods for optimal operation
- Development of new methods for cleaning fouled surfaces, etc.

TP-3.2 New Techniques to Increase Top Brine Temperature of Operation for Distillation Processes

Objective

To develop new techniques for operating the thermal desalination processes at high top brine temperature.

Background

The top brine temperature limits the performance of a thermal desalination plant. It is restricted to a maximum value of 112^0C in MSF plants to avoid scale deposition, particularly with sulphate scales due to inverse solubility. The maximum value depends on the concentration of sulphate in the feed water, recovery and type of chemical additives used. It also depends on the feed distribution system and fluid hydrodynamics in the MED processes. It is currently maintained in practice around 112^oC in MSF plants and much less than it in MED plants with the available chemical additives.

Recent developments in nanofiltration membranes permit their application to reduce the concentration of sulfate, calcium and magnesium ions, which are responsible for scale formation in the thermal desalination process. Recently, it has been demonstrated that the application of nanofiltration for treating the feed waters to an MSF plant can increase the top brine temperature, without anti-scale additives or with very low dosing rates. This concept has been tested by successfully operating a pilot MSF distiller with top brine temperature of 120^0C.

Considerable efforts have been directed toward developing anti-scale additives in the last two decades. There may be still avenues to develop new additives based on the fundamental understanding of scaling phenomena.

Flow distribution of the feed and concentrated brine, pairing pattern of heating and cooling fluids are important parameters for scale formation in the thermal desalination processes. Different process/equipment configurations and designs are developed by different organizations since last many years. Adoption of developments in the process industries may have an impact on thermal desalination processes.

Research Approach

Adopt the approach suggested in the outline for “Novel scale prevention techniques for thermal desalination”.

TP-5.1 Innovative Heat Exchanger Concepts or design approaches

Objective

Development of new heat exchangers or design concepts for thermal desalination with, for instance, the following objectives/characteristics

- Reduction in the capital cost
- Improvement in the performance
- Decrease in scaling and fouling rates
- Convenient for cleaning
- Suitable for easy installation

Background

Heat exchangers are used for preheating the feed waters, evaporating the brine and condensing the vapors in thermal desalination processes. Simple plain tubes made of different materials of construction are generally used for heat transfer surfaces in the desalination processes. Many different sizes and shapes of special surfaces have been proposed in the past for desalination processes, the majority of which were discarded because they caused problems either with installation or performance, or they were too expensive.

The heat transfer surfaces form a major component of the capital cost of desalination plants. These surfaces also affect the fluid pressure drops and thereby the operation costs, including energy consumption. The shape and size of the heat transfer surface also influence the scaling and fouling rates, which in turn affect the performance and the cleaning cycles. Frequency cleaning cycles considerably affect the plant availability and plant life.

Research Approach

A selection from but not limited to the following could form components of the project. The proposing team, however, is encouraged to specify their preferences and emphasis.

- Survey and critical analysis of the earlier proposed configurations for desalination plants
- Propose new configuration and design
- Fabricate the proposed configuration
- Operate the proposed configuration in the operating range and conditions of commercial plant
- Perform the critical analysis of the collected data
- Develop the design basis for commercial plan

TP-5.2 Optimization of acid cleaning and Taprogge operation

Objective

Develop criteria/methodology for optimizing the acid cleaning and Taprogge operation cycles in MSF plants.

Background

The control of scale formation is essential in any desalination unit if it is to be operated for long periods at optimum efficiency. The soft scales are removed by Taprogge operation and hard scales are removed by acid cleaning in MSF plants. Taprogge operations are performed at regular intervals to prevent the soft scale fouling in MSF plants. The sludge buildup and degree of adherence to the tube surface is influenced by temperature, fluid velocity, seawater composition, and presence of trace impurities, notably iron and in some instances by microorganisms. An experienced operator based on certain measured parameters in the plant, like gain output ratio, production rates etc., adjusts the frequency of Taprogge operation. It is essential to quantify the need for Taprogge operation cycle based on measured parameters in the plant. It is difficult to predict the length of time that an evaporator can operate satisfactorily before acid cleaning is necessary. Field operations showed that the frequency between cleaning can be as short as every seven days to as long as several months (without Taprogge operation). Hence the Taprogge and acid cleaning cycles are interlinked. The acid cleaning cycles should be weighed considering the cost of cleaning and the loss in performance due to scale formation.

Research Approach

- Collect operating data for a number of existing MSF units, which includes variations in the feed conditions, plant capacity, performance ratio, maintenance frequency, consumption rate of anti-scalent, Taporgge, and acid.
- Analyze the data to provide variations in specific values, i.e., variations in consumption rate of balls, acid, or anti-scalent per unit mass of distillate product. Also, determine the plant fact or the percentage of actual production time versus down time. Other data may include variations in the production capacity or performance ratio and how much it deviates from design values.
- Correlate variations in the plant performance data versus the acid or Taporgge ball cleaning frequency. Data should provide analytical measures and guidelines for consumption rate and cleaning frequency.

TP-5.4 Use of plastic materials in desalination processes

Objective

Investigate the use of plastic materials in thermal desalination processes.

Background

Plastic materials are cheap and corrosion resistant to saline water. The surface properties of plastic materials reduce scaling and fouling rates. Also, removal of scale or fouling layers can be done more easily. Plastics are cheaper than metals, consume less energy during manufacturing, and have lower density. Drawbacks of plastics include lower thermal conductivity and larger expansion ratio than metals. Another disadvantage of plastic materials is the degradation of their mechanical strength over relatively short periods of time, when exposed to high temperature or extreme pH values.

Research Approach

- Conduct a survey of plastic materials available in the market and collect their properties.
- Identify locations in thermal desalination processes where plastic materials can be used.
- Identify the appropriate plastic materials suitable for different applications in various desalination processes.
- Evaluate performance of plastic tubes in condensers, evaporators, and transport lines as a function of temperature and salinity. Evaluation should provide heat transfer characteristics, fouling and scaling features, and mechanical/chemical resistance.

TP-5.6 Basic experimental studies of the CO_2 release in the carbonate system in seawater distillation

Objectives

1. to acquire an in-depth understanding of the reaction kinetics and the mass transfer phenomena controlling the release of CO_2 in desalination distillers,
2. to study the effects of various process parameters and the seawater composition on the release of CO_2 and the carbonate system,
3. to obtain experimental data that help to verify and improve the CO_2 release model which is presently being developed by the principal investigator in the frame of the project "The Release of CO_2 in Multiple-Effect Distillers" supported by MEDRC and to improve scale prediction and prevention methods,
4. to study the role of CO_2 release in scale formation and the interaction of these processes,
5. to enhance experimental know-how for fieldwork applications in desalination distillers.

Project Tasks

1. Set up of the gas-liquid stirred vessel

   (a) Modifying and improving the existing stirred vessel test rig for studying the effects of the parameters listed in 2
   (b) Installing the test rig and the measuring instrumentation

2. Execution of various experiments in the stirred vessel

In various test series the effects of influencing parameters on CO_2 release and the carbonate system will be studied, as for example:

   (a) Operating temperatures
   (b) Agitation
   (c) Composition of the test solution
   (d) pH and ionic strength of the test solution
   (e) Simultaneous precipitation of $CaCO_3$ and $Mg(OH)_2$

3. Evaluation of the measurement results obtained from the stirred vessel experiments

   (a) Summarizing the experimental results and indicating the effects of influencing parameters
   (b) Calculating the CO_2 release and the ion concentrations in the carbonate system by applying the theory of mass transfer with chemical reaction to the various experiments
   (c) Comparing the experimental results with the calculation results and with the results of previous experimental work

4. Detailed design and set up of the falling film apparatus

(a) Manufacturing the falling film device for studying the effects of the parameters listed in 5
(b) Installing the test rig and the measuring instrumentation

5. <u>Execution of various experiments in the falling film apparatus</u>

In various test series the effects of influencing parameters on CO_2 release and the carbonate system will be studied, as for example:

(a) Operating temperatures
(b) Film thickness (wetting rate)
(c) Composition of the test solution
(d) pH and ionic strength of the test solution
(e) Simultaneous precipitation of $CaCO_3$ and $Mg(OH)_2$

6. <u>Evaluation of the measurement results obtained from the falling film experiments</u>

a) Summarizing the experimental results and indicating the effects of influencing parameters
b) Calculating the CO_2 release and the ion concentrations in the carbonate system by applying the theory of mass transfer with chemical reaction to the various experiments
c) Comparing the experimental results with the calculation results and with the results of previous experimental work

7. <u>Consolidation and improvement of the model for the predictive simulation of CO_2 release in ME distillers currently developed within the project “The Release of CO_2 in Multiple-Effect Distillers” (No. 00-AS-006) supported by MEDRC</u>

(a) Examining if the approach applied to the simulation of CO_2 release in ME distillers is consistent with the experimental results
(b) Based on the above, suggesting improvements for the model

8. <u>Comprehensive literature survey accompanying the experimental work</u>

(a) Reviewing experimental work on CO_2 desorption / absorption with chemical reactions
(b) Surveying the field tests performed at desalination sites
(c) Studying sampling and analysis methods for the gas, liquid and solid phase
(d) Reviewing the approaches and methods used for evaluation of the experimental results with regard to consideration of reaction kinetics and mass transfer processes
(e) Summarizing the results of previous experimental work

It is the aim of this work task to collect and evaluate the information available and put them in a convenient frame to be used not only for the proposed work, but also as reference material for other investigations, e.g. in the field of scale formation and control.

Anticipated Results

- fundamental and applied know-how on the gas release process and on the carbonate system in desalination distillers,
- experimental data for verifying and improving models for predicting CO_2 release and scale formation,
- improved model for the prediction of CO_2 release and the carbonate system in ME distillers,
- experimental know-how for further laboratory tests and fieldwork applications

The practical benefits of the proposed project are:
- optimisation of the venting system of desalination distillers,
- reduction of the total specific energy consumption,
- more appropriate determination of the overall heat transfer coefficient and dimensioning of the design heat transfer area,
- better diagnosis of distiller performance,
- better diagnosis of operation instabilities,
- better understanding of the carbonate system and scale formation and thus improvements in scale control.

A better understanding of the CO_2 release will help to reduce capital, operating and maintenance costs of seawater distillation plants.

MEMBRANE PROCESSES

MP-1.3 Microbial attachment mechanisms

Objective

To carryout a state of the art review of mechanism of microbial attachment and growth on the RO and other membrane surfaces during the operation.

Background

There are many studies on the fouling of surfaces by bacteria and organic foulants present in seawater. The organics and bacteria are believed to act dependently upon each other in the formation of bioorganic film that eventually forms on the immersed surface. Generally any surface exposed to seawater would become populated with attached bacteria by formation of a film of cells and their products and that the surface enhanced microbial growth by concentrating organic nutrients that were present in the seawater. As the surface characteristics become changed, more complex organisms will appear on the surface, replacing simpler ones.

Surface chemical composition will influence the microbial contribution to bio-films. Since bacteria in seawater generally will carry a net negative surface charge, the most important effect of the immersed surface will concern the nature of the surface electrical charge.

The forces involved in the RO process, such as permeation drag, back-diffusion transport and cross flow velocity will influence the attachment of bacteria and its growth. Concentration polarization on RO membrane also helps in bacteria colonization due to enrichment nutrients.

Therefore there is a necessity for a state of the art review considering all the factors that effect the attachment of bacteria and its growth on membrane surfaces in sea and brackish waters.

MP-1.4 Surface Chemistry Modifications to Avoid Fouling

Objective

To develop membranes with surface characteristics able to reduce fouling and increase the permeate flux. The effectiveness of these membranes is to be evaluated in desalination of various feed water sources with different fouling potentials.

Background

Reverse osmosis (RO) is a pressure driven-membrane separation process. RO has principally seen a wide range of applications in the processing of aqueous solutions especially in desalination of brackish water and seawater. One of the major problems in the RO process is the reduction of flux to far below the theoretical capacity of the membrane. It is well known that membrane fouling is the main phenomenon responsible for this. In surface seawater, suspended solids and colloidal dissolved substances are the main causes of membrane fouling.

In general, fouling cannot be prevented, but can only be controlled. The control of fouling increases the permeate flux and limits the need for severe cleaning regimes, so prolonging the life of the membrane. The tendency towards membrane fouling depends on several factors, among which is the surface chemistry of the membrane. Modifying the chemistry of the membrane surface can reduce the rate of colloids attachment extending the time between chemical cleanings.

It is expected that the hydrophilic character of the membrane surface reduces rate of adsorption of organic matter present in the feed water, thus reduces membrane fouling. Therefore, it is of interest to develop membranes with surface characteristics suitable to reduce fouling.

Research Approach

- Thorough literature review of the state-of-the-art of RO membranes.
- Develop new membrane formulations that resist membrane fouling.
- Conduct experiments on bench or pilot scale to test these membranes.

MP-1.8 Study of the interactive effects of inorganic and biological fouling in RO desalination units

Objective

The objective of this project is to study the interactive effects in composite fouling by developing a theoretical approach and model that takes into account the interactive effects and conduct experiments to assess and validate the theoretical model predictions.

Tasks

Task 1: Experimental work on biological fouling and individual fouling types

This task mostly encompasses the experimental work on individual inorganic and biological fouling. In these experiments the effect of salinity, nutrient and bacterial count on biological growth will be investigated with simulated waters. Psuedomonas fluorescens will be used for the experimental investigations. The effect of operating conditions such as concentration and salinity on inorganic foulant formation will also be investigated. The structure of the foulant formed will be assessed.

Task 2: Experimental Work on Composite Fouling

Initially selected runs will be carried out to investigate the individual fouling processes to obtain a base comparison lines. For the inorganic fouling, salt concentrations will be in the range of those usually encountered in RO desalination. Two different salts ($CaSO_4$, $CaCO_3$) will be tested, as they are predominant scaling salts in process equipment. Distilled water will be used for preparation of the feed and the unit will be sterilized to alleviate or minimize the possibility of bacterial growth in the system (aseptic technique).

Simulated feed water will be used to determine the effect of biological fouling in composite fouling under given conditions. Psuedomonas fluorescens that it is prevalent in industrial water systems will be used as the model micro-organism. Glucose will be used as a source of carbon (nutrient). Again the system will be sterilized (aseptic technique) and distilled water will be used for preparation of the feed solution. After the information on the inorganic fouling and biological fouling in isolation is obtained, tests will be performed using simulated model feed waters, containing both inorganic salts and micro-organisms, to determine the simultaneous effects.

The above experiments will provide some indication of the synergistic effects in composite fouling. At this stage, the focal point is to determine the effect of biological fouling on inorganic fouling. However, if the above results indicate that there is significant particulate fouling present, then additional experiments are required to determine the relative effects biological fouling on particulate and crystallization fouling on by repeating some of the experiments with a filter on the line. Also, the effect of humic acids on inorganic fouling will be investigated as humic acids are sometimes included as inhibitors.

Task 3: Develop a theoretical model which could take into account the interactive effects

Theoretical model will be developed which would be able to incorporate some of the interactive effects. The model will be modified, if required, to take into account the effect of simultaneous fouling processes.

Task 4: Assessment of composite fouling model

In this task model predictions are compared with experimental data. First, the experimental data will be used to substantiate the applicability of the model to individual fouling. Further experimental results on composite fouling will assess the applicability of the model to composite fouling.

Task 5: Complementary experiments to refine the model

In this task complementary experiments will be carried out to assess the composite fouling structure. Refinement and suggestions will be made for improvement of the model and extension of this theoretical approach.

MP-1.9 Application of molecular modeling to understand crystallization fouling and the interactive effects

Objective

In this project a study of the crystallization fouling will be carried out based on Molecular Modeling methods. This will include crystal morphology analysis under different operating conditions, studying the interactive effects on Gibbs free energy and thermodynamic solubility constants and crystal growth and strength, and the effect of the presence of other species on the crystal habit (coprecipitation). Experimental work also will be done in order to compare, and validate the results that will be obtained from the computations. Ultimately, it is hoped that once this project is completed and at later stages, the results and output from these molecular modeling simulations and investigations would be coupled with kinetic data and fed to a CFD software for coupling with hydrodynamic effects. Therefore, this possibility will be assessed to establish the future directions.

Tasks

1. Comprehensive literature review: This will include the review of the basics of molecular modeling, ab initio quantum mechanics (QM) based on Density Functional Theory (DFT) and Molecular Dynamics (MD).
2. Software and module assessments: The specifics of the software modules and their applicability for the inorganic salts will be assessed. Not much simulation techniques are available for inorganic salts.
3. Energy minimization analysis: Energy minimization techniques will be assessed and analyzed.
4. Calibration of software and modules: The software and modules will be calibrated by comparison with previous experimental work. Experimental data are available for simple salts such as NaCl. Also, simple inorganic salts such as NaCl could be modeled relatively easier than more complicated ones and as such will be used for calibration and preliminary assessments.
5. Thermodynamic approach: Development of thermodynamic approach involves the lattice energy determination by using ab initio quantum mechanics (QM) based on Density Functional Theory (DFT) method. The obtained lattice energy is incorporated with the thermodynamic relationships to determine the formation enthalpy of the crystal by implementing the Born-Haber thermodynamic cycle and then by determination of Gibbs Free energies and hence the solubility products. In addition, molecular dynamics (MD) simulation will be carried out.
6. Heat of formation analysis: It is performed at different temperatures, pressures and feed concentrations. Heat of formation of any given salt is related to the heat of formation of its constituents and also the entropy of products and reactants. The relationships will be developed for the salts in concern and the thermodynamic relationships will be developed based on the thermodynamic principles.
7. Gibbs free energy evaluations: Gibbs free energy of the reaction will be determined based on those of products and reactants. That would provide a means to theoretically calculate the solubility product.

8. Ksp evaluation: The method of theoretical calculation of Ksp will be validated and the results compared with the available experimental data. Also the effect of temperature and possibly salinity will be theoretically investigated and compared with available experimental data.
9. Experimental analysis for the same scaling salts and under same conditions: Experimental wok will be conducted to fill the gap in the availability of data and for the purposes of comparison of the theoretically calculated values and those obtained experimentally.
10. Comparison and validation: The thermodynamic technique developed and used for theoretical determination of Ksp will be compared with the experimental results.
11. Assess linkage between the outputs from the software with CFD package: Gibbs free energy determination can be used to determine Ksp and it will be endeavored to also develop sub-modules in CFD package that can access the theoretically calculated Ksp at a local conditions of temperature and pressure with the process stream.
12. Simulations and the experimental work: Continuation of simulation and experimental work and further comparisons of the results.

MP-1.12 Preparation of thin film composite RO membrane with reduced fouling for seawater desalination

Objective

To study systematically the effect of surface charge, hydrophobicity/philicity and surface roughness on the TFC membrane fouling, aimed at the design of a novel polyamide TFC membrane for seawater desalination with reduced fouling.

Tasks

1. To prepare TFC polyamide reverse osmosis membranes for seawater desalination based on the conventional interfacial polycondensation of diamine and polyfunctional acid chloride monomer on a porous support membrane.
2. To change the surface charge density, hydrophobicity/philicity and surface roughness systematically by adding an organic solvent or a surfactant or an electrolyte into the aqueous diamine solution. An attempt will also be made to add a surface modifying macromolecule (SMM) into the organic phase.
3. To characterize the membrane surface by streaming potential measurement, contact angle measurement, atomic force microscope (AFM), X-ray photoelectron microscope (XPS) and scanning electron microscope (SEM).
4. To conduct reverse osmosis experiments with aqueous 3.5 % sodium chloride solution with potential foulants. The rate of flux reduction is measured in this experiment.
5. To correlate the rate of flux reduction with the surface properties by regression analysis and optimize the conditions of membrane preparation to achieve a membrane of the least fouling.

MP-1.13 Development of particulate/colloidal fouling indicators in SWRO: Further development of MFI-UF concept

Objectives

- Given that high ionic strength induces particle/colloid aggregation through destabilization, the key focus will be to investigate the effect of salinity on MFI-UF and SDI values.
- To correlate values of MFI-UF with RO fouling trends to ascertain its predictive capabilities.

TASKS

Task 1: Literature review

Literature review on fouling indicators and their use in assessing pre-treatment for reverse osmosis systems

Task 2: Experimental set-up

Define experimental matrix, test parameters / variables (e.g., pH, temperature, ionic strength, organic matter, membrane material, membrane MWCO, flux, etc).

Task 3: Analysis and evaluation of the results

If necessary, additional tests will be performed to verify and extend results.

Task 4: Improvement of MFI-UF

On basis of the experimental results obtained, provide suggestions for further development of the MFI-UF considering particulate and colloidal fouling.

MP-1.14 Optimization of the membrane sub-layer for development of RO membranes with improved fouling resistance

Objectives

To improve the stability of operation of reverse osmosis membranes by optimizing the properties of the membrane's sub-layer. This includes the membrane's overall mass transfer resistance (and therefore, its water permeability), and the occurrence of fouling.

TASKS

Task 1: Sub-layer optimization

Asymmetric polyethersulfone sub-layer membranes in the low ultrafiltration – high nanofiltration range will be synthesized for reverse osmosis membranes (molecular weight cut-off 800-1,000) by using the DIPS technique. The properties of the sub-layer will be changed by changing the synthesis parameters (polymer concentration, solvent type, choice of non-solvent, air humidity, temperature, additives). Initially, monolayers on a non-woven support will be used; subsequently, multilayered structures also will be used.

The water flux, pore size and pore size distribution will be used as the optimization parameters for the sub-layers. Fluxes with pure water will be measured for the sub-layer. This should eventually lead to the highest flux and the highest hydrophilicity for the sub-layer; an iterative procedure with back coupling of the pore size and pore size distribution to membrane will be used.

Task 2: Addition of a top layer by in-situ polymerization

A conventional approach will be used to apply in-situ polymerization on the support layers. Well known procedures will be used to this purpose, as described in the literature. Comparison of top layers is not considered. However, it will be necessary to select appropriate conditions during synthesis so that a representative reference is obtained.

Task 3: Assessment of membrane performance

Assessment of membrane performance includes (1) evaluation of the physico-chemical properties of the membrane and its ideal conditions, i.e., determination of the pure water flux and salt rejection using standard filtration conditions, and (2) evaluation of membrane fouling.

The membrane performance will be evaluated experimentally by carrying out filtration tests with the membranes synthesized in task 2, relative to commercial membranes. These experiments will be carried out in a cross-flow filtration unit using flat sheet membranes with a diameter of 0.09 m.

For the evaluation of membrane fouling, synthetic solutions mimicking seawater in terms of ionic composition will be applied. The focus, however, will be on organic fouling; the synthetic matrix will be used as a reference condition only. To this matrix, organic foulants will be added; in contrast to the study of fouling of the sublayers, a series of small organic molecules will be used here; a selection of compounds with molecular weight close to 150 but with a large variation in hydrophobicity will be used. Filtration of "seawater" with addition of small concentrations of one of these compounds will allow to compare the different membranes, relative to commercial membranes.

MP-1.15 Toward better calcite scaling understanding in SWRO

Objectives

The main goal of this study is to eliminate the use of chemicals for $CaCO_3$ scaling prevention in SWRO systems through induction time.

Tasks

Experiments will be performed to estimate the scaling potential of artificially prepared (supersaturated) concentrates that simulate typical SWRO plant recoveries (10-50%). Induction times and growth rates of calcium carbonate will be measured in the supersaturated concentrates and the maximum safe recovery in the absence of antiscalants/acid will be elucidated. The induction time will be measured using ICP at various thermodynamic conditions e.g. temperature, flow conditions and ionic interference. Measurements of the induction time for $CaCO_3$ will involve the use of a high sensitivity pH meter to monitor real time changes in pH concentration. The tests will be done on synthetic seawater with ionic constitute resembles that of SWRO concentrate of recoveries range from 10 to 50% with 10% step.

MP-2.1 Membrane fouling, its control and removal

Objectives

Since the inception of membrane processing, the detrimental affects of fouling on the membrane surface have been known as the major problem preventing more widespread use particularly in the Middle East. Both inorganic and organic fouling cause process inefficiency and result in the requirement for more frequent cleaning, and perhaps, shorter useful membrane life. The objectives of this research project will be:

- to find more effective methods of removing potential foulants from feed water,
- to develop chemicals which will be more effective in preventing fouling,
- to develop new membrane formulations which may deter or resist membrane fouling,
- to develop chlorine resistant membranes,
- to study the fundamental relationships of organisms as related to membrane fouling,
- to develop better operational methodology which may deter severe fouling,
- to study the fundamental hydrodynamic relationships which may aid in resisting fouling.
- To study the fouling mechanism.

Background

A solution to membrane fouling will be widely applied throughout the membrane desalination field and will have applicability to many industrial and municipal uses for the processes. The ability of reverse osmosis membranes to achieve higher flux has been known for many years. The process has never reached its maximum potential of value, due to the resistance caused by membrane fouling. An answer to this problem will have far reaching affects throughout the world, and may finally make desalinated seawater a solution for underdeveloped countries in the world.

Research Approach

As it is impossible to estimate the nature of the final solution to membrane fouling problems, a multi-faceted approach will probably be required. Research proposals in the following areas will be considered:

a) Membranes: Fouling resistant, chlorine resistant, etc.
b) Physical: Hydrodynamic improvements, concentrate spacer design, enhanced mixing, etc.
c) Chemical: Anti-foulant chemicals, membrane cleaning chemicals, membrane coatings, etc.
d) Fundamental: Bacterial attachment, bacterial growth, prediction methods, etc.
e) System design: Improved flow conditions, operational methodology, detection methods, etc.

MP-2.2 Improved Pretreatment Techniques, Simplifications, Alternative Disinfectants and Impact on RO design

Objective

Critical review of the pretreatment processes that are in practice and those reported in the literature, with an overall objective to provide recommendations for appropriate process for various types of feed waters with different fouling indices and study the impact of these processes on RO process design.

Background

Feed water to the membrane desalination processes is treated to reduce the fouling and scaling of the membrane surfaces to achieve better recovery, and to increase plant availability and membrane life. Conventional pretreatment methods consist of coagulation, sedimentation and filtration operations for removing the suspended solids. Additional treatment operations are added if the feed contains other constituents like iron, oil, biological matter or chemically reactive solids.

Recently it has been reported in the literature that membrane filtration operations are used for pretreatment of feed water and claimed their superiority over conventional pretreatment processes. However, none of these processes has been commercialized yet.

Since pretreatment consume substantial amount of desalination cost, it may be desirable to revisit the conventional pretreatment process or develop/implement the new processes.

Research Approach

The following approach may be adopted but other suggestions are welcomed.

- Review of pretreatment processes currently in practice by clearly highlighting their merits and limitations.
- Literature survey and critical review of the processes reported.
- Perform techno-economic feasibility of the different processes and recommend appropriate pretreatment processes for each feed water condition selected considering their impact on the design & operation of RO process.

MP-2.3 Nanofiltration for Fouling Control

Objective

To conduct a techno-economic feasibility study of the application of nanofiltration for fouling control in membrane desalination processes.

Background

Nanofiltration is a promising unit operation to soften the saline water by reducing the concentration of sulfate, calcium and magnesium ions, which are responsible for scale formation in thermal and membrane desalination processes. It is also capable of removing other inorganic, organic compounds and bacteria from the feed waters, which are responsible for fouling the membranes in desalination application.

Reducing the concentration of scale forming components in the feed will improve the operating flux and recovery ratio in RO desalination processes. Nonofiltration is recently applied for treating the feed waters to RO desalination process.

Research Approach

Adopt an appropriate research approach, which will accomplish the above project objectives.

MP-2.7 Minimize the use of chemicals in sea water Reverse Osmosis: Impact on scaling & concentrate disposal

Objectives

The objective of the study is to minimize/eliminate the use of chemicals for scale prevention in Sea Water Reverse Osmosis.

- Determine the maximum safe (i.e., limits of) recovery in the absence of acid and/or an anti-scalant in SWRO systems
- Determine the minimum dose of anti-scalant and/or acid required to prevent scaling above the safe conversion in SWRO systems
- Determine the impact of using NF-RO sequence for unsafe conversion
- Technical and commercial comparison between different systems

Tasks

Task 1: General literature review on the subject of the study will be carried out

Task 2: Critical review of methods used for the calculation of the scaling potential and kinetics of $CaSO_4$ and $CaCO_3$ will be carried out. Improvements will be proposed and/or new methods will be developed and verified with experimental results obtained with laboratory and pilot scale experiments.

Task 3: Laboratory scale experiments

Laboratory scale experiments will be performed at the UNESCO-IHE laboratory using the bench scale RO unit and other experimental facilities to estimate the scaling potential of artificially prepared (supersaturated) concentrates that simulate typical SWRO plant recoveries (20-60%). Induction times and growth rates of calcium carbonate and calcium sulphate will be measured in the supersaturated concentrates and the maximum safe recovery in the absence of antiscalant/acid will be elucidated. The laboratory experiments and modeling will focus on

- Determination of critical recovery
- Bulk crystallization measurements
- Induction time measurements
- Determination of solubility ratio
- Determination of the effect of anti-scalant dose on unsafe conversion
- Determine the effect of acid doses using unsafe recoveries and its effect on induction time
- Determine the benefits of NF-RO sequence in increasing the threshold scaling limits

Task 4: Pilot scale experiments

To verify the experimentally determined safe conversion estimated for artificially prepared concentrate in laboratory scale experiments, pilot plant trials employing natural seawater will be performed using the maximum safe conversion estimated in laboratory scale experiments. The relation between induction time and recoveries again will be tested in order to confirm laboratory scale results. Compositions of the raw and treated feed water and of the reject brine will be determined using inductively coupled plasma (ICP) spectrometry and ion chromatography (IC) while analytical visual methods using environmental scanning electron microscopy (environmental SEM) will be utilized to confirm the scaling mechanism and components. The pilot scale experiments will focus on

- Determination of critical recovery
- Determination of the effect of anti-scalant dose for unsafe conversion
- Determination of the effect of acid doses using unsafe recoveries and its effect on induction time

Task 5: Technical and cost comparison between different systems

Technical and operational comparison between SWRO system utilizing minimum chemical doses and that using NF as pre-treatment will be addressed. The comparison will cover the following.

- The ease of system operation and maintenance
- The difference in design and equipments
- The power consumption
- The difference in instrumentations and control.

Cost comparison between SWRO system utilizing minimum chemical doses and that uses NF as pre-treatment will be addressed and will depend on the following.

- The change in capital cost
- The change in the operational and maintenance cost
- The change in power consumption

Deliverables

1. Six monthly progress report
2. Final report covering all the work carried out in the project
3. PhD Thesis

MP-2.8 Boron pre-treatment for seawater and brackish water desalination

Objectives

The proposed research work is targeted at arriving at pre-treatment options and increase membrane efficiency for removal of boron from feed water resources (such as sea water and brackish water). The main objectives for the proposed program are:

- To review the existing approaches for the removal of boron as a possible pre-treatment option for sea water/brackish water desalination.
- Evaluate the feasibility of using coal/fly-ash or cations to remove boron under seawater/brackish water desalination conditions.
- Investigate feasibility of pre-treatment for Boron removal using aluminum oxide.
- Investigate commercially available Boron selective membrane efficiency for brackish water.

Tasks

- A through literature review will be carried out to evaluate various pre-treatment options.
- Selection of two pre-treatment technologies (most probably it would be the use of coal/fly ash or cations) to remove boron under seawater desalination conditions.
- Parametric study to evaluate retention time, pH, and temperature effect under seawater conditions for each of these processes.
- Conduct experiments using FILMTEC NF90-2540 polyamide thin film composite spiral wound membrane under variable conditions (e.g. single pass, second pass, pH control, etc.)
- Column experiments using aluminum oxide as a pre-treatment agent.

MP-2.9 Application of solar energy in RO pre-treatment process – Phase I

Objective

To investigate the application of photo catalytic oxidation using solar energy in Reverse Osmosis pre-treatment process

Tasks (Phase I)

1. Extensive literature review on photo catalytic applications especially in desalination process.
2. To conduct feasibility studies for application of photo catalytic mechanisms in RO pre-treatment process.
3. Visit to a major research center where photo catalytic research is under progress especially in the area of desalination.

MP-3.1 Advanced reverse osmosis membranes

Objective

To develop advanced reverse osmosis membranes for high recovery and high salt rejection.

MP-4.6 Investigating the residence time distribution in a membrane module in order to improve the module and gain better operational understanding

MP-4.7 Using Particle Image Velocimetry (PIV) technique to investigate the flow next to the spacer between membranes in order to increase the turbulence without increasing the pressure drop

MP-4.10 New desalination process for enhanced recover from brackish water: Smart system utilizing Ultrasonic Reflectometry (UR) and Flow Reversal (FR) - Phase I

Objectives

The overall goal of the project is to combine a novel membrane separation process, flow reversal, with unique detection methodology, ultrasonic reflectometry, to create a successful and practical high-recovery brackish water desalination unit.

Tasks

Task 1: Adaptation and optimization of Flow Reversal to Tapered-Flow RO Desalination through bench scale experiments using synthetic brackish water feeds

Task 2: Adaptation of Ultrasonic Sensors for Control of Flow Reversal through bench scale experiments using synthetic brackish water feeds

Task 3: Development of bench scale combined unit of Tapered Flow RO with Flow Reversal and Ultrasonic Sensors for control

Task 4: Testing of Tapered Flow with Flow Reversal and Ultrasonic Sensors bench scale unit with Real Brackish Water for performance studies and collection of data for the design of pilot scale unit

Task 4: Training of the project partners in operation of the developed Flow Reversal Tapered-Flow RO Desalination bench scale unit and Ultrasonic Sensors for Control and the unit combining these two systems.

MP-5.3 Development of polymer nano-fiber, micro-fiber and hollow-fiber membranes for desalination by membrane distillation

Objectives

To prepare nano-fiber, micro-fiber and hollow-fiber membranes for Membrane Distillation (MD) desalination using hydrophobic homopolymers and copolymers.

Tasks:

- Literature survey that includes:
  - i) brief description of both commercial and laboratory made membranes for MD as well as different MD configurations
  - ii) summary of different methods for porous hydrophobic membrane preparation
  - iii) summary of the different involved parameters in dry/jet wet spinning method and their effects on hollow fiber membrane morphology and structure
  - iv) summary of already prepared nano-structured polymer webs by electrospinning method and effects of different involving process parameters on the structure of nano- and micro-fibers as well as on the nano-structured membrane
  - v) Summary of MD for desalination and other applications

- Membrane preparation that includes:
  - i) preparation of hollow-fiber membranes for MD by dry/jet wet spinning method using PVDF hydrophobic polymer
  - ii) preparation of nano-fiber and micro-fiber membranes by electrospinning method using hydrophobic homopolymers and copolymers
  - iii) preparation of nano-structured based electrospun nano-tubes.
  - iv) Determination of appropriate conditions for electrospinning the above fibrous membranes.

- Membrane characterization that includes:
  - i) determination of geometrical, physical, mechanical, thermal and chemical properties of the fiber membranes
  - ii) measurement of water contact angle of nano-structured membranes
  - iii) measurement of liquid entry pressure (*LEP*) of water and salt aqueous solutions of hollow-fiber membranes and nano-structured membranes
  - iv) measurement of mean pore size and pore size distribution of hollow-fiber membranes and nano-structured membranes
  - v) measurement of void volume of hollow–fiber and nano-structured membranes
  - vi) measurement of thermal conductivity of nano-structured membranes

- Design and module preparation that includes:
  - i) shell-and-tube and plate-and-frame membrane modules
  - ii) packing of dry/jet wet spinning hollow-fiber (capillary) membranes prepared above in shell-and-tube modules
  - iii) packing of electrospun nano- and micro-fibrous (tubular) membranes prepared above in plate-and-frame modules.

- MD desalination experiments that include:

i) seawater and aqueous sodium chloride feed solutions

ii) various membranes prepared above and two commercial polyvinylidene fluoride (PVDF) and/or polytetrafluoroethylene (PTFE) membranes for comparison
iii) effect of membrane parameters (web structure, pore size, void volume, roughness and thickness)
iv) effect of MD operational conditions: temperatures and flow rates.

All MD experiments will include the measurement of the permeation flux and the salt concentration in feed and permeate. Comparison of desalination performance by the membranes prepared in this project and the commercially available membranes will be made.

- Model development that includes:

  Application of available theoretical MD models to electrospun fibrous (tubular) membranes in order to predict their MD performance under various operating conditions and MD configurations (DCMD and AGMD).

Deliverables

- Comprehensive periodic reports every 6 months
- Comprehensive Final Report
- Ph.D. Thesis by student Shadi Sawalha

MP-6.4 Cleaning of Membranes

Objective

To develop criteria for optimizing the cleaning frequencies and to develop cleaning process for RO desalination process with different feed water pretreatment processes of various feeds.

Background

Membrane fouling is the most serious problem in RO desalination process. Appropriately treating the feed water and operating the membrane process at proper operating conditions will slow the fouling rate. There are five types of membrane fouling, namely colloidal fouling, biological fouling, metal oxides fouling, scaling and device plugging in RO desalination. Fouling affect the performance of the membrane process and also permanently damage the membrane. In order to overcome these problems proper feed treatment method, appropriate operating conditions and adequate membrane cleaning cycles are generally employed.

As it is not possible to eliminate fouling with the most complicated feed treatment procedures and the best operating conditions, cleaning of the membrane is still essential. Better procedure for feed water treatment and membrane operation will change the cleaning frequency. But there will be an optimum pretreatment procedure, membrane operating conditions and cleaning frequency for each kind of feed, membrane type and configuration.

The type of chemicals used in cleaning also affects the cleaning cycle and also the extent of permanent damage to the membrane and other components of the process. Generally, the membrane suppliers specify the type of chemicals to be used and their concentration and cleaning procedures. In the literature it is reported that the chemicals specified by the membrane manufacturers are not the best and other chemicals were tried as reported in the literature and are found more effective.

Research Approach

Adopt an appropriate research approach suitable for achieving the above objectives.

MP-6.6 Natural organic matter characterization in seawater around the Gulf and its relation to membrane fouling and pretreatment

MP-6.8 Development of training program guidelines to develop a training course targeted at plant operators in the Middle East.

MP-6.9 State of the art of wastewater purification by advanced desalination techniques

Objective

To conduct critical literature review aimed at focusing on this growing area of research and development in saline wastewater treatment by applying advanced desalination techniques.

MP-1.13 An integrated membrane operation in desalination of sea and brackish water

Objectives

The proposed research project focuses on the elaboration of an innovative technological approach in order to:

- Improve the efficiency of membrane desalination systems (combining the single membrane units in a globally optimized and compact integrated membrane desalination system; processing NF/RO retentate by Membrane Distillation/Crystallization units in order to increase the overall recovery factor – up to 95% - and to decrease the volume of concentrated wastes).
- Produce safe water (remove a wider range of contaminants – particular attention will be paid to boron - by using evaporative membrane units able to reach 100% retention of solutes, colloids, non-volatile organic contaminants etc.).
- Keep water costs affordable (decrease capital and operating costs).
- Ensure sustainability of desalination systems (facing the brine disposal problem by processing superconcentrated streams in order to produce crystalline salts with high purity, controlled shape and crystal size distribution).

Task 1: Modeling and optimization of the integrated membrane system
Task 1.1: Analysis and simulation of a Gas-Liquid Membrane Contactor unit.
Task 1.2: Analysis and simulation of a Membrane Distillation/Crystallization unit.

Task 2: Energetic and exergetic analysis of the integrated membrane system

Task 3: Cost analysis and sensitivity study of the integrated membrane system

Task 4: Experimental tests on Membrane Contactor units
Task 4.1 Experimental tests on Gas-Liquid Membrane Contactor unit.
Task 4.2 Experimental tests on Membrane Distillation/Crystallization unit.

Task 5: Running a Bench-Scale Prototype of Integrated Membrane Desalination System

MP-6.14 Study of the Adsorption-Membrane Filtration (AMF) hybrid process for Boron removal from RO permeate, Part 2: Evaluation of desorption circuit and advanced MF study

Objective

The main objective of this project (phase II) is to evaluate the desorption circuit in adsorption-membrane filtration (AMF) hybrid process through bench scale experiments, generation of data for design of AMF pilot plant and to assess the economic viability of complete AMF process.

Tasks

Task 1: Regeneration and recovery of chemicals

- Evaluation of BSR stability
- Recycling of acid from the brine (ED case)
- Boron as the by-product (sea mining)

Task 2: Fluids and materials characterization

- Determination of the sorbent stability
- Long time evaluation of sorbent deposition
- Membrane and sorbent material stability
- Sludge and suspension rheology

Task 3: Advanced study of MF of sorbent suspensions, simulation and design of AMF process

- Advanced study of cross-flow micro-filtration of concentrated adsorbent suspension in prolonged operation to estimate sustainable permeate flux and preferable mode of operation.
- Advanced study of micro-filtration of concentrated adsorbent suspension in submerged MF module in prolonged operation to estimate sustainable permeate flux and preferable mode of operation.
- Cleaning of polymeric and ceramic membranes in studied systems.
- Generation of data for design and operation of AMF pilot plant based on task3.
- Simulation and optimization of the AMF process based on data from all tasks.
- Economical analysis of the AMF process

Task 4: Optimization of resin regeneration conditions, running a bench top AMF system and its modeling

- Evaluation of BSR regeneration methods, selection of the most efficient case
- Running a bench scale system
- Modelling and optimisation of AMF system

NON-TRADITIONAL OR ALTERNATIVE PROCESSES

NT-1. Innovative Concepts

Objective

To encourage research and development in new desalination concepts, or to review and study the feasibility of desalination concepts that have not yet been fully explored, or to investigate new concepts for a component of a desalination process.

Background

In the past three decades R & D in desalination was essentially dedicated to improvements in what, today, can be labeled as the conventional desalination processes. Even in these processes, there are still many problems to be solved and there is still great potential for reducing the capital costs of the systems, as well as the costs of consumables, operation and maintenance.

Compared with the thermodynamic minimum separation energy, today's desalination methods are still very inefficient. The ancillary processes, like those for make-up water pre-treatment, incur high costs for installation, consumables and operation.

It is believed that there are still many meritorious concepts in desalination, which have not yet been fully explored. Many new theoretical and technical tools have been developed since the early days of desalination and many physico-chemical principles are better understood today. It may, therefore, also be worthwhile to re-investigate concepts that were labeled as failures in the past.

The objective of this request for proposals is to provide the initial funding for researchers to investigate or to study the feasibility of innovative concepts. This need not necessarily be a separation method, but could also concern a new solution for one of the ancillary processes in a conventional desalination system.

Research Approach

The type of investigation and the necessary approach will very much depend on the topic of research. These are, therefore, at the researchers' freedom to propose. Researchers are invited to propose the objectives and scope of their investigations. Some general requirements are as follows:

The investigation should contain a thorough literature survey to determine to what extent others have investigated the innovative concept.

A central topic of the project must be an investigation of the feasibility of the concept with respect to physical, chemical and design principles, with respect to energy and other consumables consumption in comparison with conventional technologies, with respect to manufacturing costs, etc.

The proposal for research is expected to convincingly illustrate the originality of the concept. It must also provide sufficient information for the Project Advisory Committee to evaluate the concept and the proposed approach, and to appreciate the goals of the project.

The Center will also consider proposals that deal with a description, an evaluation or an assessment of the potential comparison with conventional methods, of a number of innovative concepts that have been recently proposed or were considered as failures in the past.

NT-9 Development and analysis of the diffusion driven desalination process

Objectives

1. Experimentally measure the fresh water production rate and associated energy consumption required to pump water and air through the facility. Measurements will be made over a wide range of operating conditions in order to find an optimum condition where fresh water production is maximized with low energy consumption.
2. Develop a computational modeling tool that reliably simulates the thermal and mass transfer processes within a DDD facility. Such a tool has already been developed for the diffusion tower and the development of a modeling tool for the direct contact heat exchanger is required. The successful completion of this objective will allow the performance of a specified design to be predicted as well as provide design recommendations for a specific application.
3. Use the computational model to assess the required sizes for the diffusion tower, direct contact condenser, and associated secondary heat exchangers, pumps, and blowers applied to a commercial scale DDD plant.

Tasks

1. A detailed literature survey of direct contact heat exchangers and associated heat and mass transfer transport properties will be conducted.
2. A direct contact condenser will be fabricated based on design considerations recommendations from the literature, and will be installed in series with the diffusion tower to complete the fabrication of the bench scale DDD experimental facility.
3. A detailed computational model that simulates the heat and mass transfer processes within the direct contact condenser will be developed. This model will be combined with an existing model that simulates the heat and mass transfer processes within the diffusion tower. The combined model will simulate the entire desalination process and will be very useful as a design tool and a predictive analysis tool.
4. Extensive measurements of the heat and mass transfer coefficient within the condenser will be obtained. These will be used to calibrate a computer simulation for the condenser operation, and integrated with the diffusion tower simulation to provide a detailed simulation of the entire DDD process.
5. The fresh water production rate and pumping energy consumption through the DDD facility will be measured over a wide parameter space and compared with those predicted from the computer simulation.
6. Using the experimental results and aid of the computer simulation, the required size of the components within the DDD facility will be estimated.
7. The outcome of the experiments and results from the computer simulation will be used to make design recommendations for commercial scale facilities and will be useful in designing the pilot scale plant to be fabricated with FPL Corporation.

NT-10 Experimental and theoretical studies on integration of new PCM-based components in solar desalination

Objectives:

Examine the technical and economical feasibility of a PCM based humid air distillation system. The benefits of PCM storage in solar air distillation units shall be worked out and documented clearly.

Applying porous components, an optimum between porosity, pore-width and pressure loss has to be found in theoretical as well as experimental investigations. In a second step, characteristics of various PCM materials have to be compiled and an optimal solution has to be integrated into the process. Regarding the general plant setup, flow characteristics between evaporator and condenser as well as the dynamic thermal charging/discharging behavior of the PCM cans have to be studied carefully. An energetic simulation of the whole plant with periphery has to be performed in order to figure out suitable plant configurations.

Based on these studies, a test plant shall be built up and provide data for validating a simulation model. Given suitable meteorological data for continuously varying climate conditions, the detailed design and performance of the desalination plant can be optimized for every location and environment.

Tasks:

1) Theoretical studies on PCM materials including a compilation of switching temperatures, long-term stability in about 70.000 cycles, crystallization and melting behavior.

2) Elicitation of suitable encapsulating technologies, mainly welding of plastic cans. Evaluation of costs, mass manufacturing potentials and long-term stability.

3) Study of a preliminary evaporator and condenser design and assessment of the main influencing parameters. Based on these parameters, a detailed plan of the further experimental program and theoretical studies can be worked out and boundary conditions for both experimental plant and numerical simulation can be fixed.

4) Realization of different test series on non-PCM cubical and spherical filling material evaluating the flow characteristics using the existing evaporator test rig.

5) Adequate modification of the existing desalination test rig, add-on of suitable PCM condenser testing possibilities. Assessment of design possibility for realizing a discontinuous PCM wheel. Performance of systematical test series yielding characteristic maps of both evaporator and condenser behavior as a function of Reynolds-number, brine mass flow, brine temperature. Assessment of suitable operation strategies.

6) Enhancement of an existing energetic model describing the plant configuration based on the dynamic simulation platform “TRNSYS”. Therefore, characteristic maps measured in 5) serve as a crucial boundary condition. Assessment of different

plant configurations and operation strategies with given meteorological data (Egypt, India, Spain, others).

7) Development of a thermodynamic model and use of computational fluid dynamic modeling (FLUENT) to have a good comprehension of the physical phenomena in the desalination module. With the thermodynamic model, heat and mass transfer coefficients and transient phase change phenomena in the porous bed can be determined.

8) Topics 6) and 7) shall be iterated, until detailed predictions of an optimal design and performance of the plant can be made for every suitable location and environment throughout the world. Numerical results can be validated with experimental data, and can therefore yield high accuracy.

9) Accompanying the numerical studies, the already existing test rig shall be enlarged and adapted stepwise, until a close-to-production prototype of the system is available in the laboratories of Technische Universität München. Future field tests should be made in Egypt, but due to the tight working schedule should not be part of the present studies.

Deliverables:
- Comprehensive periodic reports every 6 months
- Comprehensive Final Report
- Ph.D. Thesis by student Abdel Hakim M. Hassabou

NT-11 Development of a solar still desalination system with enhanced productivity

Objective

The objective of this project is to increase the productivity of solar still desalination system while maintaining their simplicity, relatively low cost, and ease of operation and maintenance.

Tasks

1. Setting up the solar still system: Build the experimental still using different materials for the proposed modifications. All the systems are to be constructed taking into account the optimal design parameters as found in the literature.
2. Selecting the best materials for the proposed modification: Compare the performance of the constructed stills in terms of both quantity and quality the distilled water produced.
3. Determining the optimal design characteristics: For the best performing material, further experimental work is required to determine the optimal geometrical and operational parameters relevant to the proposed design
4. Developing a simulation model for the proposed still: The objective is to obtain a descriptive behavior of the proposed solar still by correlating productivity with relevant climatic and operating conditions.
5. Model calibration and validation: The developed model is calibrated based on records of collected data that include technical, operating and climatic conditions
6. Analysis of results

OPERATION AND MAINTENANCE ISSUES

OM-3 Preventive maintenance

INTAKE AND OUTFALLS

IO-3 Literature Survey of Intake / Outfall Systems for Desalination of Brackish and Seawater – Including Structures, Materials of Construction

Objective

To perform a critical literature review of the intake and outfalls systems, which are in current practice, including the problems encountered with structures, materials of construction etc.

Background

Intake and outfall systems form significant components in a desalination process. The type of process selected for these systems will alter the cost of desalination and affect the environment. Thus proper system selection is critical for the various desalination processes based on the available resources.

There is not much published literature on these topics. It is suggested to collect the information from company's brochures and other documents. Collected references and review details should be compiled in such a way to help the process designer in selecting the appropriate systems.

Research Approach

- Collect the literature related to all the intake and outfall systems including the structures and materials of construction from the published literature and companies brochures.
- Review the collected literature clearly highlighting the merits and drawbacks in the context of their specific application.
- Provide general guidelines for the selection of appropriate intake and outfall systems for various desalination technologies and feed water sources.

IO-4 Survey of Existing Models and Development of improved Simulation for Discharge Brine Dispersion

Objective

To perform a detailed survey and to recommend/develop concentrate dispersion models for the concentrates discharging into the seawaters.

Background

Immense volumes of concentrated seawater and brackish water, in some cases a few degrees above ambient are discharged continuously into the environment. Although it is known that some mathematical models exist for predicting dispersion of this concentrate into the receiving waters, most have been developed for the dispersion of fresh water into seawater. Recently, some efforts have been made to either adapt existing models, or to develop new ones, to take into account the effect of increased specific gravity and elevated temperature in the application of the model. Without this feature, accurate prediction of plume shape and size, distance and direction of travel and rate of mixing to near-homogeneity is not possible.

Rapid dispersion of concentrate plumes in predictable directions and depths will permit a more accurate assessment of the ecological impact of the plume on the marine environment of the receiving water. This knowledge will then permit the design and location of outfalls to minimize the impact on the marine environment, possibly avoiding the decimation of native species due to increased salinity or temperature.

Research Approach

This project should concentrate on critical review of the concentrate dispersion models. The available models should then be evaluated for their applicability to the adaptation for predicting the dispersion phenomena of concentrates discharged into the seawaters and provide the recommendations to make the existing models suitable for the purpose. The existing models may then be modified or new models may be developed to be suitable to the regional conditions, and then calibrate at various sites in the MENA region in the next phase.

ENERGY ISSUES

EG-5 Development of Robust and Energy Efficient Small Desalination Systems

Objective

To encourage the development, the assessment of feasibilities, the testing, and the improvement of new designs or concepts for small desalination systems or an essential component

Background

There is a large demand for small desalination units, not only in locations not connected to a water supply network, but also as units for additional or independent supply, for cheap or waste energy exploitation, for water supply on construction sites, in tourist resorts, etc. Apart from the general demand for reducing the installation costs and energy consumption, the specific requirements in these applications are: robustness, simplicity of hardware and operation, easy transportation to site, minimization and availability of spare parts, and simple intake systems and pretreatment. There are a huge number of small units worldwide, which went out of operation soon after installation because they did not satisfy these requirements.

Research Approach

This request for proposals is not restricted to a particular desalination principle or source of energy. The emphasis is on innovative solutions and on satisfying the requirements for small desalination units as indicated above. Very roughly, the size limit can be about 5 m^3/day and suitable to transport as a package by road. The project program and the approach will be determined by the status of development of the system concerned and is, therefore, at the researcher's freedom to propose.

EG-7 Assessment of Integrated Energy Recovery Systems

Objective

To critically assess the integrated energy recovery systems reported in the literature or in practice in reverse osmosis desalination plants.

ENVIRONMENT ISSUES

EV-1 Assessment of the composition of desalination plant disposal brines

Objective

To collect and provide comprehensive data and information on the composition of disposal waters from plants undertaking the desalination of seawater.

Project Tasks

Task 1: General introduction to the technology and the waste streams

- Summary of desalination technology processes, categorization for purposes of this research. [GU]
- Initial identification of generic types and specific substances present in waste streams [GU, STL, ARSU]
- Summary of procedures in the development of an Environmental Impact Assessment, 'EIA'. [GU, STL, ARSU]

Task 2: General literature review of composition of disposal brines

- General review of previous work on individual substances/species in reject streams, as identified in the "Overview" above, sub-classified into thermal and RO processes and including impact on bio-systems. [ARSU, GU]
- Output of Task 2.1 to be organized into a data bank. [ARSU]

Task 3: process specifics: MSF re-circulation plant

- Multistage Flash Distillation (MSF): General treatment of water discharges from a "standard re-circulation plant" (e.g. 1 MGD or 5 MGD): discharge rates of brine, brine concentration, temperature, acids, alkalinity, ejector condensates, chlorine and chlorinated compounds oxygen content (relevant to bio-systems): seasonal variations, operational variations. Identification of process operating parameters, that influences discharge quality (e.g. acid cleaning procedures, start-up/shutdown). Distinctions in relation to plant emissions associated with the operation of MSF plants in the (very rare) once-through mode as opposed to the normal re-circulation process [GU, STL, ARSU].
- Multiple Effect Distillation (MED): General treatment of water discharges as summarized above in 3.1 [GU,STL, ARSU].
- Specific treatment of corrosion products - overview of materials selection practices and subsequent corrosion phenomena and corrosion product discharges. This task to involve consideration of different ages of plant - reflecting evolution of materials selection philosophy + anti-corrosion procedures + leachates form polymeric components [STL, GU].
- Specific treatment of scale-control strategies; the emphasis will be on the conventional use of scale-control additives (including reactions with other chemical constituents) but some consideration will be given to alternative scale-control procedures (use of membranes, ion exchange) that have been

considered for use to facilitate increased top brine temperatures in MSF units [GU, ARSU].

- Other pre-treatment issues: e.g. anti-foams, chlorination (including specific issues associated with on-site electrochlorination units) [GU, ARSU].
- Post-treatment issues: General review of post-treatment procedures and any impact on discharges [STL, GU].
- Other effluent issues: detergents, cleaning chemicals, lubricants [STL, GU].
- Identification and treatment of wastewater contaminants from thermal plant in operating modes such as acid cleaning. State-of-art procedures currently practiced to reduce environmental impact of the contaminants. Summary of possible additional wastewater treatment measures to meet future environmental discharge regulations. Identification of preferred discharge modes for certain types of waste streams (e.g. from cleaning processes). [STL, GU].
- Aspects associated with power production equipment: There are two aspects of this task:-

  Examination of any issues associated with coupling of thermal desalination plant with power plant (i.e. in dual purpose configuration) but ONLY in as much as this plant configuration affects discharges from the desalination plant [GU, STL]

  Investigation of any information, relevant to desalination equipment, from UK, marine-sited, power plant; the basis of this activity is the similarity between power-plant condensers and the heat-reject section of a multistage flash plant [STL, GU]

- Identification of reference plant/monitoring programs where effluent contaminants from appropriate thermal plant can be monitored. Summary of contaminants and analytical monitoring program [STL, GU, SQU]

Task 4: Process specifics: reverse osmosis (RO) plant

- General treatment of water discharges from a standard-sized plant: Discharge rates of brine, brine concentration, temperature, acids, alkalinity, chlorine complexes, oxygen content (relevant to bio-systems), implications of trends towards increasing recovery ratios. Identification of process operating parameters that influence discharge quality (e.g. membrane cleaning procedures, start-up/shutdown). [GU, STL].
- Issues related to different regimes of feed treatment in RO: including the effects upon discharges of the current trend towards membrane pre-treatment in place of conventional pre-treatment [GU].
- Specific treatment of corrosion products: overview of materials selection practices and subsequent corrosion phenomena and corrosion product discharges. [STL, GU].
- Specific treatment of scale control additives: [GU].
- Membrane cleaning agents [GU].
- Post-treatment issues: general review of post-treatment procedures and any impact on discharges [STL, GU].
- Other effluent issues: detergents, cleaning chemicals, lubricants [STL, GU].
- Identification and treatment of wastewater contaminants from RO plant in operating modes such as membrane cleaning. State-of-art procedures currently practiced to reduce environmental impact of the contaminants. Summary of possible additional wastewater treatment measures to meet future environmental discharge regulations. Identification of preferred discharge modes for certain types of waste streams (e.g. from cleaning processes). [GU, STL].

- Identification of reference plant/monitoring program where effluent contaminants from appropriate RO plant can be monitored. Summary of contaminants and analytical monitoring program [STL, GU, SQU]

Task 5: Hybrid (thermal/RO) plant:
A brief consideration of the likely "differences" in emissions between such hybrid systems and separate units [GU]

Task 6: Disposal configurations:
Survey of design/configurations of brine discharge lines from selected MSF and RO plants including influences/interactions with Power Station cooling water discharge [SQU]

Deliverables

1. Summary of procedures for the development of an Environmental Impact Assessment 'EIA'.
2. General review of previous work on individual substances/species in reject streams of MSF, MED and RO processes
3. Databank of the individual substances in reject streams of desalination plant.
4. Flow sheets of the various desalination processes illustrating the origins of each constituent of the discharge streams.

EV-5 Near field mixing of desalination plumes

Objectives

The objective for this project is to improve the current understanding of the near field mixing that takes place once effluent from a desalination plant is released into the environment, so that more accurate assessment of potential environmental impacts and the necessity of mitigation measures can be made.

TASKS

Task 1
Carryout extensive physical experiments with the saline water simulating RO and MSF plant discharge brines employing advanced optical instrumentation (Laser-Induced Fluorescence and Particle Tracking Velocimetry) to obtain detailed velocity and concentration field information for a wide range of initial conditions (discharge angles and densimetric Froude Numbers).

Task 2
With the detailed information from the physical experiments a quantitative assessment of the impact on the near field processes of the increased mixing in the region where the flow reverses direction vertically, noted in previous studies will be assessed; as well as the influence of the competing buoyant processes associated with the thermally generated, or combined, effluents.

Task 3
The generality of findings based on the physical experiments will be explored across the parameter space using numerical simulations, which will be based on standard computational fluid dynamics code. These simulations will be validated with the new physical data and it is anticipated that they will provide further insight into the behavior of these flows, because of the increased level of detailed information they provide.

Task 4
With the increased understanding gained from the physical experiments and numerical simulations, an assessment of our ability to model these flows using traditional techniques (integral models) will be assessed. If appropriate, methods of upgrading such models will be developed and made widely available. If not, a further assessment of the practical application of computational fluid dynamics code to modeling these flows will be made.

EV-6 Environmental planning, prediction and management of brine discharges from desalination plants

Objectives

Sea water desalination plants discharge a concentrated brine effluent into coastal waters. Modern, large capacity plants require submerged discharges that ensure a high dilution in order to minimize harmful impacts on the marine environment. Existing design practice is limited to poor modeling concepts and a very heterogeneous or weak regulatory base. Stakeholder opinions vary from "negligible very localized impacts" up to major objections leading to significant project modifications and unnecessary delays.

The Objective this project is to develop a modeling framework for the environmental-hydraulic design of the outfall system for desalination plants based on the following:

1. Identification of environmental impacts, regulatory frameworks and public concerns regarding brine effluent discharges with emphasis on MENA (Middle East, North African) and Mediterranean countries.
2. Elaboration of easily applicable design nomograms including the density dependence on salinity and temperature as basis for the first screening process within the assessment of brine effluents after discharge into the receiving coastal waters.
3. Development of hydrodynamic model interfaces for predicting brine effluent concentrations of key parameters in the marine environment by coupling a near-field mixing model for outfall design optimization with a far-field transport model for optimized outfall site.
4. Model application and validation for typical case studies for the compilation of design recommendations with parallel improvement of design oriented input/output features.
5. Management and realization of capacity building on environmental planning, prediction and management of brine discharges from desalination plants.

TASKS

Task 1: Identification of environmental issues and regulatory / planning needs
A thorough survey of typical effluent characteristics from desalination plants, environmental impacts and effects on the marine ecosystem caused by brine discharges, existing designs and regulations on effluent discharges in MENA and Mediterranean countries and available planning tools and synchronization of experimental data for model validation will be performed

Task 2: Nomograms and engineering screening equations
Nomograms consisting of a density calculator based on the typical characteristics of brine effluents and coastal waters in the considered project regions will be developed. The density calculator will be used to elaborate nomograms to define the density variation and estimates for general plume characteristics depending on the discharge and receiving water parameters. Simple screening equations on initial effluent dilution will be adopted based on similar approaches for wastewater discharges and conservative simplifications.

Task 3: Development of model coupling interface
For the prediction of the brine effluent concentrations in the marine environment an interface for coupling near-field mixing models with far-field transport models will be

developed. The model development will expand on an existing modeling approach for wastewater discharges by applying the new interface for the coupling of the near-field model CORMIX with the research based SQU transport model and the commercially used Delft3D (Delft Hydraulics) model.

Task 4: Optimal design and final assessment of the brine discharge system
With the help of the developed software tools, the optimal approach to design and assess brine discharges will be determined by the application of optimization algorithms, sensitivity analysis and case studies:

Task 5: Capacity building: training, workshops and beta-testing
A capacity building process is planned to improve the final products and as an important step for the product transfer to the user community.

HYBRID DESALINATION PROCESSES

HP-3 Membrane Development to Meet the Requirements of Hybrid Desalination Systems

Objective

To develop robust and high permeability seawater reverse osmosis membranes suitable for integration in distillation-RO hybrid desalination plants.

Background

The concept of power generation and desalination with hybrid distillation and reverse osmosis plants has attracted attention for a number of reasons in recent years.

- There has been considerable progress in RO technology.
- Increasing demand for water in locations with thermal desalination plant
- Integration of a RO plant into an existing dual-purpose thermal system can be more cost effective than a new plant
- The seawater intake and the out-fall can be shared, reducing their specific size
- Part of the pre-treatment of the raw water can be integrated and shared, providing a potential for improved and cheaper fouling control.
- Even at high seawater salinity only one RO stage is required if RO permeate is blended with the distillate of the thermal plant, which can also reduce the costs for post-treatment.
- In periods of low electrical power demand the RO system can be put in operation to utilize excess power.
- The general hybrid plant concept would be to use the heat rejection water of the thermal system as feed water for the RO plant. The temperature of this feed is in the order of 6 to 12 K higher than the seawater temperature.
- Whereas the permeability of a membrane increases with temperature, there are no membranes for large RO plant application with the robustness to provide a long service lifetime at elevated temperatures.

The objective of this project is to contribute to the development of such a membrane and its module.

Research Approach

The strategy and method of approach to develop a suitable membrane for hybrid distillation-RO systems are at the researchers' freedom to propose. The Center realizes that membrane development can be very costly and has been mainly pursued by membrane manufacturers.

HP-4 Process integration with air conditioning systems

HP-5 Process integration with waste heat utilization

HP-6 Energy optimization of dual-purpose power and desalination plants

CERTIFICATION PROGRAMS

CP-2 Development of standards for plant commissioning

CP-6 Develop standards (ISO) for desalination costs

ASSESSMENT STUDIES

AS-4 Electrochemistry of Seawater

Objective

To prepare a state of the art document consolidating the chemical reactions and physical factors responsible for fouling, scaling and corrosion in thermal and membrane seawater desalination processes.

Background

Seawater is a dilute electrolyte solution of inorganic compounds with organic matter and bacteria. It also contains other insoluble suspended contaminants. The composition and contaminants change depending on the location.

The constituents of the seawater are responsible for fouling, scaling and corrosion in thermal and membrane desalination processes and the basic mechanism of these processes involve chemical reactions and physical interactions. Pretreatment and post treatment operations also involve various chemical reactions. A comprehensive compilation of all reactions including the mechanism and kinetic information will be helpful in understanding the phenomena and controlling them in order to improve the performance of desalination processes.

A team of experts with good background in electrochemistry and desalination processes is required for executing this project.

Research Approach

Adopt the research approach required to achieve the above project objectives.

AS-5 Electrochemistry of Corrosion with Seawater

Objective

To review the literature related to the chemistry of corrosion and corrosion behavior of materials used in desalination processes in the operating range of different desalination processes.

Background

The corrosion of metals in seawater and brines (which are electrolytes) is an electrochemical process. The chemistry of electrochemical processes of various metals in seawater/brine is complex involving various chemical reactions. The composition of metal, the composition of liquid, the dissolved gases, and the temperature all affect the different reaction rates responsible for corrosion. Other parameters like flow characteristics also influence the corrosion rates.

Center has already sponsored a project for material selection to improve the corrosion resistance in thermal desalination with the following objectives.

- To provide a comprehensive survey of the literature, tender specifications and end users views of materials performance in MSF and MED units over the past 25 years.
- To elaborate a standard material selection based on the results of initial survey, together with a cost analysis looking at the relationship between cost and performance.
- To identify new materials with the potential for use in the various services in desalination plants that would improve corrosion resistance and decrease overall costs.

But it is essential to understand the basic corrosion phenomena of the various metals used in different desalination processes. A large number of publications dealing with this subject have been published which requires a thorough review.

Research Approach

Adopt the research approach required to achieve the above project objectives.

AS-6 Use of aquifers for the storage of desalination water

AS-8 Privatization of water desalination in Oman

Objectives

To Study the privatization of desalination projects in Oman with emphasis on its strategy, planning and regulations, and to provide over view of Oman experience in privatization of such projects thorough one of the existing/new privatized project of a capacity of not less than 10 MGD Plant.

In this study the conceptualization and argumentation for the privatization of desalination projects will be briefly reviewed, then address the move towards privatization in Oman, and identify the main issues for this development. This shall include the Oman experience on implementation of such Independent Water Desalination Projects ('IWP).

Tasks

The following are the main tasks of the project.

1. Description of research methodology
2. Literature survey
3. Survey and review of desalination projects in Oman with special emphasis on investment costs, operating costs and unit water costs including the government subsidies.
4. Review of privatization concepts of desalination projects and privatization polices and regulation in Oman.
5. Development of planning, management and tendering procedures/methodologies for privatization of desalination projects.
6. Case study: Experience of execution and monitoring of a privatized desalination project in Oman.
7. Economics and criteria for the tariff/costs calculation of desalinated water produced from such private project.

AS-9 An investigation of total composition of sea water in oman

Objectives

- To collect seawater samples at ten locations in Oman over a period of one year at two different time intervals winter and summer and analyze these samples for complete composition.
- To tabulate the total composition data for the ten locations and submit the report to MEDRC.

Tasks

4. Collect samples of seawater from ten locations in Oman during the Winter and the Summer.

5. Carry out a total composition analysis including the following summarized parameters (total 64 parameters)
   - Hydro-meteorological Information
   - General
   - Particulates
   - Alkalinity & Hardness
   - Nutrients
   - Major Ions
   - Other Inorganics
   - Organic Matter
   - Metals

6. Tabulate the total composition data analyzed for the samples collected at the ten different locations in Oman and briefly describe the methods used for analysis over a period of one year.

SOFTWARE PACKAGES

SP-6 Development of web based computer package for simulation of Thermal and membrane desalination processes

Objectives

Develop a web based computer simulation program compatible to place them on MEDRC's website, for the major desalination processes, which includes:

- Single effect mechanical vapour compression,
- Multiple effect evaporation with/without thermal or mechanical vapor compression,
- Multistage flashing with brine circulation, and
- Reverse osmosis

Tasks

1. The first task involves review, evaluation, and development of web based simulator for single effect mechanical vapour compression desalination process. This task will also include preparation of user manual for the mechanical vapour compression model. The user manual includes process description, current market status, model assumptions, model equations, solution algorithm, case study, and visual basic displays. The task includes three main steps: (a) Model development and review by PAC. (b) Code preparation, and (c) Code testing.
2. The second task involves review, evaluation, and development of web based simulator for the multiple effect evaporation process with/without thermal or mechanical vapor compression desalination processes. This task will also include preparation of user manual for the multiple effect evaporation with/without thermal or mechanical vapor compression model. The user manual includes process description, current market status, model assumptions, model equations, solution algorithm, case study, and visual basic displays. The task includes three main steps: (a) Model development and review by PAC. (b) Code preparation, and (c) Code testing.
3. The third task involves review, evaluation, and development of web based simulator for the multistage flash desalination process with brine recycle. This task will also include preparation of user manual for the multistage flash desalination model. The user manual includes process description, current market status, model assumptions, model equations, solution algorithm, case study, and visual basic displays. The task includes three main steps: (a) Model development and review by PAC. (b) Code preparation, and (c) Code testing.
4. The fourth task involves review, evaluation, and development of web based simulator for reverse osmosis desalination process. This task will also include preparation of user manual for the reverse osmosis model. The user manual includes process description, current market status, model assumptions, model equations, solution algorithm, case study, and visual basic displays.

The task includes three main steps: (a) Model development and review by PAC. (b) Code preparation, and (c) Code testing.

5. Task five is conducted in parallel to the first four tasks. The task involves web publishing of the four simulators. Also, it will involve testing by clients and subsequent review and necessary modifications. The publishing duration for each simulator extends over a period of two months.
6. Task six will involve preparation of the entire user manual. This will be made by integrating the four user manuals prepared during the work course. The final user manual will reflect any modifications or changes made during the project and subject to client comments and requests.

Deliverables

1. Develop a web based computer package, for publication on MEDRC's website, for design and simulation of thermal and membrane desalination processes, which allows users to execute the computer package and select the desired process; ownership and copyright of which will belong to MEDRC hence Clauses 11.0 and 13.0 of this Agreement do not apply.

2. Develop and provide MEDRC with a user manual including brief description of each process, model equations, assumptions, solution algorithm, case study, visual basic displays and procedures to place them on MEDRC's website. Provide MEDRC with a copy of the source code for the entire package upon completion of the project, ownership and copyright of which will belong to MEDRC hence Clauses 11.0 and 13.0 of this Agreement do not apply.