Patterned Water Desalination Membranes

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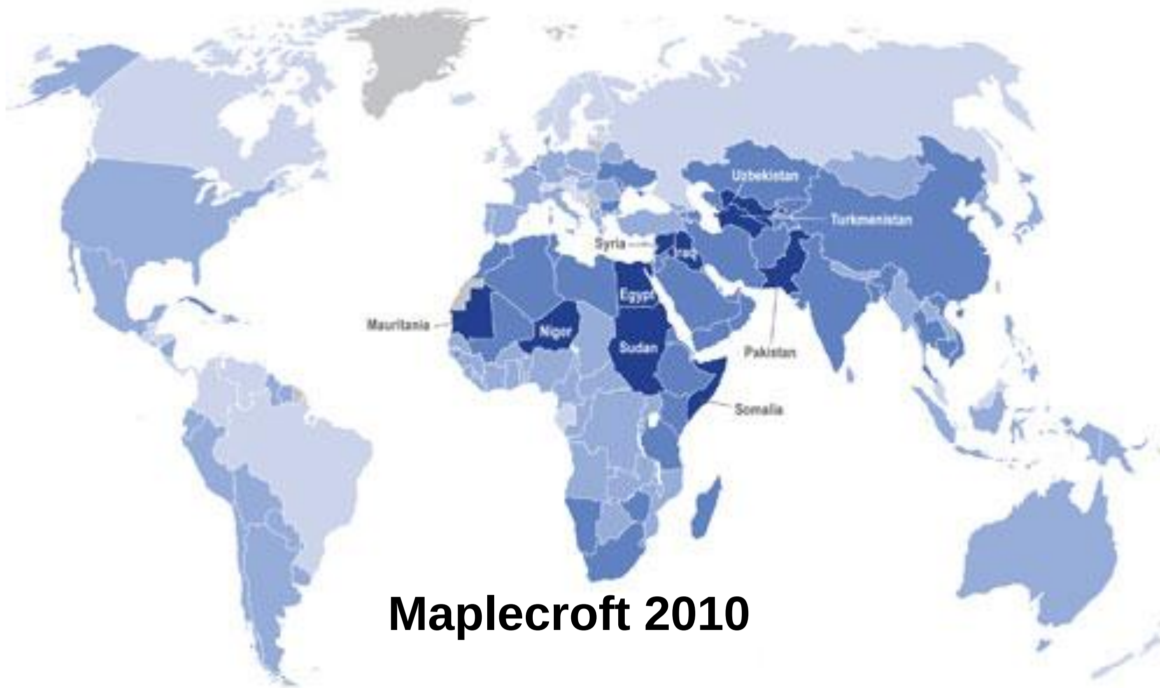
18.04.2017

Outline

- **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'

Source: Wikipedia

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

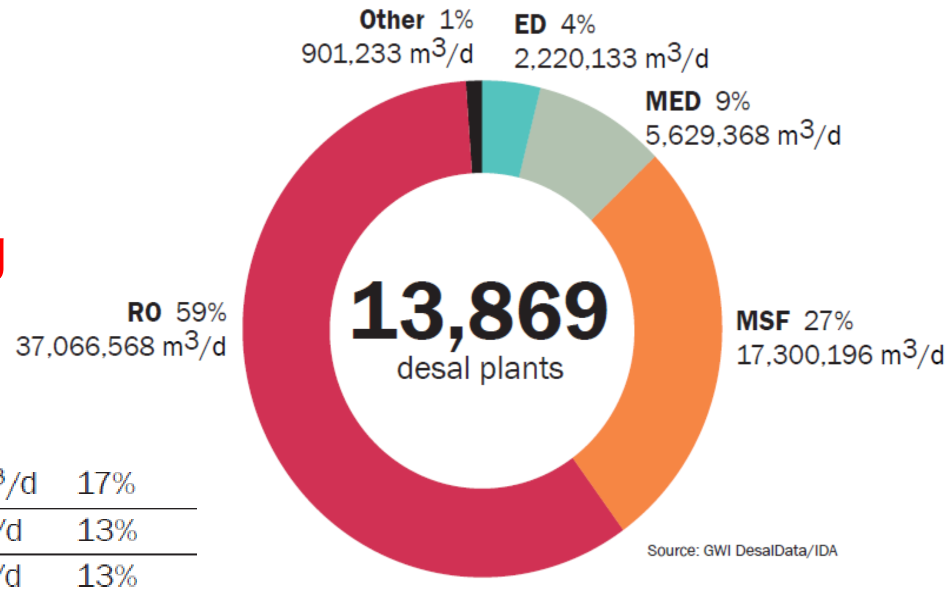
Membrane based processes

Membrane distillation

Desalination market

Desalination plants by technology:

RO is dominating

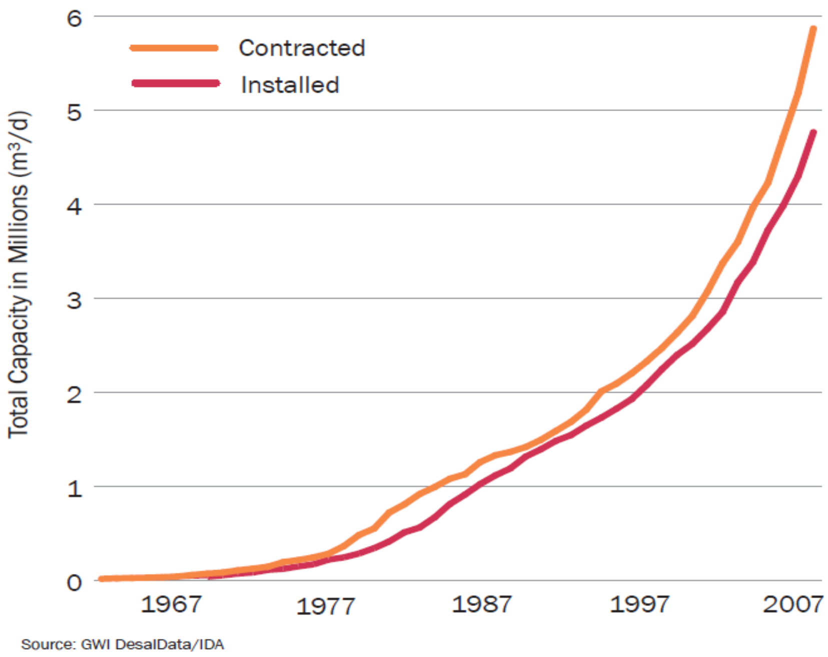


1)	Saudi Arabia	10,759,693 m^3/d	17%
2)	UAE	8,428,456 m^3/d	13%
3)	USA	8,133,415 m^3/d	13%
4)	Spain	5,249,536 m^3/d	8%
5)	Kuwait	2,876,625 m^3/d	5%
6)	Algeria	2,675,958 m^3/d	4%
7)	China	2,259,741 m^3/d	4%
8)	Qatar	1,712,886m^3/d	3%
9)	Japan	1,493,158 m^3/d	2%
10)	Australia	1,184,812m3/d	2%

Source: GWI DesalData/IDA

Top 10 desalination countries

Desalination capacity growth



- In 2010: global capacity is 68.3 million m3/d

- 17% annual growth since 1990

Top 10 desalination companies

1	Veolia Environment	5,420,072m³/d
2	Fisia Italimpianti	3,025,344m³/d
3	Doosan	2,852,305m³/d
4	GE Water	2,471,987m³/d
5	Suez Environnement	1,528,710m³/d
6	Befesa Agua	1,387,624m³/d
7	ACS (Cobra/Tedagua/Drace)	1,312,347m³/d
8	Hyflux	1,121,508m³/d
9	Acciona Agua	1,111,516m³/d
10	IDE	1,001,730m³/d

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:

RO	0.45-0.92 $/m3
MED	1.17-1.49 $/m3
MSF	1.10-1.50 $/m3

Road map published in 2007

The Cabinet
Information and Decision Support Center
Center For Future Studies

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

Desalination in Egypt: Road Map 2030

Vision

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

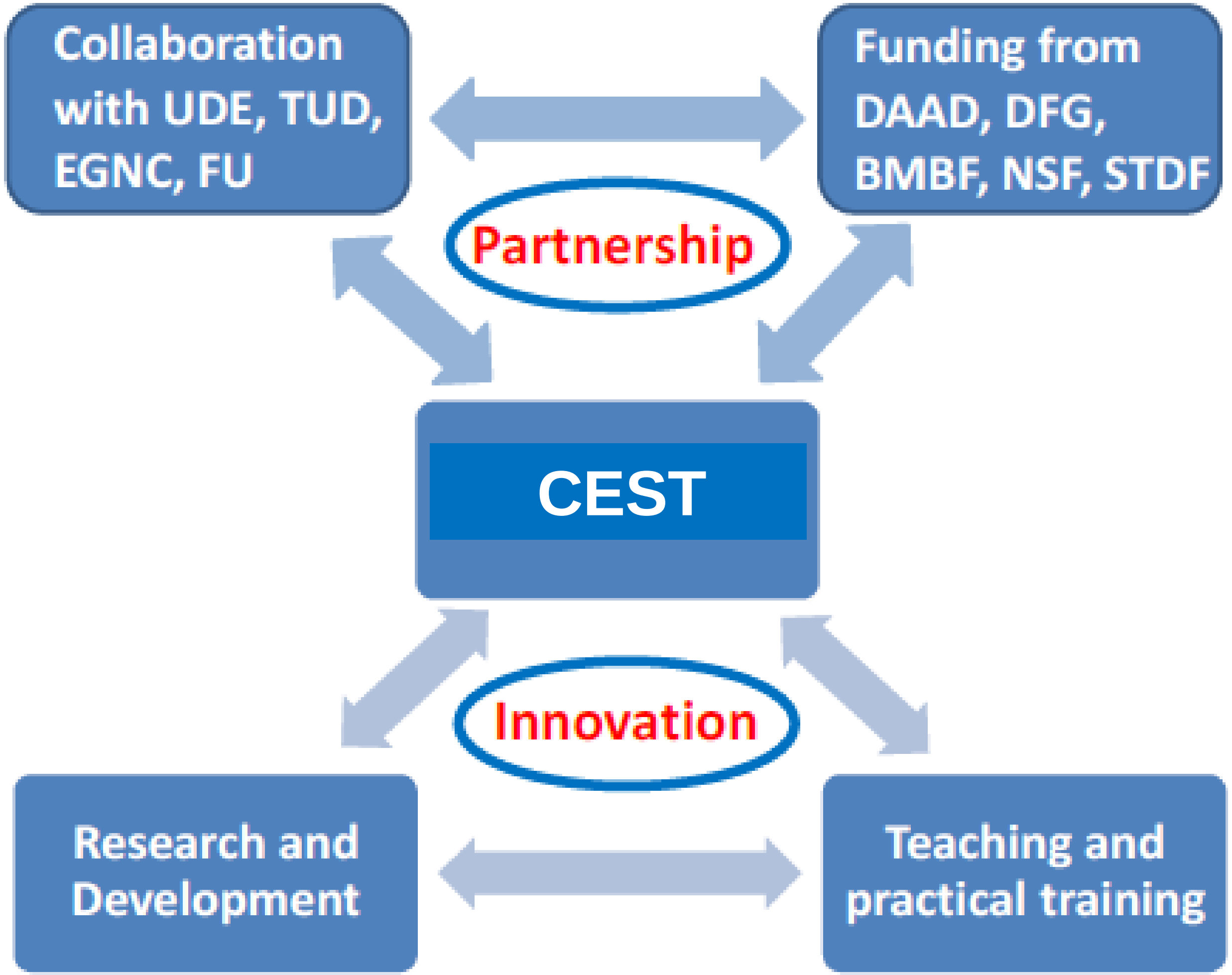
Mission

– Identification of specific desalination technology areas for meeting the national needs.

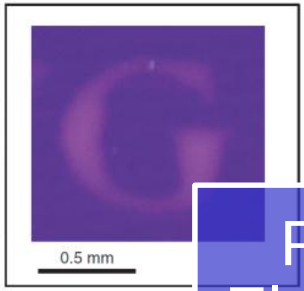
– Nature, timing and estimated cost of the required research and/or development programs.

– Priorities of technology development projects.

Our vision


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

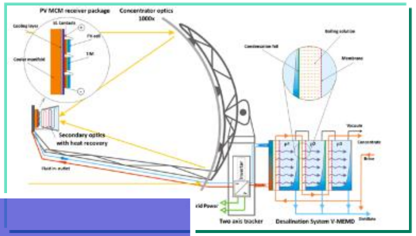
Optimization of Surfaces and Interfaces for:

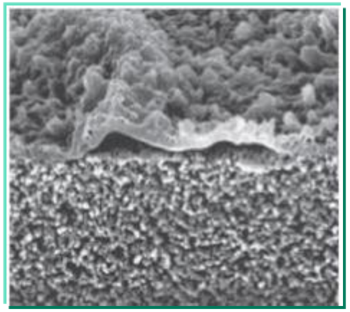


Printed Electronics

Water Treatment & Desalination

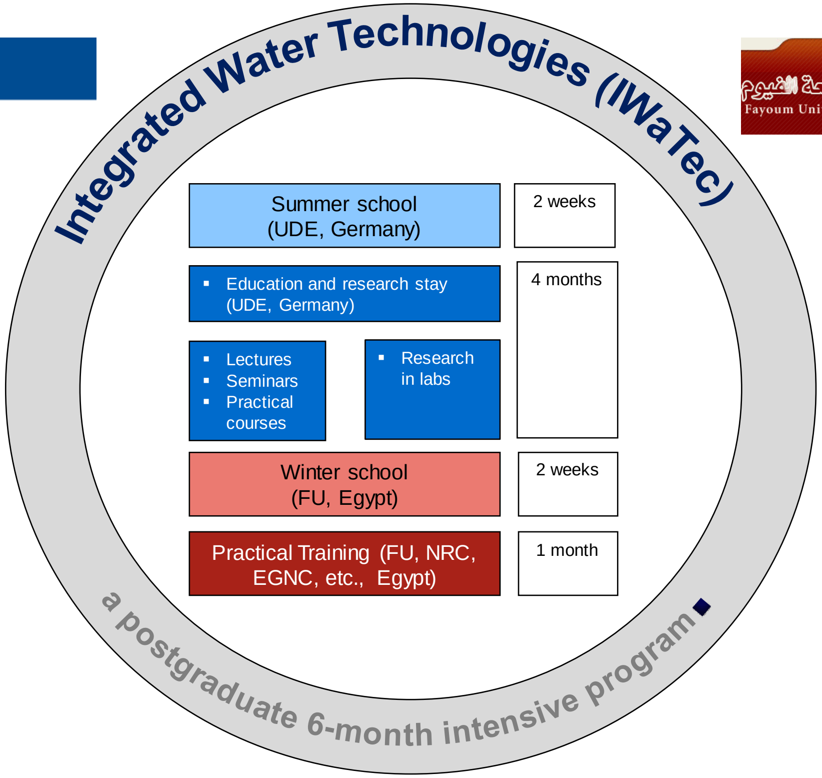
Solar Energy





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

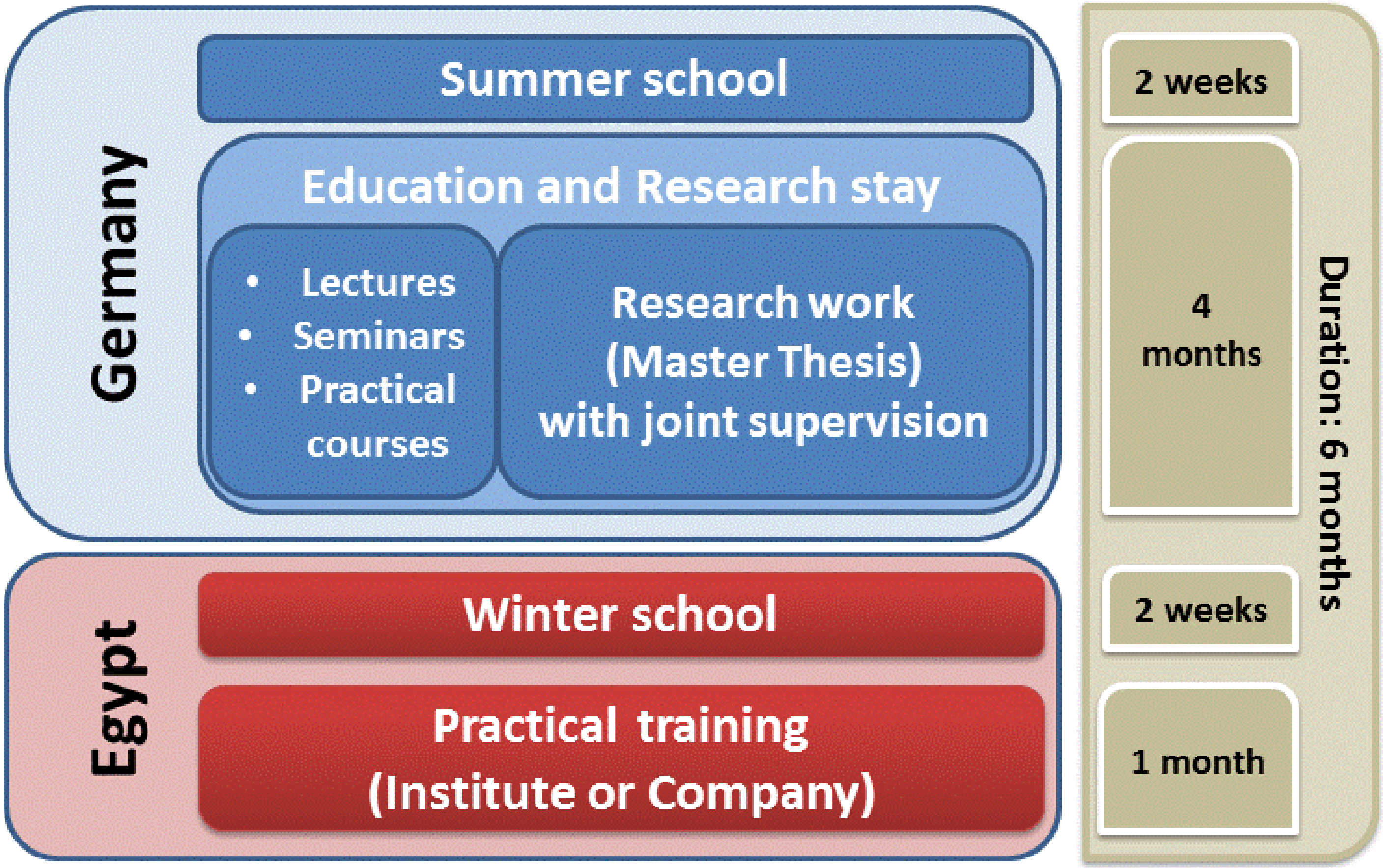
- **Duration**: 3 years (2012-2015)
- **Total budget**: 340,000 Euro from DAAD
- **Coordinator from the Egyptian side: Ahmed S. G. Khalil**



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



IWaTec students and researchers

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)

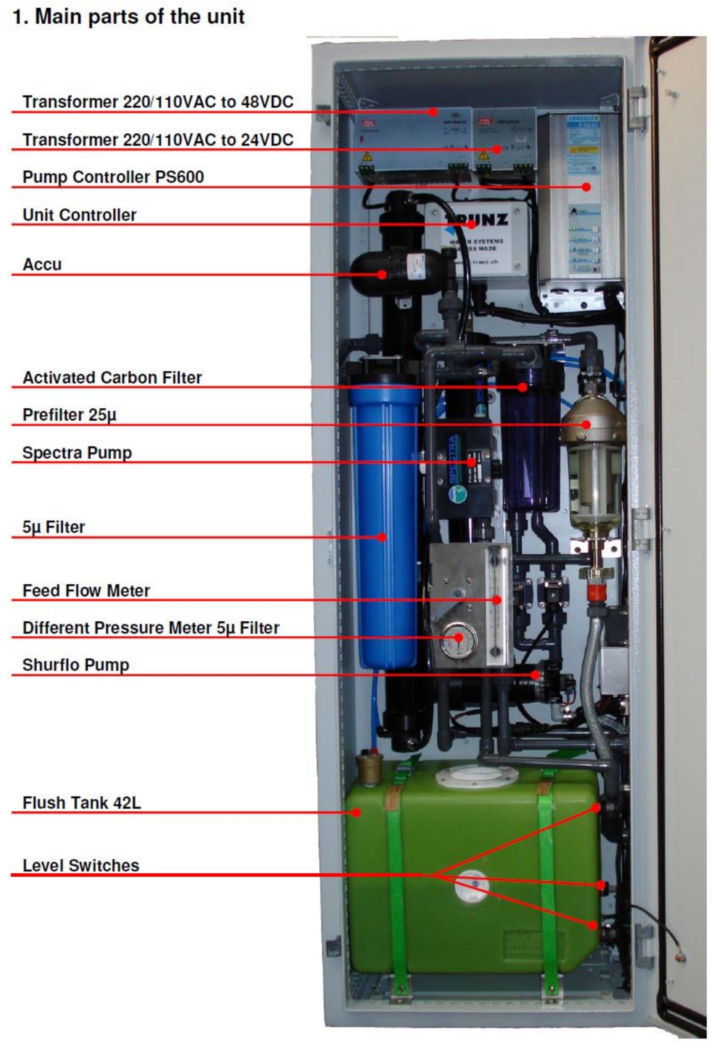
- **Partners:**
    - Egypt Nontechnology Center, Egypt
    - Fayoum University, Egypt
    - Cairo University, Egypt
    - South-Valley University, Egypt
    - German-Arab Chamber, Egypt
    - Resala Charity organization
    - Bahnas IC, Egypt
    - Aachen University for applied sciences, Germany
    - 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**
-

SOLEDA

Polysun software packages

PV driven RO desalination system

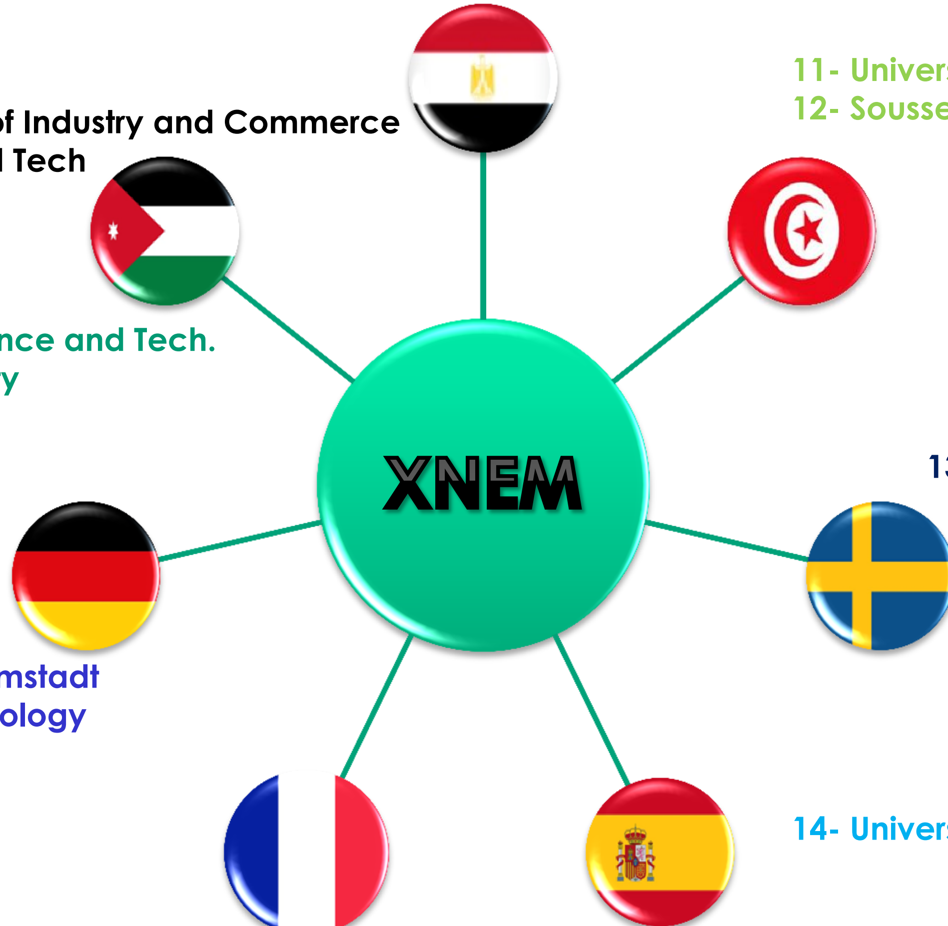


Excellence in Nanoscience Education for MENA Region

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

11- University of Carthage
12- Sousse University

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



13- Lund University

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

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

Funding from PMU

Training Center at Fayoum University for RE & Water Des.

Practical Training

Advanced Education

Capacity Building Grant on Membrane Science and Technology

11 Million L.E

جـــامعة الفـــيوم
Fayoum University

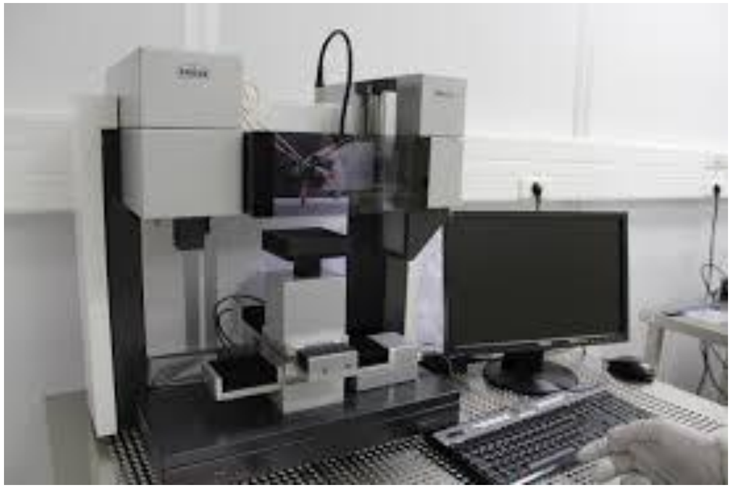
STDF
صندوق العلوم والتنمية التكنولوجية
Science and Technology Development Fund

Capacity building project

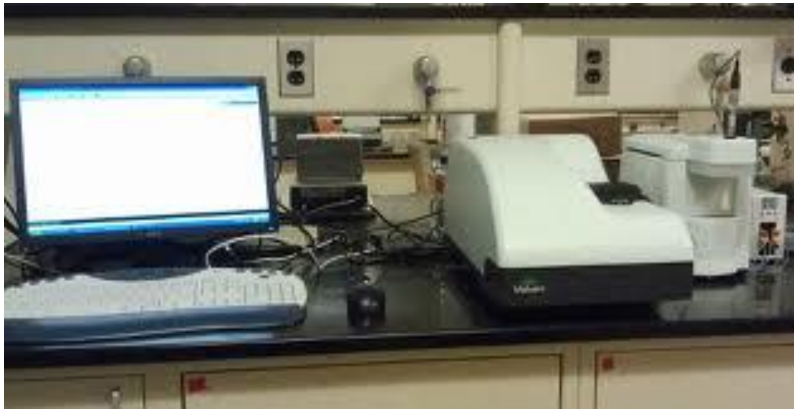
Scanning Electron Microscopy

Capillary flow porometer

Contact angle systems



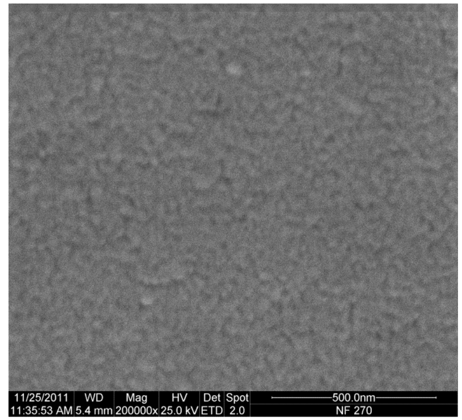
Zetasizer



Functional membranes

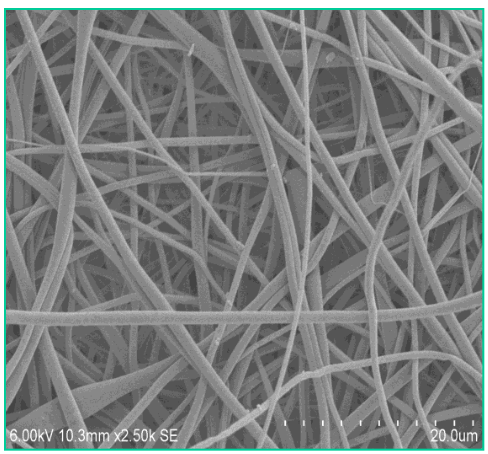
Fabrication of functional membranes

Ongoing sub projects:

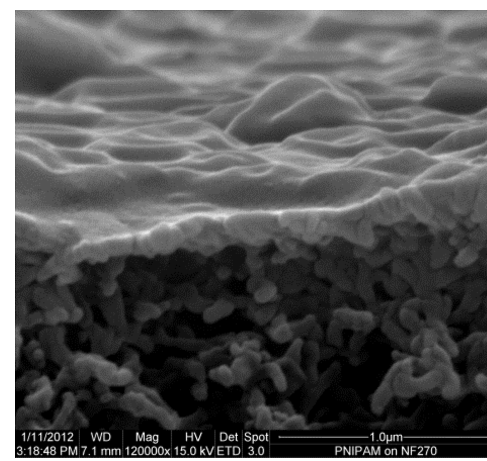


Fabrication of microfiltration membranes using electrospinning system

Fabrication of NF and RO membranes using phase inversion and interfacial polymerization



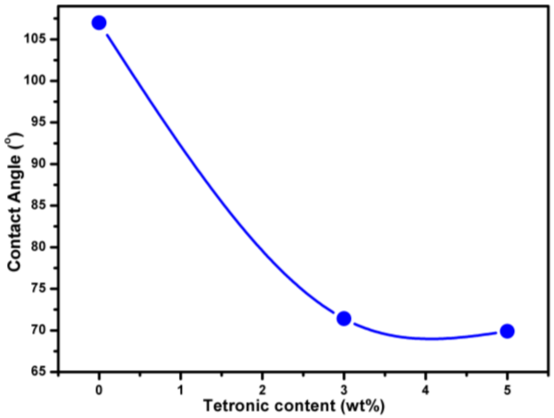
Testing commercial membranes for the removal of disinfection by products in drinking water

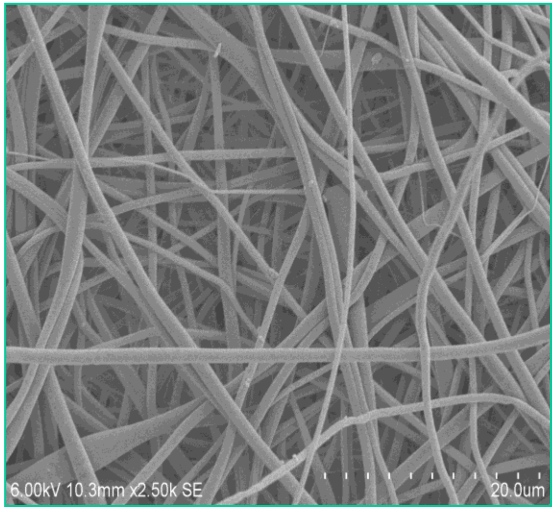


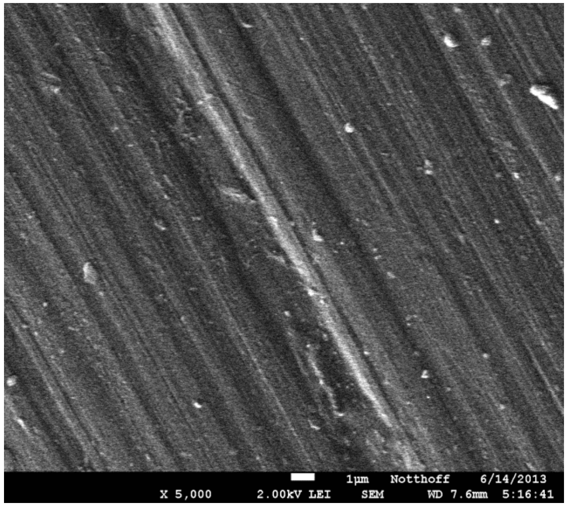
Functional membranes

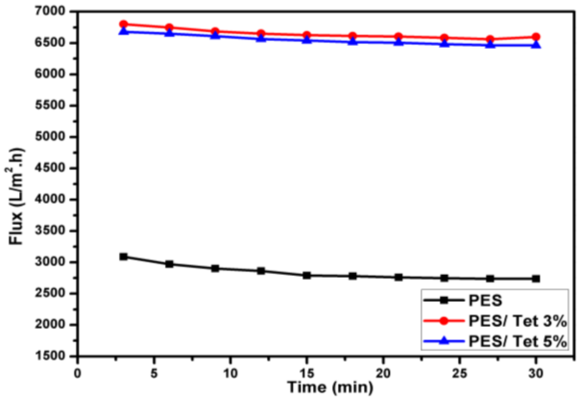
IWaTec project

Fabrication of micro and ultrafiltration membranes by electrospinning:



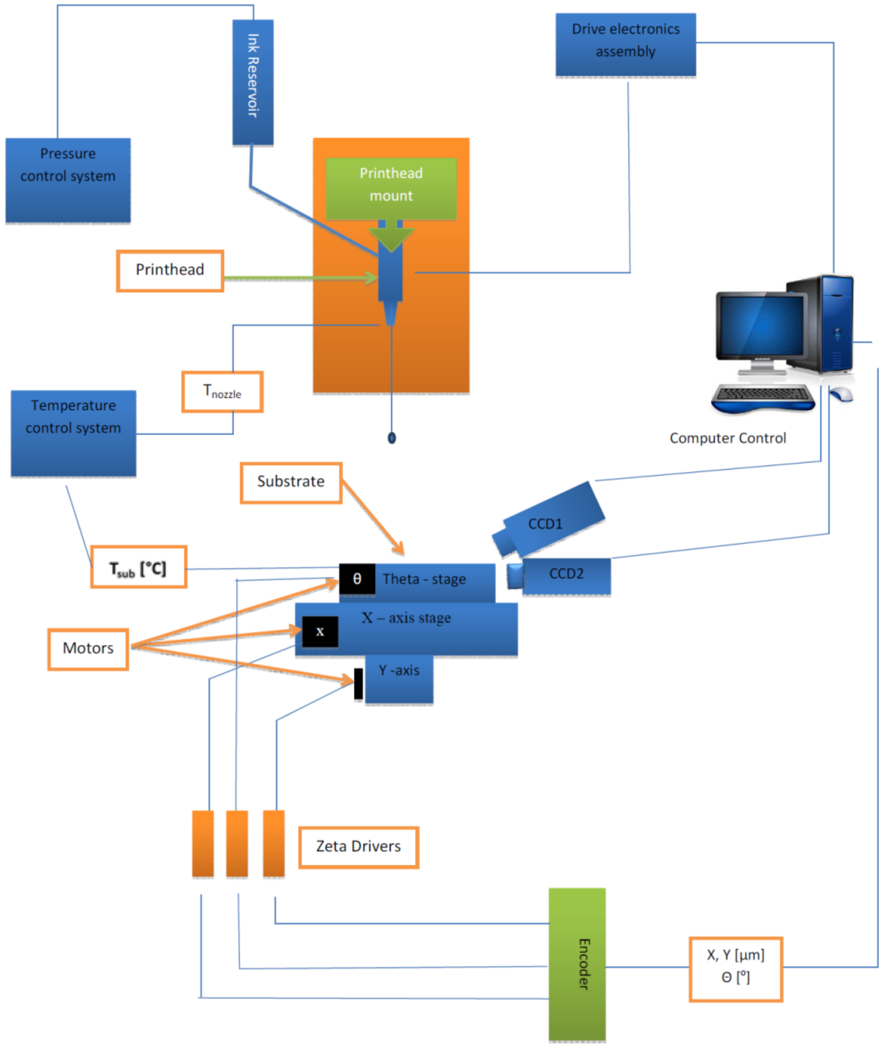






Ahmed Abdelhameed & Aya Ahmed

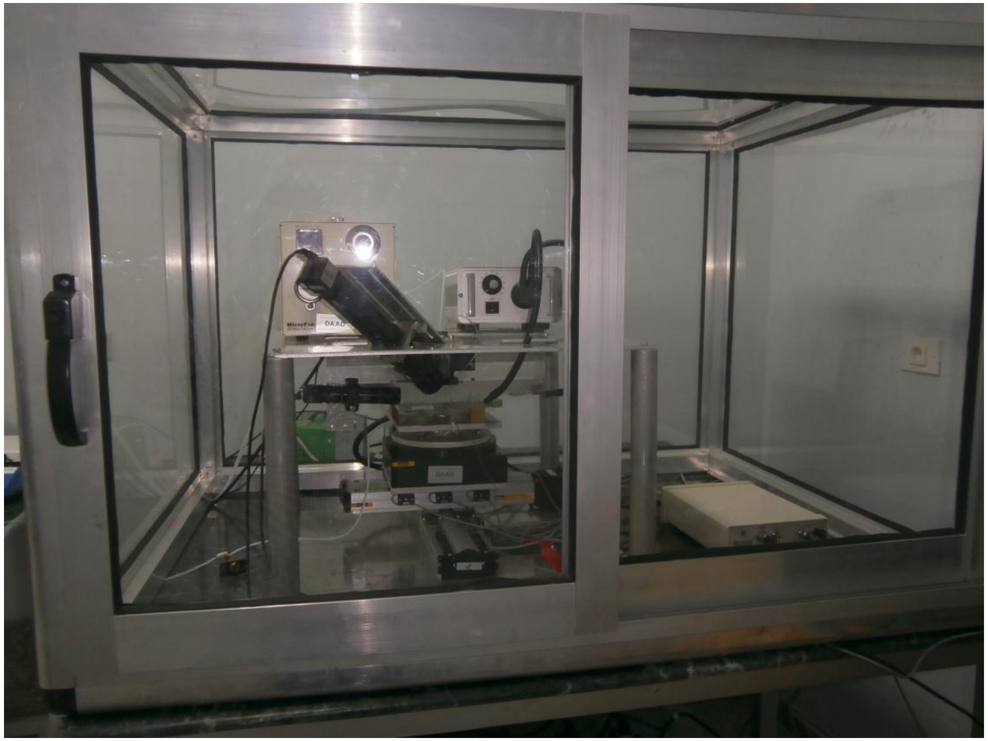
Custom inkjet printing system

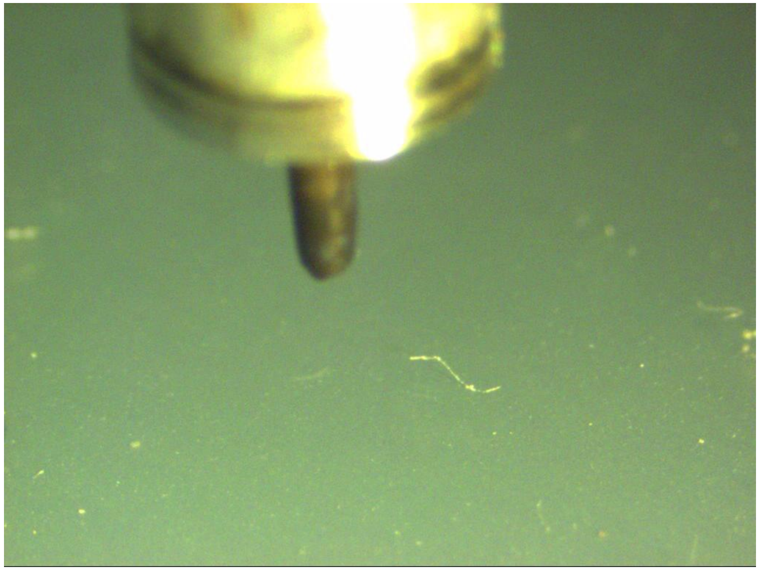


Kareem Salah Elassy

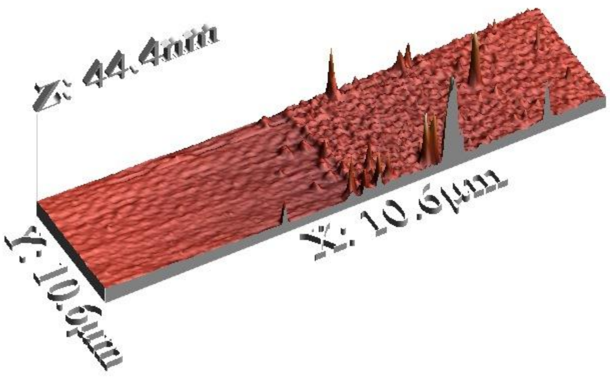
Inkjet Printing of Electronic and Optoelectronic Devices

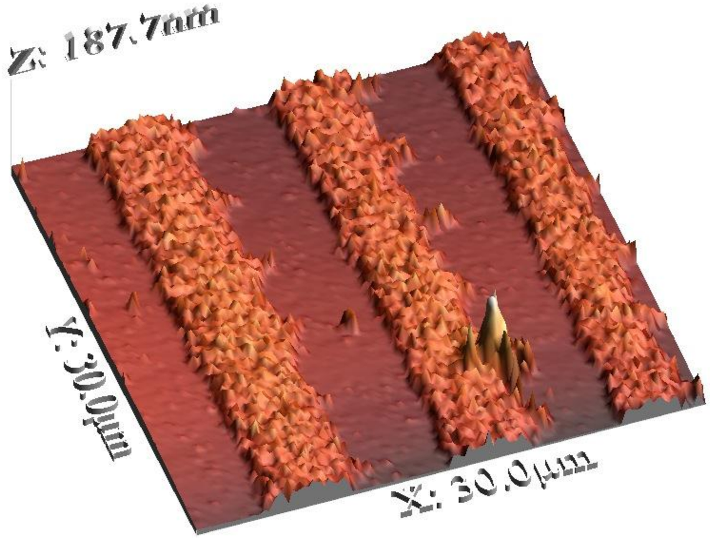
PIs: Ahmed S. G. Khalil & V. Subramanian of UC Berkeley, USA
1 PhD student: Kareem Elassy & Postdoc: Dr. Rania Elsayed

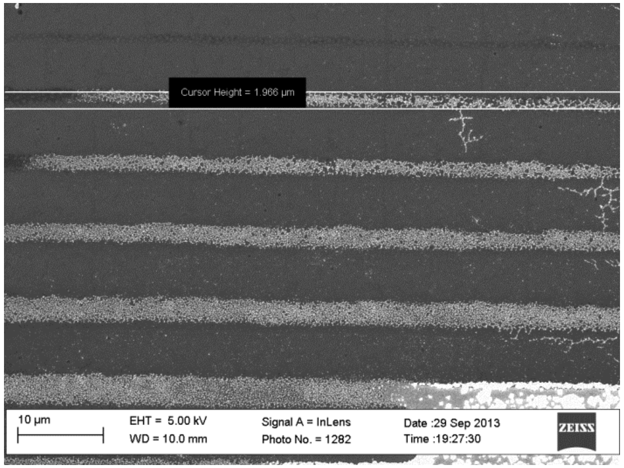


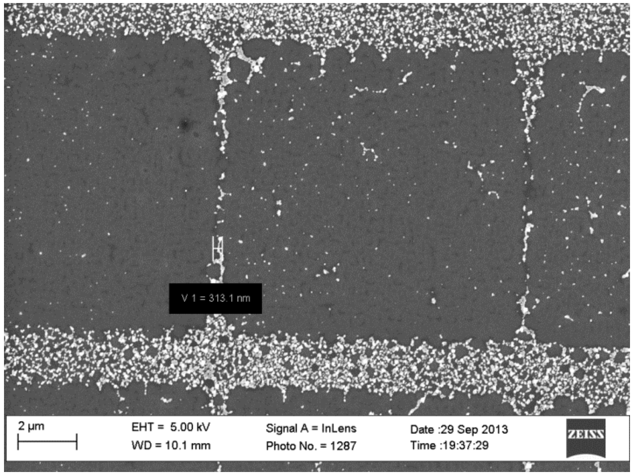


Inkjet Printing of Silver lines on Silicon:



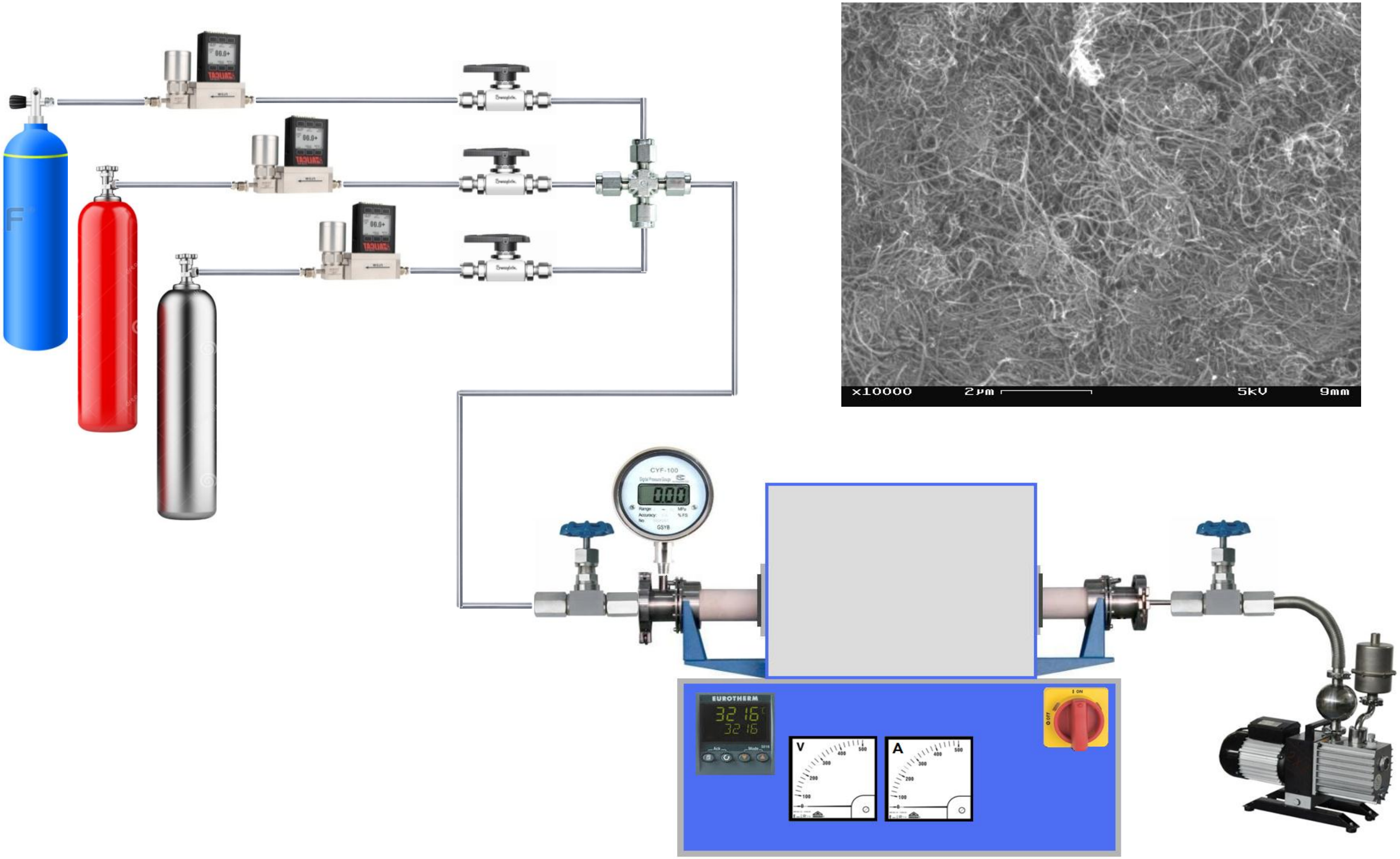




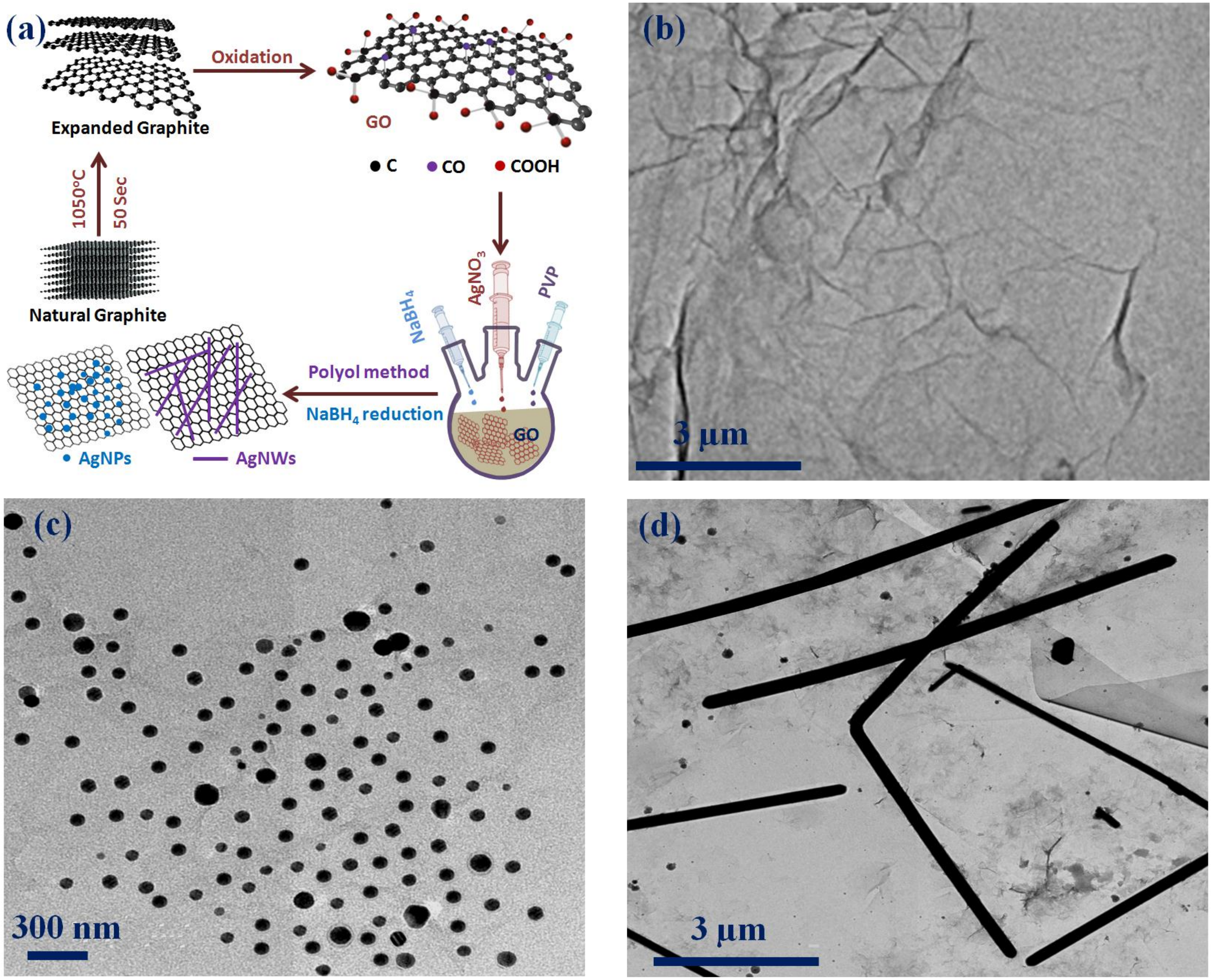


Kareem Salah Elassy

Chemical Vapor Deposition: CNT

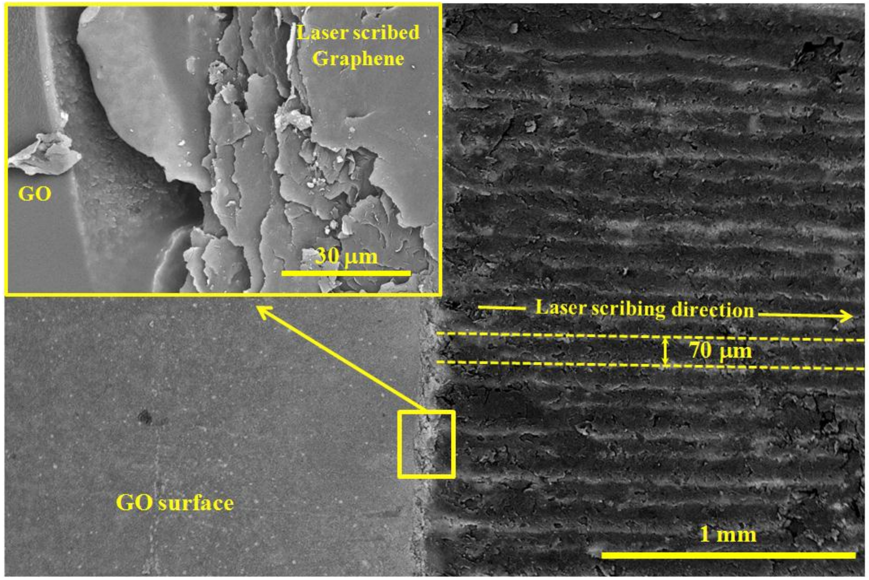


Graphene

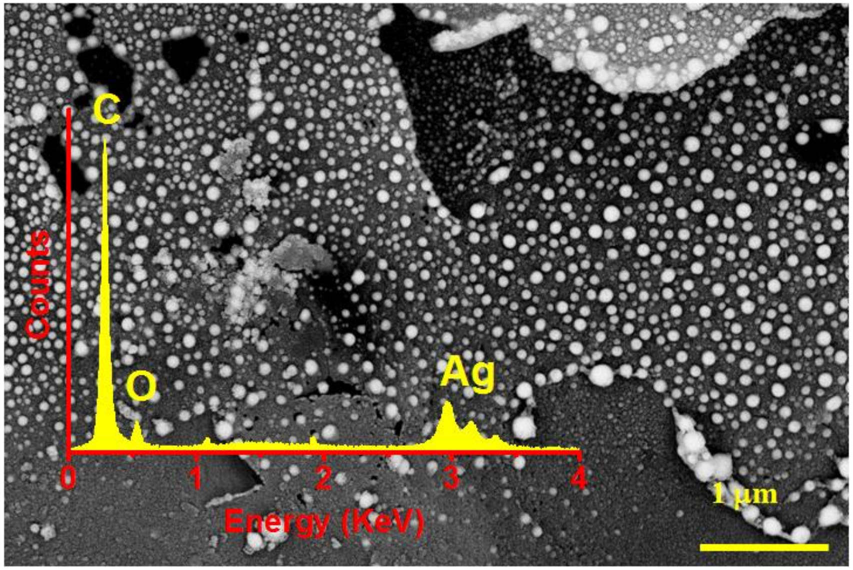


(a)
Oxidation
Expanded Graphite
GO
C
CO
COOH
1050°C
50 Sec
Natural Graphite
$AgNO_3$
$NaBH_4$
PVP
Polyol method
$NaBH_4$ reduction
GO
AgNPs
AgNWs
(b)
3 µm
(c)
300 nm
(d)
3 µm

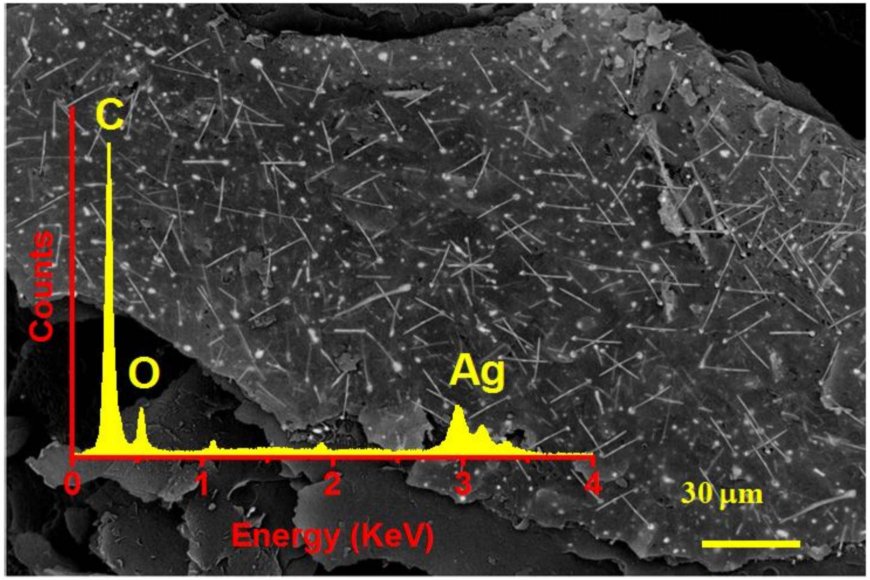
Graphene



Laser scribed Graphene
GO
30 µm
Laser scribing direction
70 µm
GO surface
1 mm



C
Counts
O
Ag
0
1
2
3
4
Energy (KeV)
1 µm



C
Counts
O
Ag
0
1
2
3
4
Energy (KeV)
30 µm

Two new projects-To be started

Project 1:

“Environmental and Supply Chain Management for the Energy, Water and Food Nexus – the basis for Sustainable Development” (EnviChain)” (2017-2019).

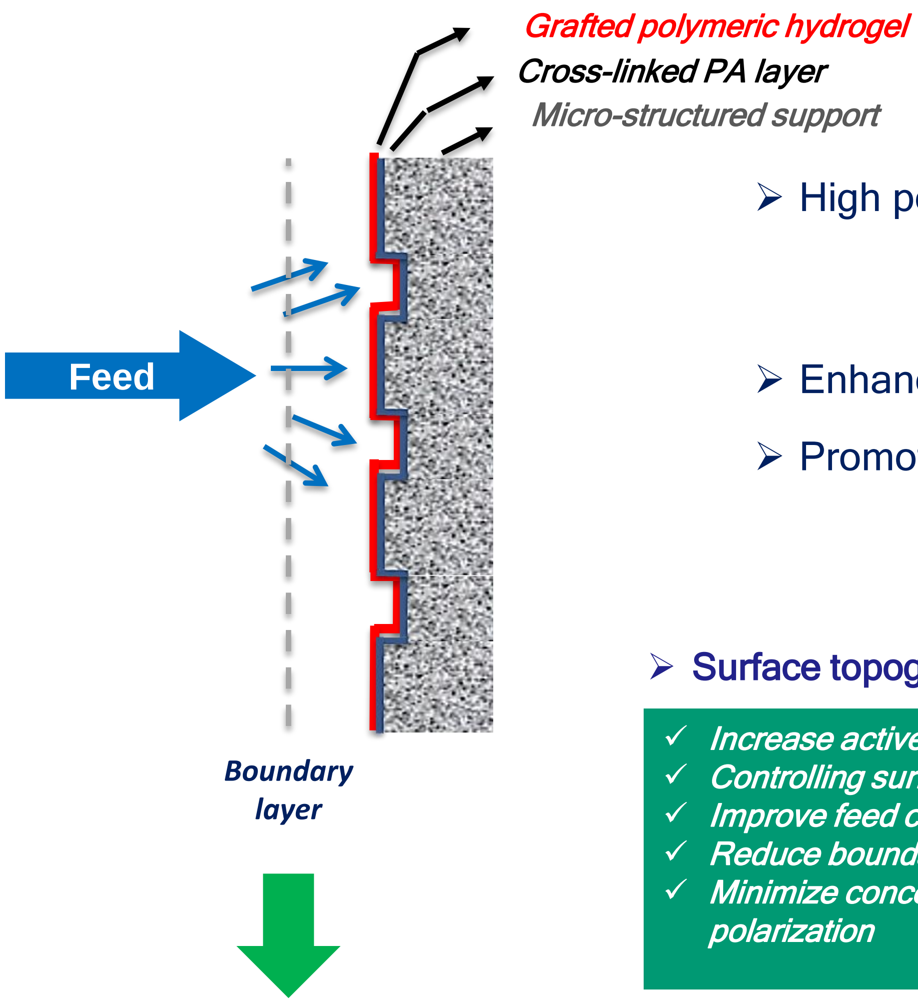
- Funded by Erasmus+ with total funding of 150,000 Euro.
- Student/researcher exchange
- Partners: UDE, FU and AASTMT

Project 2:

“Optimization of ultrafiltration membranes for the treatment of oil containing waste water” (2017-2019).

- 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*

Optimization of the PES support

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

- **The key factors determining phase inversion membrane morphology:**

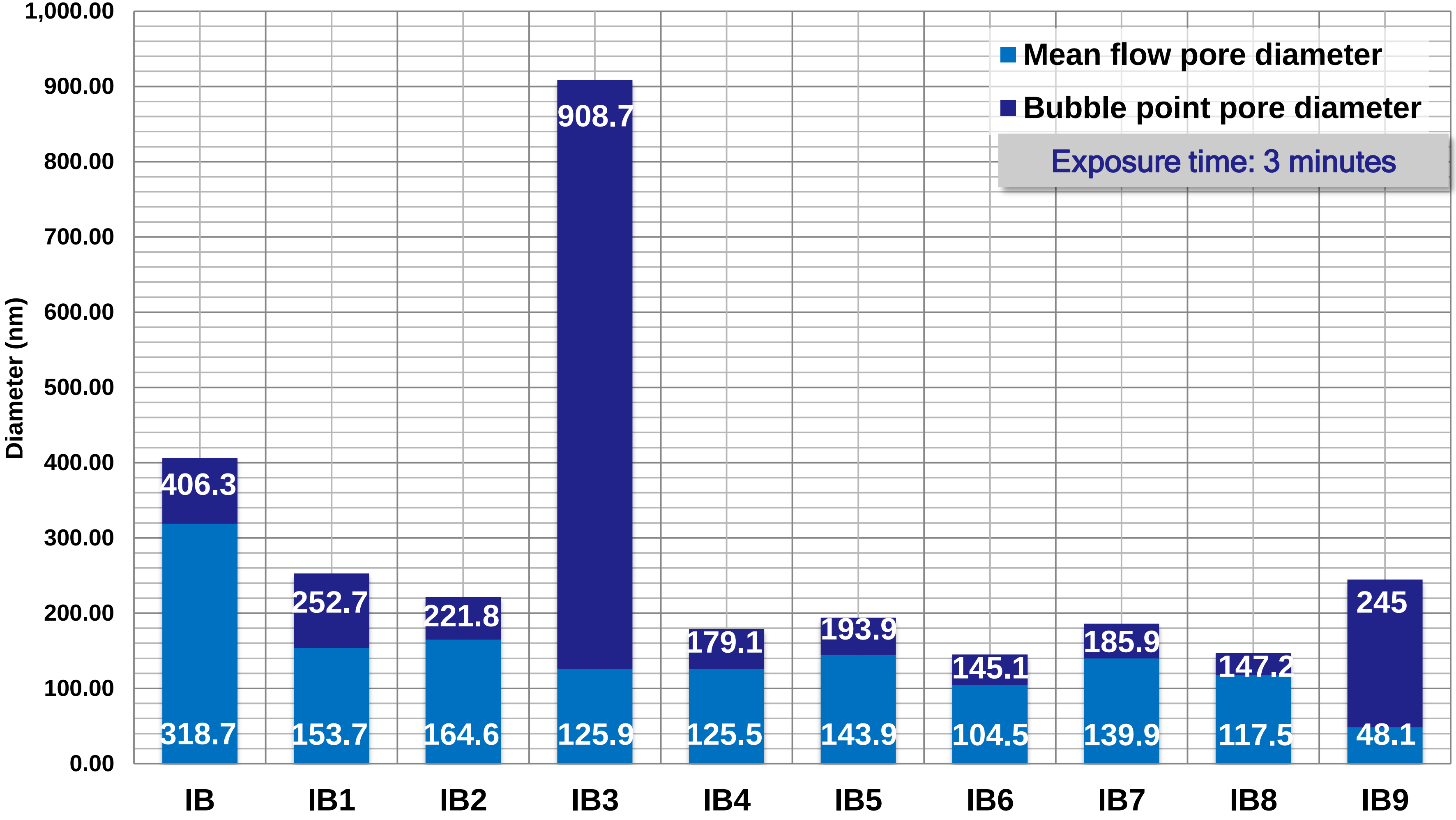
  (1) The choice of solvent : non-solvent system.
  (2) The composition of casting solution.
  (3) Choice of coagulation / precipitation conditions.

- **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 %.

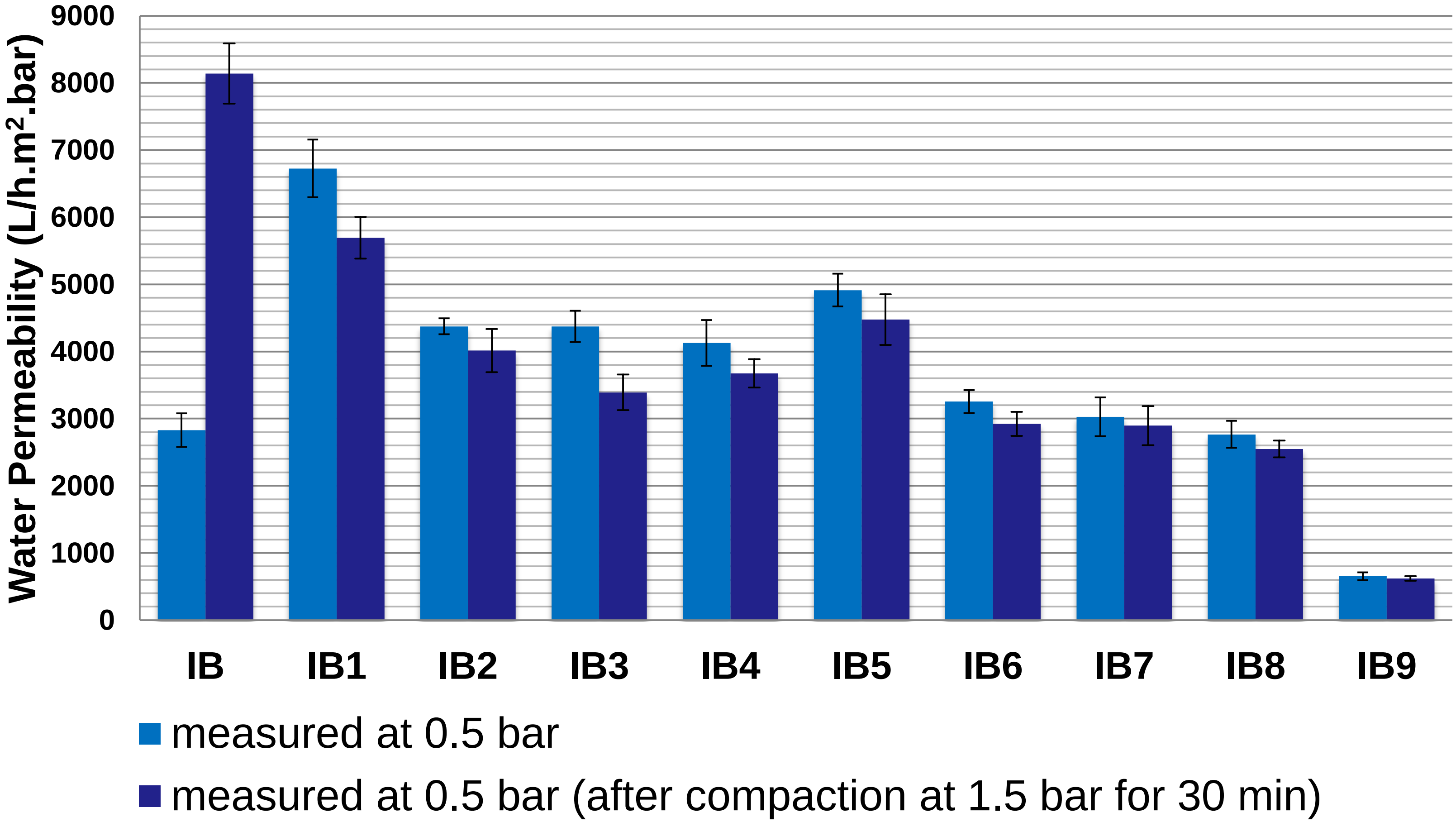
Pore size of PES membrane

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



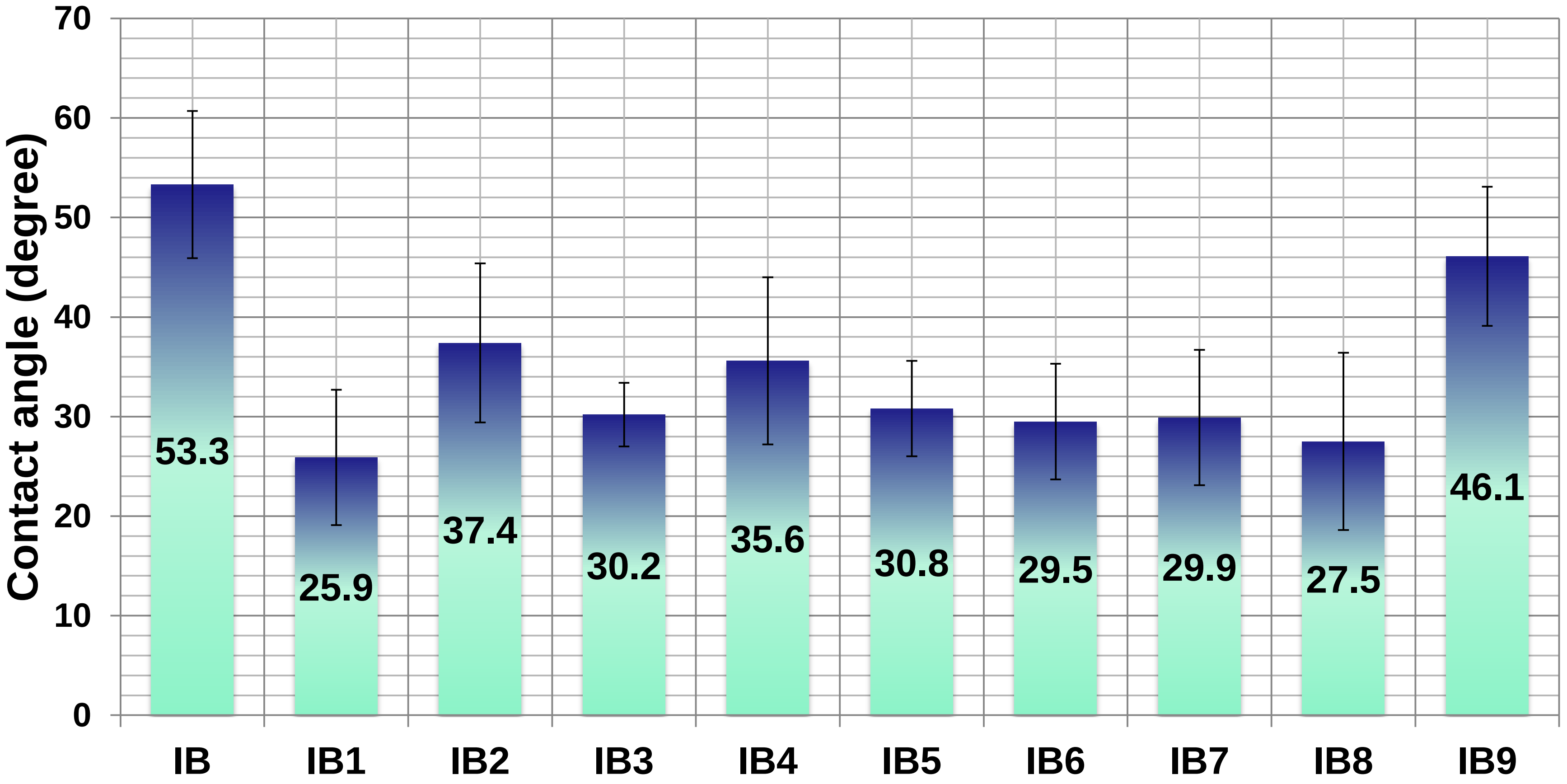
Water flux of PES membrane

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

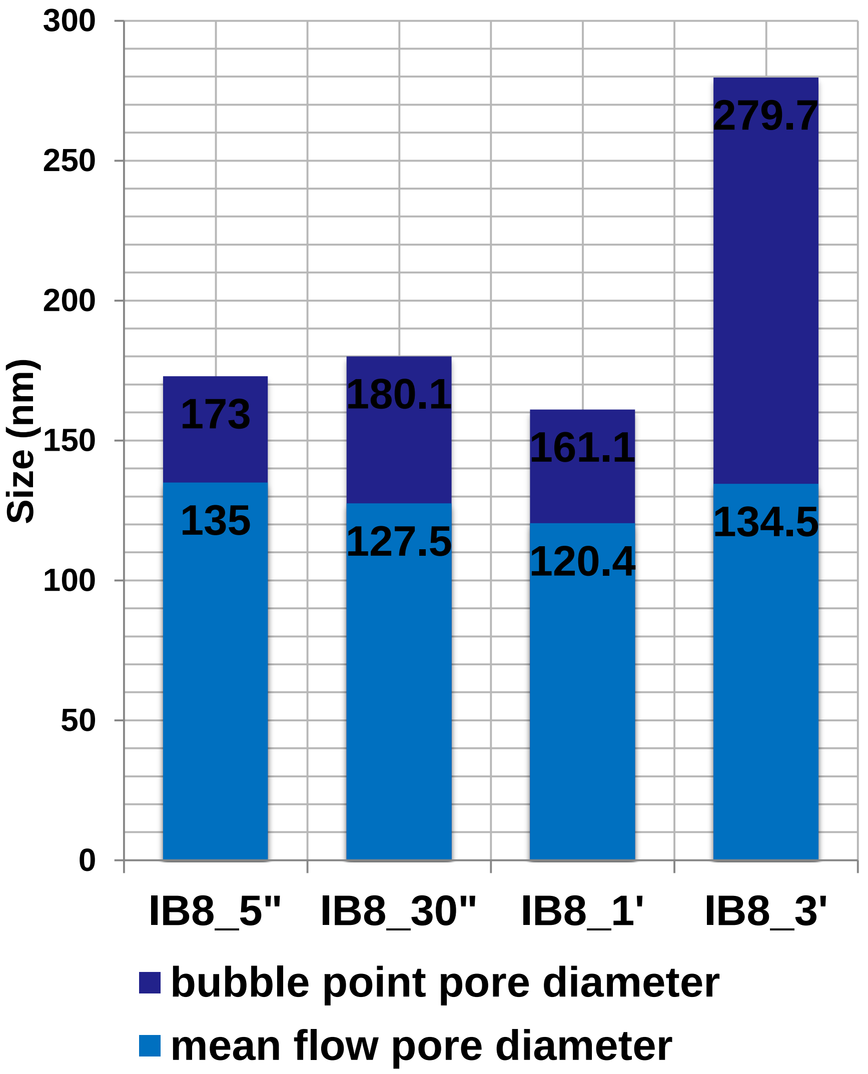


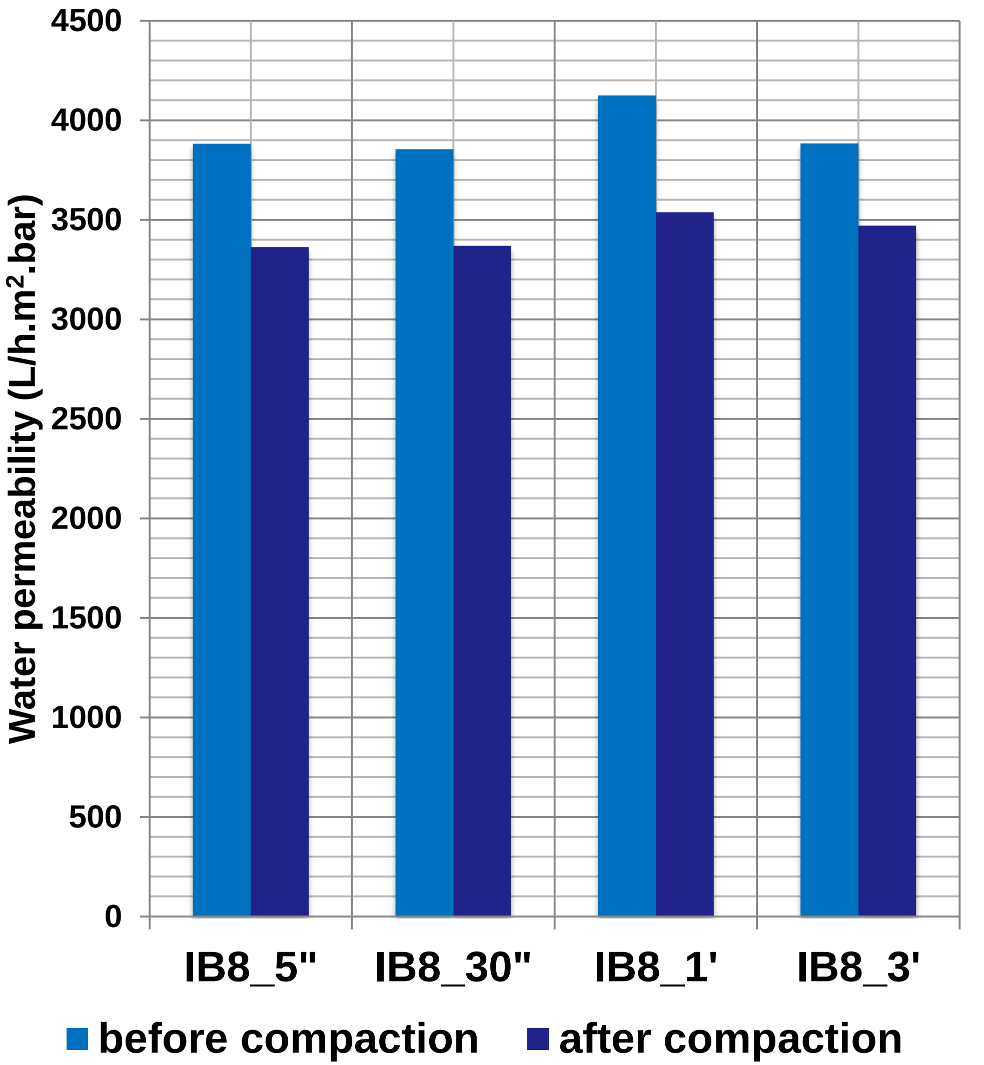
Wettability of PES base membrane

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

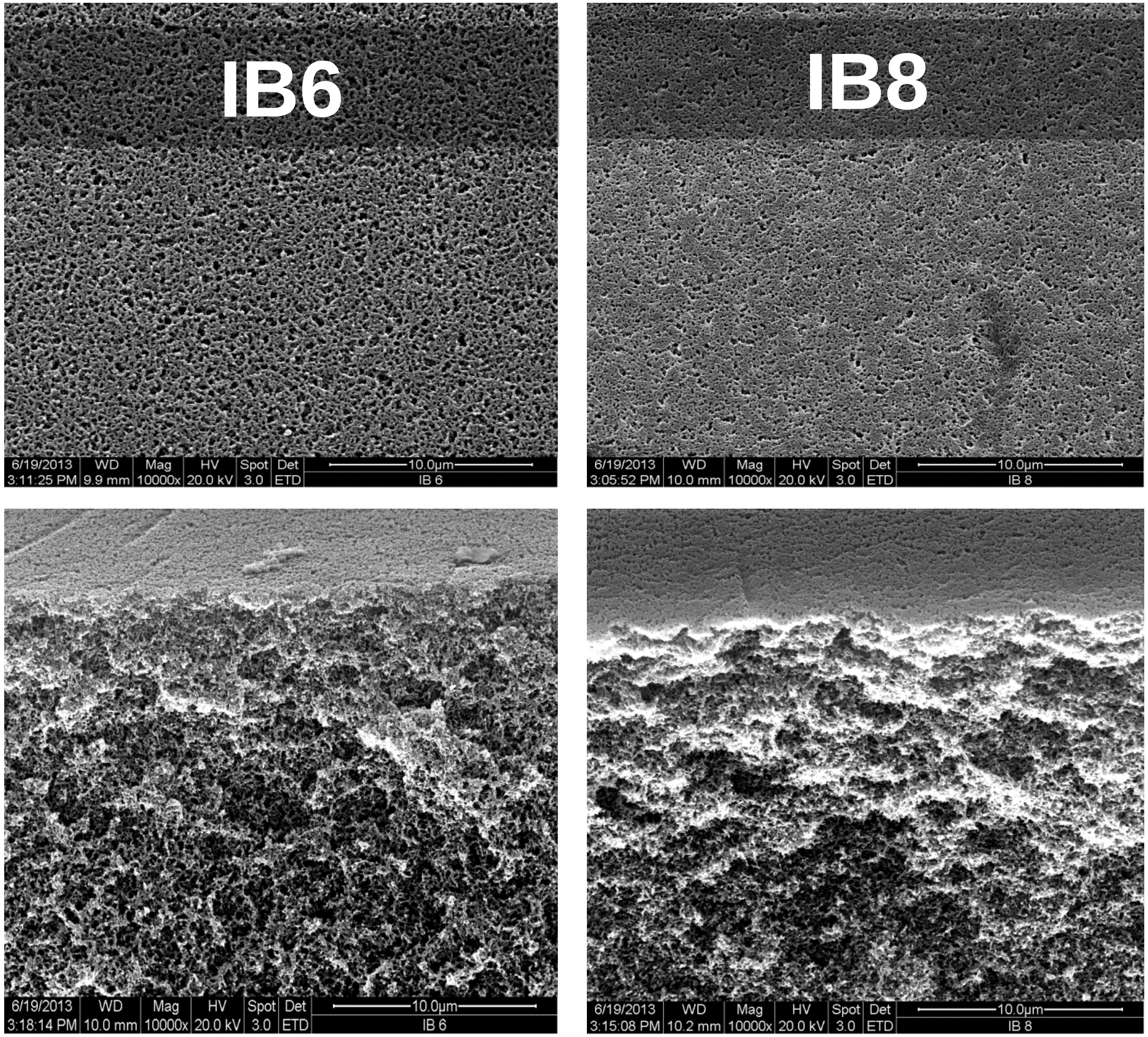


Effect of the exposure time



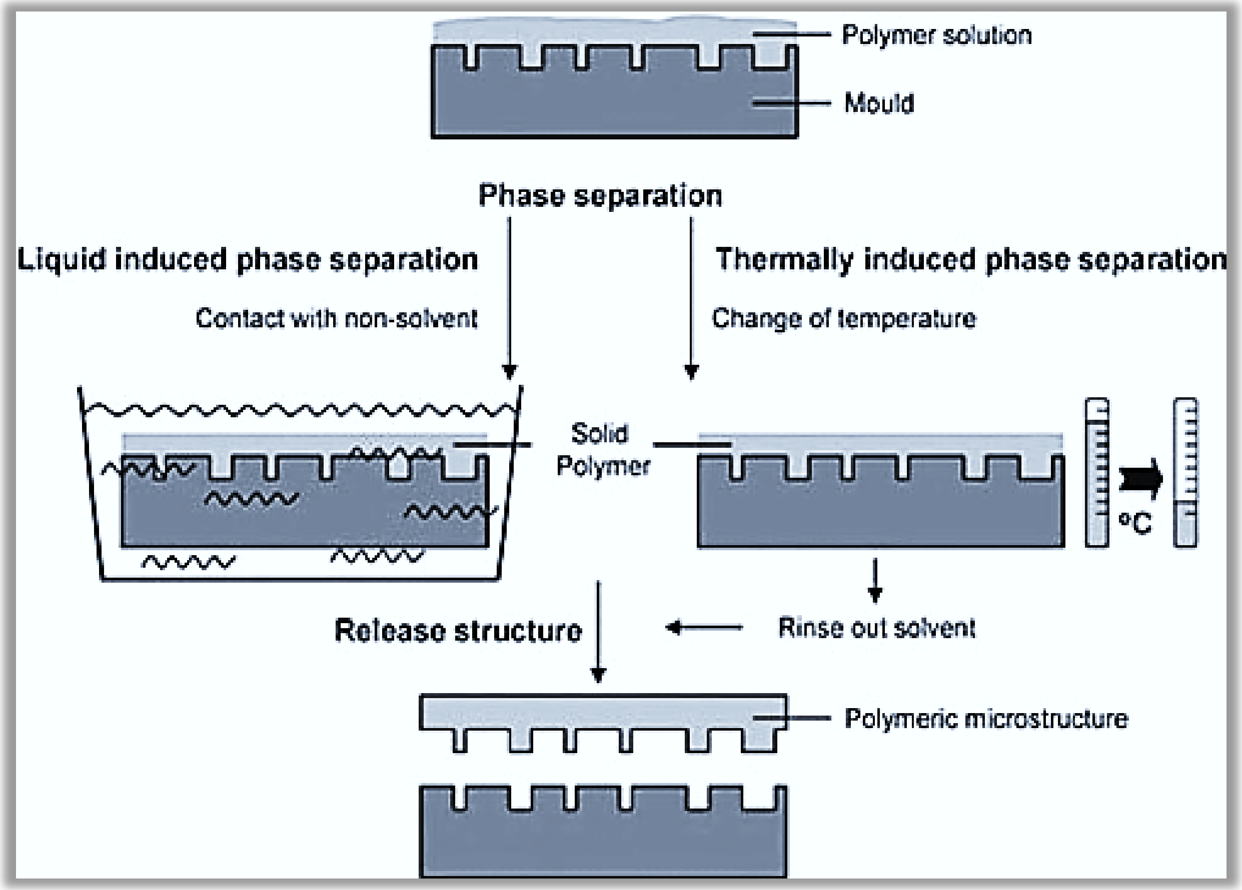


Morphology


IB6
IB8
6/19/2013 3:11:25 PM | WD 9.9 mm | Mag 10000x | HV 20.0 kV | Spot 3.0 | Det ETD | 10.0µm | IB 6
6/19/2013 3:05:52 PM | WD 10.0 mm | Mag 10000x | HV 20.0 kV | Spot 3.0 | Det ETD | 10.0µm | IB 8
6/19/2013 3:18:14 PM | WD 10.0 mm | Mag 10000x | HV 20.0 kV | Spot 3.0 | Det ETD | 10.0µm | IB 6
6/19/2013 3:15:08 PM | WD 10.2 mm | Mag 10000x | HV 20.0 kV | Spot 3.0 | Det ETD | 10.0µm | IB 8

Patterning

WP2: ***Optimization of low-cost surface pattering technologies:***
Synthesis of micro-structured PA desalination membranes



VIPSμM - LIPSμM

Schematic representation of the phase separation micromolding process

Adv. Mater. 2003, 15(16) 1385-1389.

Phase sepration micromolding

- 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

Optimized micro-patterning setup for PSμM

Microimprinting

WP2:* *Optimization of low-cost surface pattering technologies:

Synthesis of micro-structured PA desalination membranes

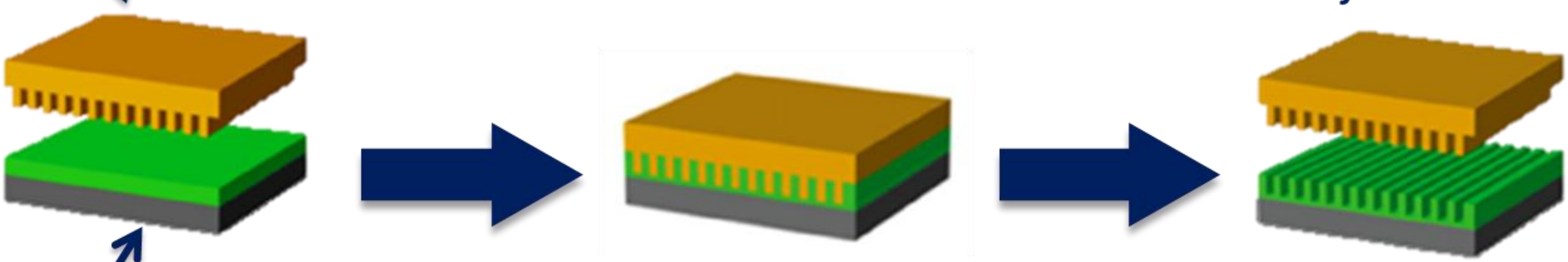
Methodology

NIL for PES

Patterned Stamp

NIL under temperature and pressure for particular time

Submicron surface patterns successfully imprinted on the membrane surface

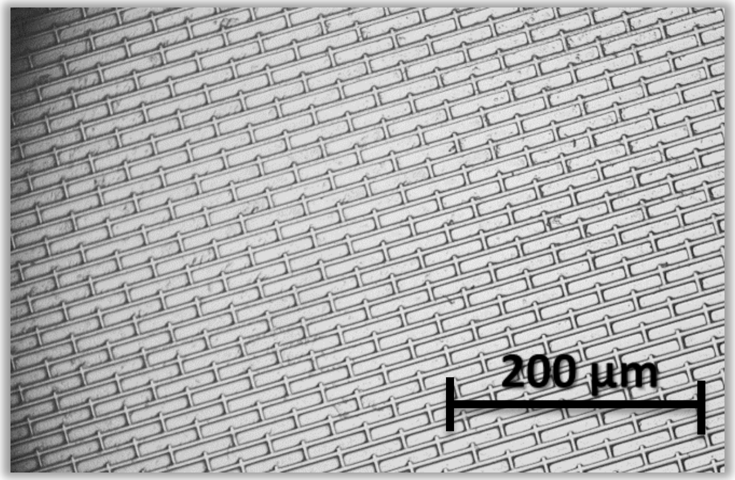


Membrane to be patterned

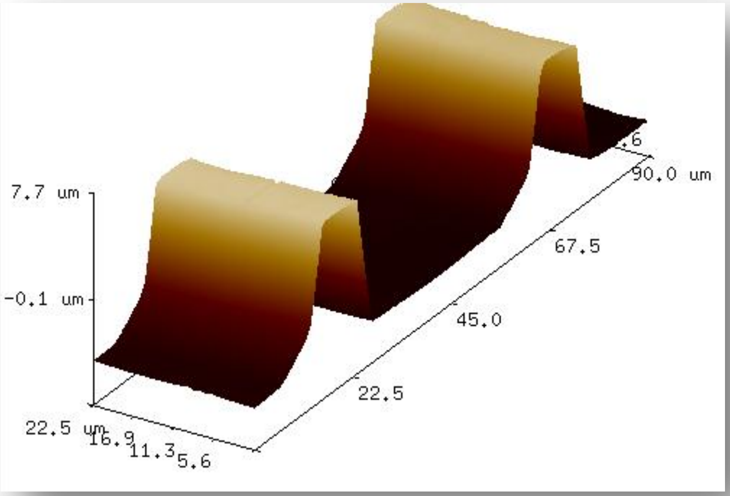
Schematic representation of nano-imprinting lithography process
J. Membr. Sc. 2013, 428, 598-607

Microimprinting

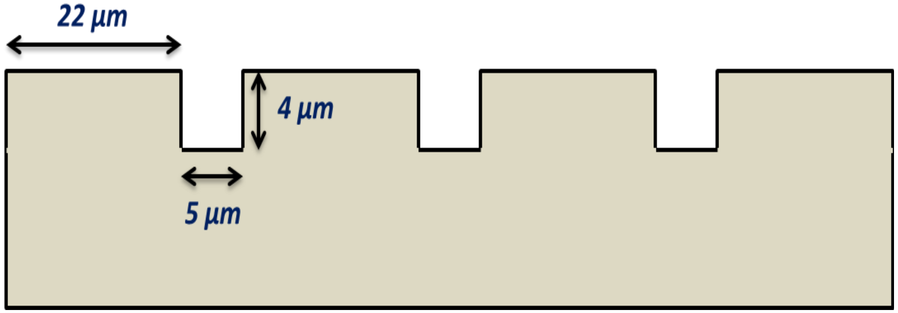
Pattern to be imprinted



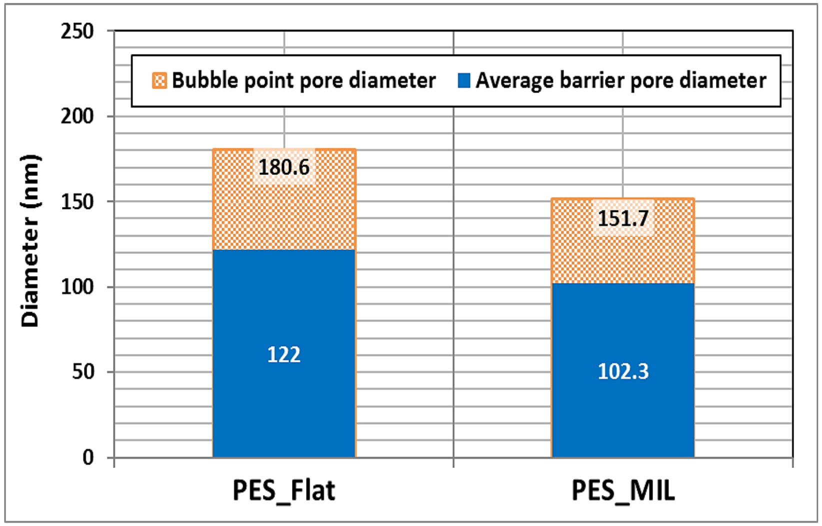
Optical microscope image for PDMS stamp used in fabrication process

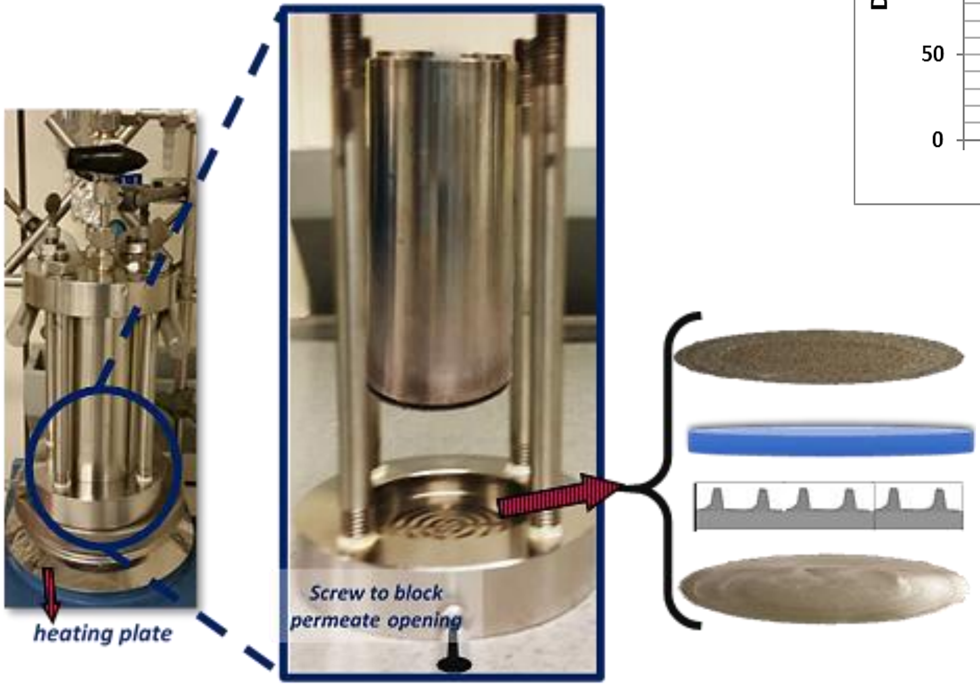


AFM 3D image for PDMS stamp used in fabrication process



- Three parameters were found to influence the MIL process:
- Temperature (60 - 130 ºC; i.e. below T_g of PES)
- Pressure (6 – 11.5 bar)
- Imprinting time (15 – 60 min)

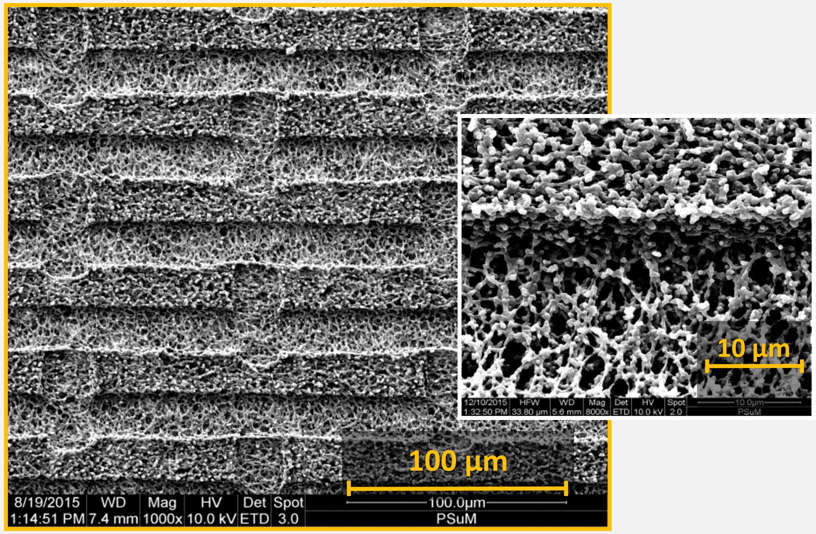




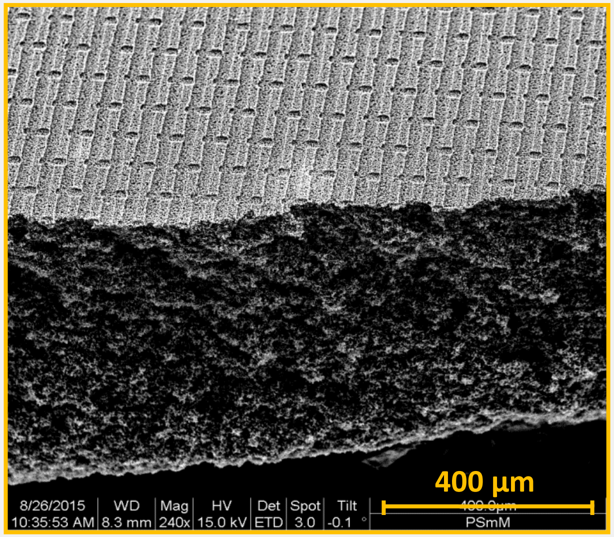
PES-PSmM

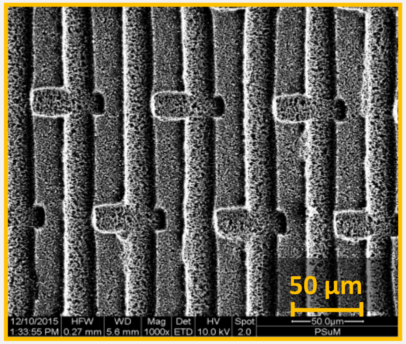
PES_PSµM

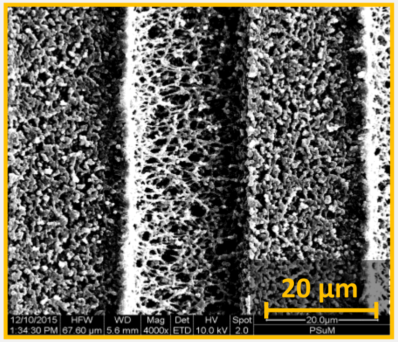
Top Surface

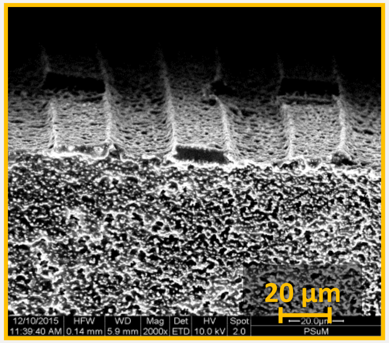


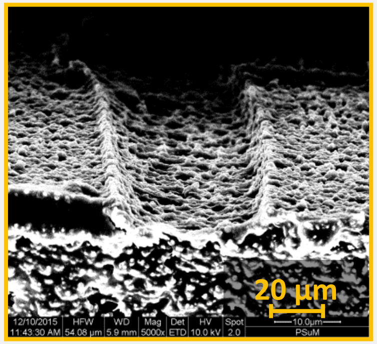
Cross section







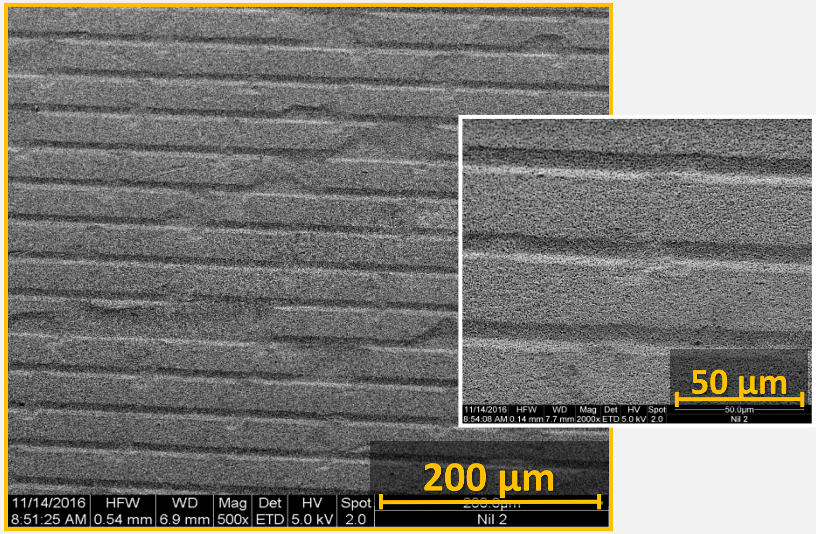


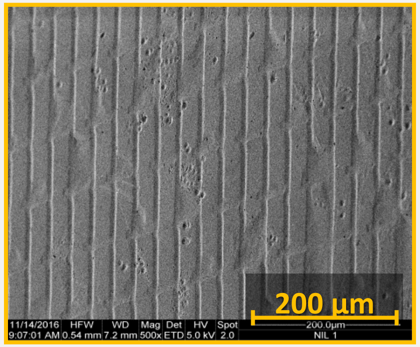


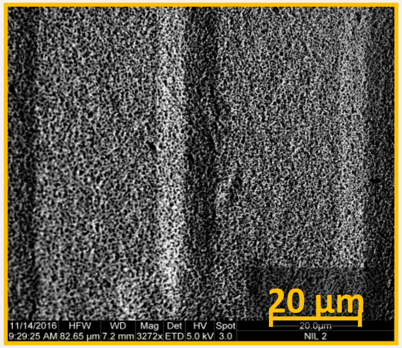
PES-MIL

PES_MIL

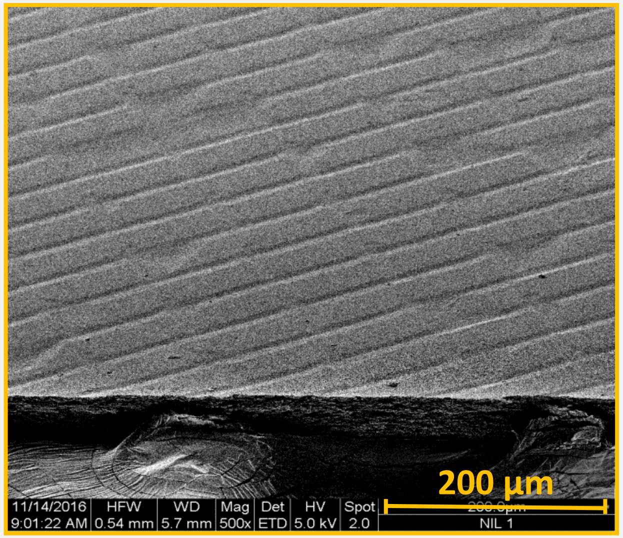
Top Surface

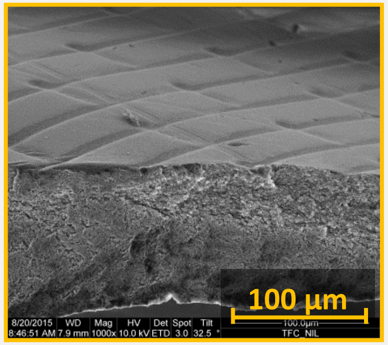


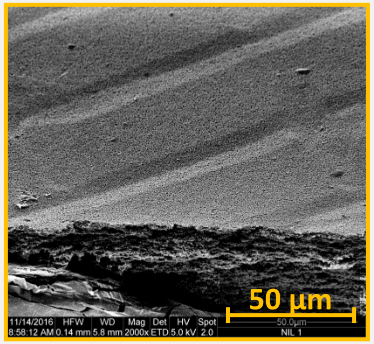




Cross section



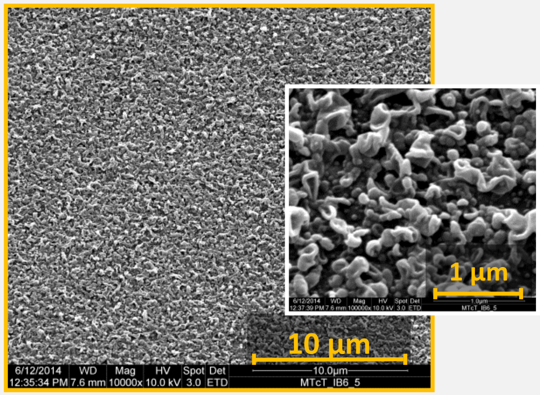




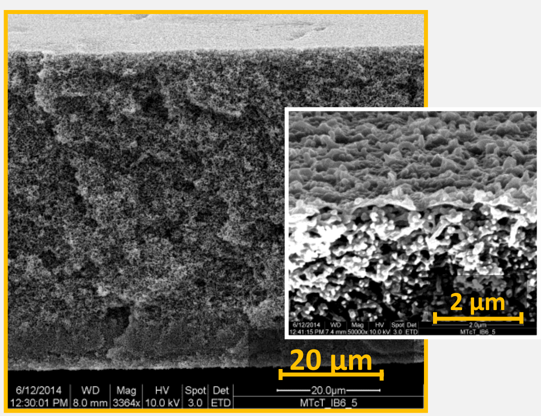
PA on patetrned PES supports

TFC_Flat

Top Surface

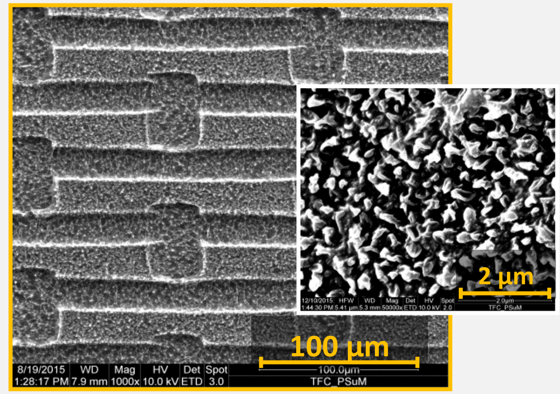


Cross section

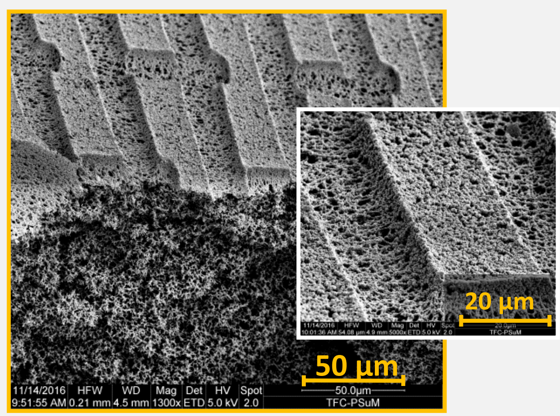


TFC_PSµM

Top Surface

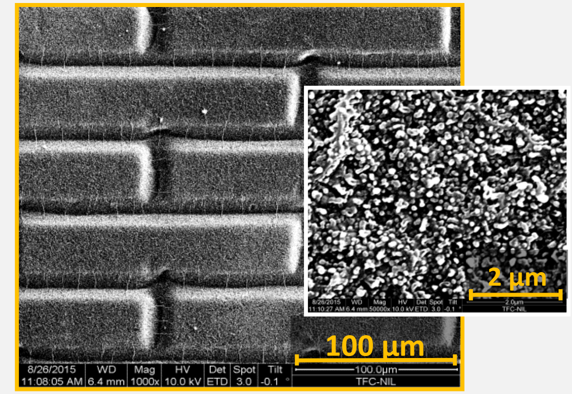


Cross section

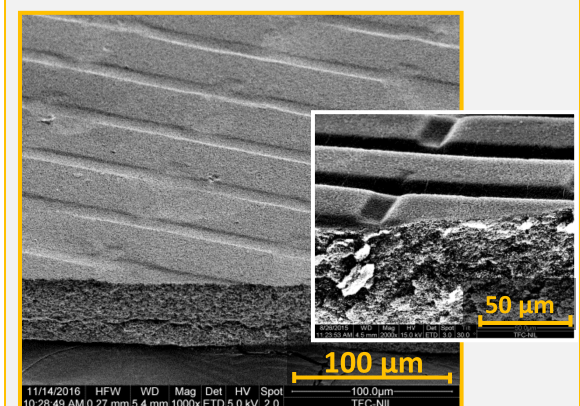


TFC_MIL

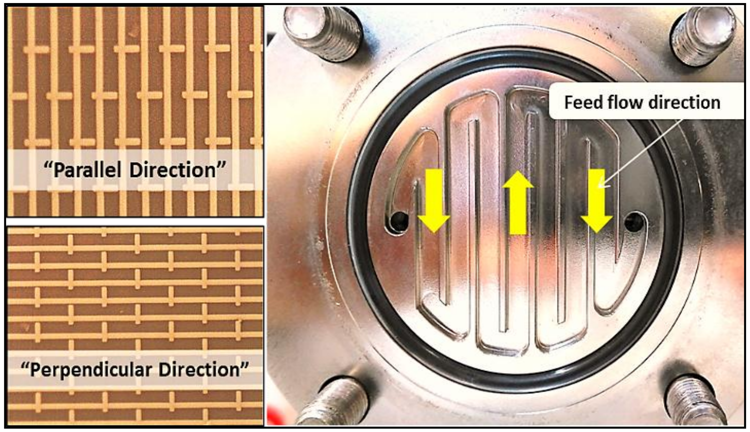
Top Surface

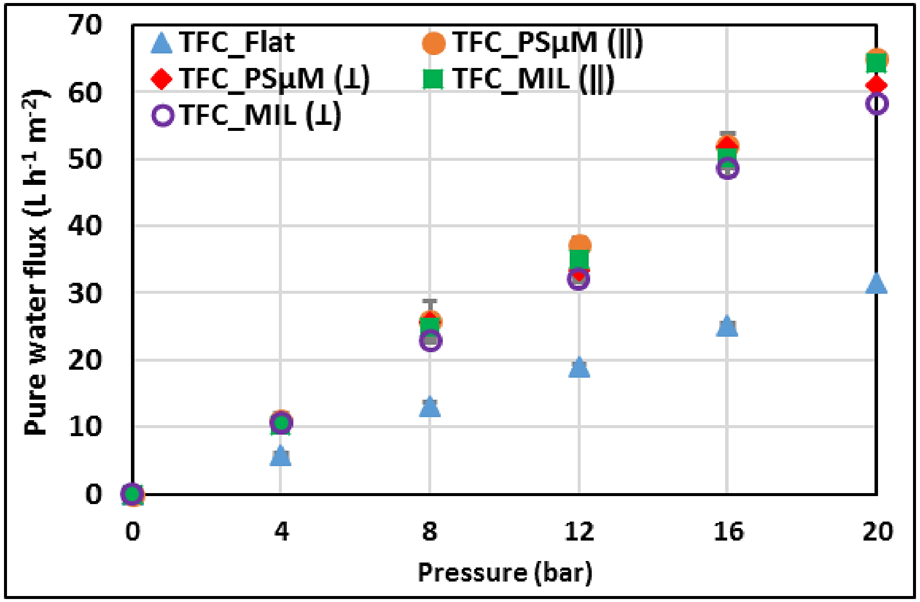


Cross section



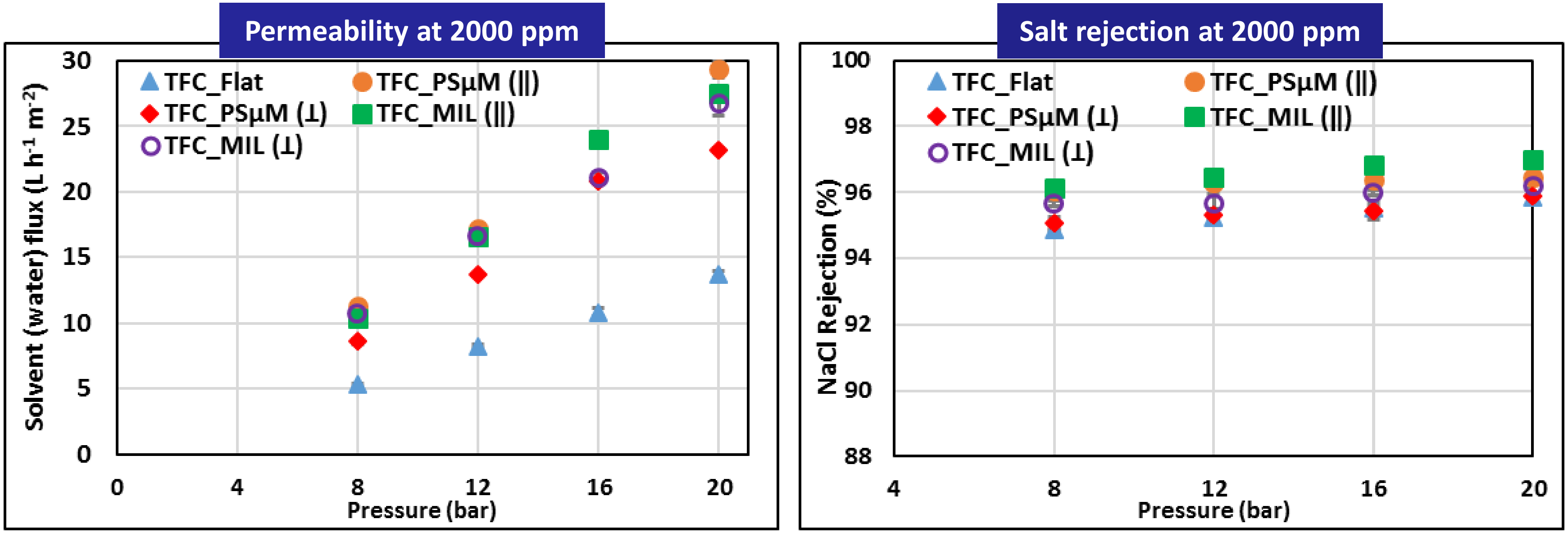
Cross flow filtration





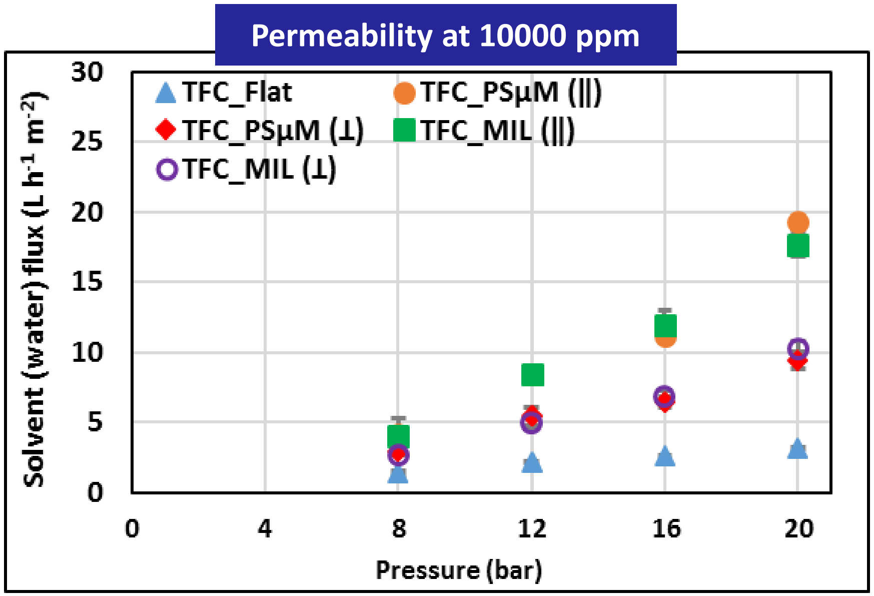
- The patterned membranes exhibited superior water permeability compared to the flat membranes because of the development of the membrane surface characteristics upon the surface micro-patterning.

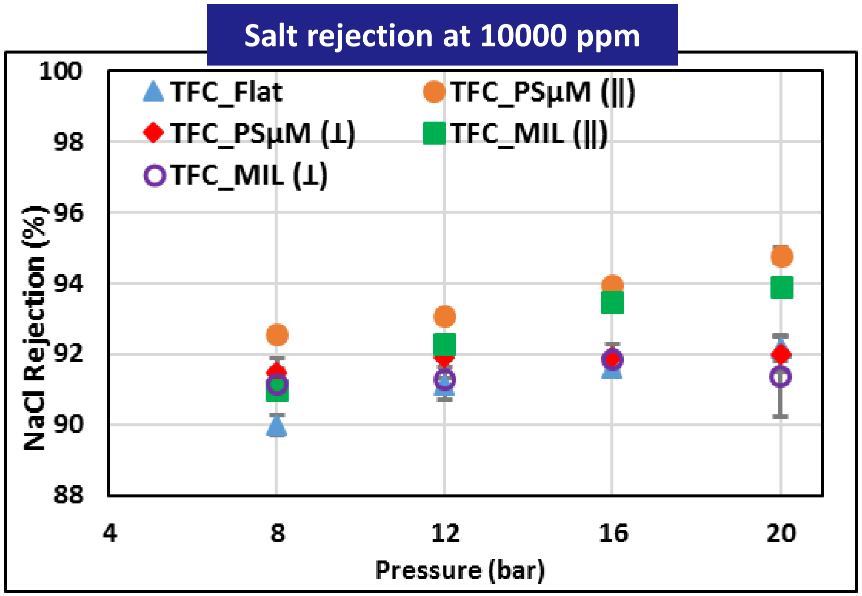
Rejection of low salt conc



- 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.

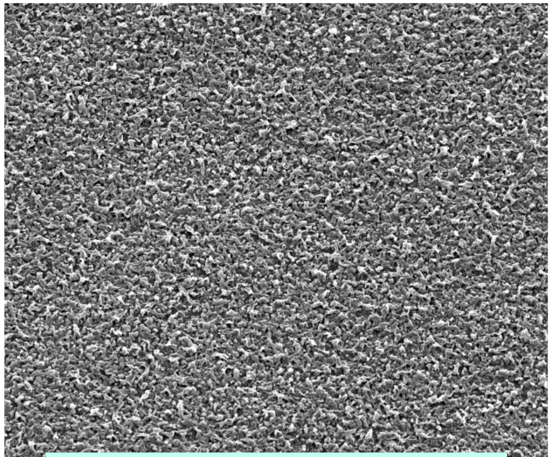
Rejection of high salt conc





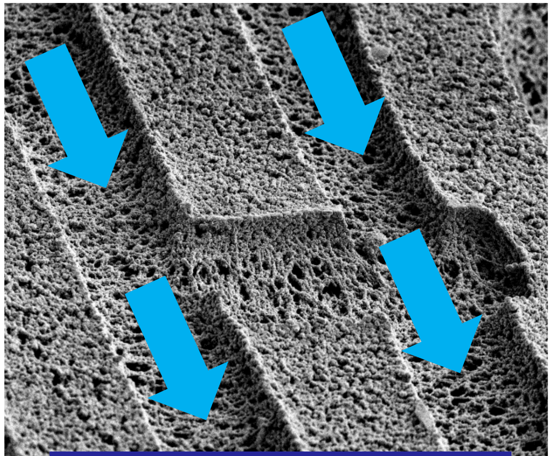
- TFC_PSμM exhibited a relatively higher permeability and salt rejection than those of TFC_MIL.
- The consequences of the membrane orientation on the separation performance were more pronounced.
- Improvement in the permeability and the salt rejection were observed for the patterned membranes that were employed in a parallel orientation.

Difference mechanisms



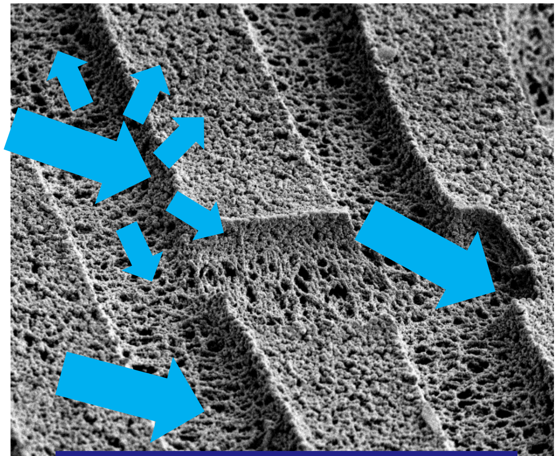
Flat Membranes

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



Parallel Orientation

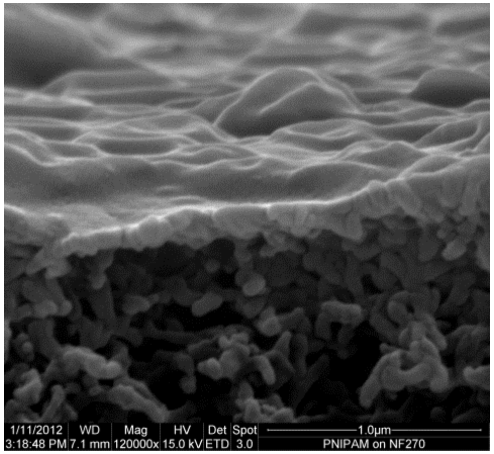
The micro-patterns work as water channels to stabilize the liquid streamlines, equilibrate the shear stress and promote surface mixing effects over the entire membrane surface area.



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

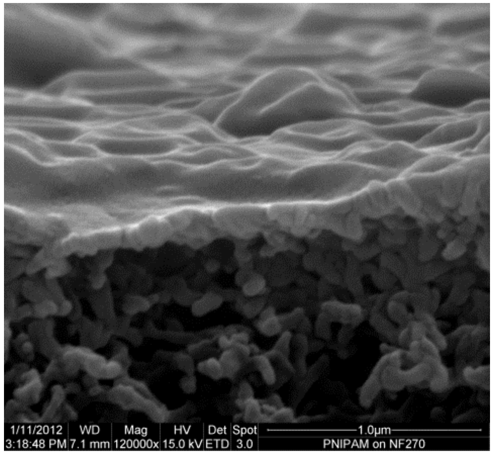
one year diploma in water technologies

(Eng/Science)

Practical Training

Practical Project

Ideas for funding



PhD/Postdoc Egy/Arab students

International Graduate School for Water Desalination

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

ARAB-GERMAN
YOUNG ACADEMY
OF SCIENCES AND
HUMANITIES

Thank you