Patterned Water Desalination Membranes

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• Water resources and desalination in Egypt
• Overview about CEST and its activities
• Patterned RO membranes
• Ideas for new joint projects/initiatives
Water resources

Maplecroft 2010

- Access to improved drinking water and sanitation
- The availability of renewable water
- The relationship between available water and supply demands
- The water dependency of each country’s economy

Egypt is ranked number 8 out of 165 nations in ‘Water Security Risk Index’
Actions needed to solve some of the problems:

- Efficient management of water usage
- Reduction of water pollution
- Treatment and reuse of wastewater
- Desalination of brackish and seawater

ALL NEED Qualified PERSONAL
Desalination processes

Distillation
- Multi-stage flash
- Multi-effect boiling

Membrane
- Reverse osmosis
- Electrodialysis
- Forward osmosis

Two-phase processes
Membrane based processes

Membrane distillation
Desalination market

Desalination plants by technology:

RO is dominating

Top 10 desalination countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Desalination Capacity</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Saudi Arabia</td>
<td>10,759,693 m³/d</td>
<td>17%</td>
</tr>
<tr>
<td>2) UAE</td>
<td>8,428,456 m³/d</td>
<td>13%</td>
</tr>
<tr>
<td>3) USA</td>
<td>8,133,415 m³/d</td>
<td>13%</td>
</tr>
<tr>
<td>4) Spain</td>
<td>5,249,536 m³/d</td>
<td>8%</td>
</tr>
<tr>
<td>5) Kuwait</td>
<td>2,876,625 m³/d</td>
<td>5%</td>
</tr>
<tr>
<td>6) Algeria</td>
<td>2,675,958 m³/d</td>
<td>4%</td>
</tr>
<tr>
<td>7) China</td>
<td>2,259,741 m³/d</td>
<td>4%</td>
</tr>
<tr>
<td>8) Qatar</td>
<td>1,712,886 m³/d</td>
<td>3%</td>
</tr>
<tr>
<td>9) Japan</td>
<td>1,493,158 m³/d</td>
<td>2%</td>
</tr>
<tr>
<td>10) Australia</td>
<td>1,184,812 m³/d</td>
<td>2%</td>
</tr>
</tbody>
</table>

Source: GWI DesalData/IDA
Desalination market

Desalination capacity growth

- In 2010: global capacity is 68.3 million m³/d
- 17% annual growth since 1990

Top 10 desalination companies

<table>
<thead>
<tr>
<th>Rank</th>
<th>Company</th>
<th>Capacity (m³/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Veolia Environment</td>
<td>5,420,072</td>
</tr>
<tr>
<td>2</td>
<td>Fisia Italimpianti</td>
<td>3,025,344</td>
</tr>
<tr>
<td>3</td>
<td>Doosan</td>
<td>2,852,305</td>
</tr>
<tr>
<td>4</td>
<td>GE Water</td>
<td>2,471,987</td>
</tr>
<tr>
<td>5</td>
<td>Suez Environnement</td>
<td>1,528,710</td>
</tr>
<tr>
<td>6</td>
<td>Befesa Agua</td>
<td>1,387,624</td>
</tr>
<tr>
<td>7</td>
<td>ACS (Cobra/Tedagua/Drace)</td>
<td>1,312,347</td>
</tr>
<tr>
<td>8</td>
<td>Hyflux</td>
<td>1,121,508</td>
</tr>
<tr>
<td>9</td>
<td>Acciona Agua</td>
<td>1,111,516</td>
</tr>
<tr>
<td>10</td>
<td>IDE</td>
<td>1,001,730</td>
</tr>
</tbody>
</table>
The cost depends on:
1- Energy costs vary over time and geography
2- Quality of seawater (concentration of salt)
3- Transporting of the water and disposal of the brine
4- Government subsidies
5- Plant size

Example of the calculated costs from literature:

<table>
<thead>
<tr>
<th>Process</th>
<th>Cost Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>RO</td>
<td>0.45-0.92 $/m3</td>
</tr>
<tr>
<td>MED</td>
<td>1.17-1.49 $/m3</td>
</tr>
<tr>
<td>MSF</td>
<td>1.10-1.50 $/m3</td>
</tr>
</tbody>
</table>
Road map published in 2007

Desalination Technology
Roadmap 2030

Prepared by
Reham Mohamed Yousef
Mostafa Lotfy Sakr

Supervised by
Dr. Abeer Farouk Shakweer

Dr. Diaa El Quosy, Advisor to the Minister of Water Resources and Irrigation, for his supervision of the project.
Dr. Hassan El Banna, Professor, Faculty of Engineering, Alexandria University and
Dr. Boshra Salem, Professor, Faculty of Science, Alexandria University
Vision

“Develop desalination technologies that aim to secure cost-effective, drinkable, fits for its uses and sustainable water for Egypt till 2030”

Mission

- Identification of specific desalination technology areas for meeting the national needs.
- Nature, timing and estimated cost of the required research and/or development programs.
- Priorities of technology development projects.
Our vision

- Collaboration with UDE, TUD, EGNC, FU
- Funding from DAAD, DFG, BMBF, NSF, STDF
- Partnership
- Innovation
- Research and Development
- Teaching and practical training

CEST
Scope of the work

Optimization of Surfaces and Interfaces for:

- Printed Electronics
- Water Treatment & Desalination
- Solar Energy
IWaTec

Development of a Postgraduate Program in Integrated Water Technologies for Egyptian Students (IWaTec)

- **Duration**: 3 years (2012-2015)
- **Total budget**: 340,000 Euro from DAAD
- **Coordinator from the Egyptian side**: Ahmed S. G. Khalil

**Partners:**
1. Fayoum University
2. Univ. Duisburg-Essen, Germany
3. EGNC
4. National Research enter
5. Holding Company for Water
Intensive 6-months program for postgraduate students

Germany
- Summer school
- Education and Research stay
  - Lectures
  - Seminars
  - Practical courses
  - Research work (Master Thesis) with joint supervision

Egypt
- Winter school
- Practical training (Institute or Company)

Duration: 6 months
- 2 weeks
- 4 months
- 2 weeks
- 1 month
IWA Tec students and researchers

Visit EGLV Waste Water Treatment Plant Bottrop

Dr. Azeem, Dr. Gad-Allah, Dr. Ibrahim, Prof. Teichgräber, Prof. Shendi, Dr. Khalil
Organization of the Egyptian-German Workshop on Sustainable Water Technologies

Total budget: 30,000 Euro from DAAD

278 participants & 30 oral presentations & 44 poster presentations
Water Tech. Lab at FU
Solar System Design Using Advanced Learning Aids (SOLEDA)

- **Partners:**
  - Egypt Nontechnology Center, Egypt
  - Fayoum University, Egypt
  - Cairo University, Egypt
  - South-Valley University, Egypt
  - German-Arab Chamber, Egypt
  - Resala Charity organization
  - Bahnas IC, Egypt
  - Aachen University for applied sciences, Germany
  - Hariot Watt University, UK
  - University of Complutense Madrid, Spain
  - Vella Solaris, Italy, Italy
  - Agricultural University of Athens, Greece

- **Duration:** 4 years (2012-2015)
- **Co-PIs:** R. Ghannam & A. S. G. Khalil
- **Total budget:** 1,150,437.99 Euro from EU Tempus
Polysun software packages
PV driven RO desalination system

1. Main parts of the unit

- Transformer 220/110VAC to 48VDC
- Transformer 220/110VAC to 24VDC
- Pump Controller PS600
- Unit Controller
- Accu
- Activated Carbon Filter
- Prefilter 25μ
- Spectra Pump
- 5μ Filter
- Feed Flow Meter
- Different Pressure Meter 5μ Filter
- Shurflo Pump
- Flush Tank 42L
- Level Switches
Excellence in Nanoscience Education for MENA Region

1- Arab academy for Science, Technology and Maritime Transport
2- Cairo University
3- Fayoum University
4- South Valley University
5- German-Arab Chamber of Industry and Commerce
6- Zewail City of Science and Tech

7- Jordanian University of Science and Tech.
8- German Jordanian University

9- Technical University of Darmstadt
10- Karlsruhe Institute of Technology

11- University of Carthage
12- Sousse University
13- Lund University
14- University of Rovira I Virgili
15- Pierre and Marie Curie University
“Surface and Interface Engineering of Integrated Systems” (SURSYS)

Duration: 3 years (2013-2016)
Total Budget: 230,000 Euro from DAAD
PI: Ahmed S. G. Khalil & Co-PI: Rami Ghannam
Partners: Univ. Duisburg-Essen (M. Ulbricht) & TU Darmstadt (E. Dorsam) & Max Planck Institute (F. Marlow), Germany
Fayoum University & Cairo University, Egypt

Team: 4 PhD students & One Posdoc

Ongoing sub-projects

- Formulation and printing of nanoinks for electronic and optoelectronic devices
- Fabrication of smart anti-fouling stimuli-response NF and RO membranes
- Performance enhancement of solar cells using low cost methods
Funded project from the ministry of higher education

Training Center at Fayoum University for RE & Water Des.

Funding from PMU

Practical Training

Advanced Education
Capacity Building Grant on Membrane Science and Technology

11 Million L.E

STDF
Science and Technology Development Fund
Capacity building project

Scanning Electron Microscopy

Capillary flow porometer

Contact angle systems

Zetasizer
Fabrication of functional membranes

Ongoing sub projects:

- Fabrication of microfiltration membranes using electrospinning system
- Fabrication of NF and RO membranes using phase inversion and interfacial polymerization
- Testing commercial membranes for the removal of disinfection by products in drinking water
IWA Tec project

Fabrication of micro and ultrafiltration membranes by electrospinning:
Custom inkjet printing system

Kareem Salah Elassy
Inkjet Printing of Electronic and Optoelectronic Devices

PIs: Ahmed S. G. Khalil & V. Subramanian of UC Berkeley, USA
1 PhD student: Kareem Elassy & Postdoc: Dr. Rania Elsayed
Inkjet Printing of Silver lines on Silicon:
Chemical Vapor Deposition: CNT
Graphene
Two new projects - To be started

Project 1:

• Funded by Erasmus+ with total funding of 150,000 Euro.
• Student/researcher exchange
• Partners: UDE, FU and AASTMT

Project 2:

• Funded by BMBF-STDF (GERF) with total funding of 200,000 Euro.
• Partners: FU, UDE, Magawesh Comp, Inge Membrane in Germany
• 3 PhD students and one Postdoc will be involved.
Patterned RO Membranes (J. Memb.Sci. 2015/2017)

**Aim of Work**
- High performance TFC water desalination membranes

**How?**
- Enhance flow behavior & increase water permeability
- Promote antifouling & anti-scaling properties

**Strategy**
- Surface topography
  - Increase active surface area
  - Controlling surface roughness
  - Improve feed circulation
  - Reduce boundary layer
  - Minimize concentration polarization

- Surface Modification
  - Reversible Super-Switching
  - Control surface wettability
  - Enhance fouling resistance
  - Improve cleaning efficiency

**Feed**

**Boundary layer**

**Grafted polymeric hydrogel**

**Cross-linked PA layer**

**Micro-structured support**
**WP1: Optimization of hydrophilic, highly water permeable and robust isotropic PES base membranes**

- The key factors determining phase inversion membrane morphology:
  1. The choice of solvent: non-solvent system.
  2. The composition of casting solution.
  3. Choice of coagulation / precipitation conditions.

- Membrane casting system was as following:
  1. Commercial PES (Ultrason E6020P, bulk density: 200 - 300 g/l) as base polymer.
  2. NMP as solvent, high boiling point solvent that requires long evaporation time so it promotes VIPS process.
  3. PVP (K-30) as macromolecular additive, controls viscosity, delays demixing, and increases porosity and hydrophilicity.
  4. TEG as a hygroscopic specified non-solvent additive, determines the stability of the dope casting solutions.
  5. VIPS process should be carried out prior to NIPS, R.H. = 80 %.
Pore size of PES membrane

- Pore characteristics for flat PES membranes prepared from different casting solutions (PES:PVP:NMP:TEG) at the same conditions

Exposure time: 3 minutes
Transport characteristics for flat PES membranes prepared from different casting solutions (PES:PVP:NMP:TEG) at the same conditions.
Wettability of PES base membrane

- **Contact Angles for flat PES membranes prepared by different casting solutions (PES:PVP:NMP:TEG) at the same conditions**

![Graph showing contact angles for different PES membranes](image_url)
Effect of the exposure time

- **Size (nm)**
  - IB8_5: 173, 135
  - IB8_30: 180.1, 127.5
  - IB8_1: 161.1, 120.4
  - IB8_3: 279.7, 134.5

- **Water permeability (L/h.m².bar)**
  - Before compaction
  - After compaction

- **Legend**
  - Bubble point pore diameter
  - Mean flow pore diameter
  - Before compaction
  - After compaction
Morphology

IB6

IB8
WP2: Optimization of low-cost surface patterning technologies: Synthesis of micro-structured PA desalination membranes

Schematic representation of the phase separation micromolding process

Anisotropic pore size distribution skin formation should be avoided.

Pre-optimized casting solution is used.

Casting conditions had to be adapted to achieve maximum conformity and hold the replicated features over the entire membrane surface.

(1) Exposure time to humid air.
(2) Treatment of PDMS molds
**WP2: Optimization of low-cost surface patterning technologies:**
*Synthesis of micro-structured PA desalination membranes*

**Methodology**

1. **Patterned Stamp**
2. **Membrane to be patterned**
3. **NIL under temperature and pressure for particular time**
4. **Submicron surface patterns successfully imprinted on the membrane surface**

Schematic representation of nano-imprinting lithography process

*J. Membr. Sc. 2013, 428, 598-607*
Microimprinting

Pattern to be imprinted

Optical microscope image for PDMS stamp used in fabrication process

AFM 3D image for PDMS stamp used in fabrication process
Three parameters were found to influence the MIL process:
- Temperature (60 - 130 °C; i.e. below $T_g$ of PES)
- Pressure (6 – 11.5 bar)
- Imprinting time (15 – 60 min)
Top Surface

Cross section

PES-PSM

PES-PSμM

50 µm

20 µm

100 µm

20 µm

400 µm

10 µm

50 µm

20 µm

20 µm

20 µm
Top Surface

Cross section
PA on patterned PES supports

- **TFC_Flat**
  - Top Surface
  - Cross section

- **TFC_PSµM**
  - Top Surface
  - Cross section

- **TFC_MIL**
  - Top Surface
  - Cross section
The patterned membranes exhibited superior water permeability compared to the flat membranes because of the development of the membrane surface characteristics upon the surface micro-patterning.
The patterned membranes showed a large enhancement in the permeability (~ 2 - 2.4 times) accompanied by a high salt rejection (> 96% at 2000 ppm).

A slight difference in the separation performance between TFC_MIL and TFC_PSμM was noticed.

The membrane orientation was emphasized to influence the separation performance to some extent.

The one in a parallel orientation to the feed flow was always better than that in a perpendicular orientation.
TFC_PSµM exhibited a relatively higher permeability and salt rejection than those of TFC_MIL.

The consequences of the membrane orientation on the separation performance were more pronounced.

Improvement in the permeability and the salt rejection were observed for the patterned membranes that were employed in a parallel orientation.
**Difference mechanisms**

**Flat Membranes**

Limited surface area available for filtration, with finite surface roughness, intrinsic properties of barrier PA are predominant, higher chance of concentration polarization.

**Parallel Orientation**

The micro-patterns work as water channels to stabilize the liquid streamlines, equilibrate the shear stress and promote surface mixing effects over the entire membrane surface area.

**Perpendicular Orientation**

The micro-patterns work as obstacles that disturbed the feed streaming, yielding regions of low shear and others with high shear (vortex) leading to a partial salt accumulation in low shear regions.
Ideas for funding

Core/elective courses

one year diploma in water technologies (Eng/Science)

Practical Training

Practical Project
Ideas for funding

**International Graduate School for Water Desalination**

- **PhD/Postdoc**
  - Egy/Arab students

- **Academic partners**
  - from Egypt, Germany, and USA

- **Industrial partners**
  - from Egypt, Germany, and Arab countries
Ideas for funding

Online platform to link Arab students with German Profs
Thank you