PROAGRO LECTORIUM

Dual Freshwater and Salts Harvesting from Brine via Photothermal Membrane

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Our Dream

Desalination

- Desalination is the process of removing salts or other minerals and contaminants from seawater, brackish water, and wastewater effluent and it is an increasingly common solution to obtain fresh water for human consumption and for domestic/industrial utilization[1].

Introduction

Is Desalination a Sustainable Process ?

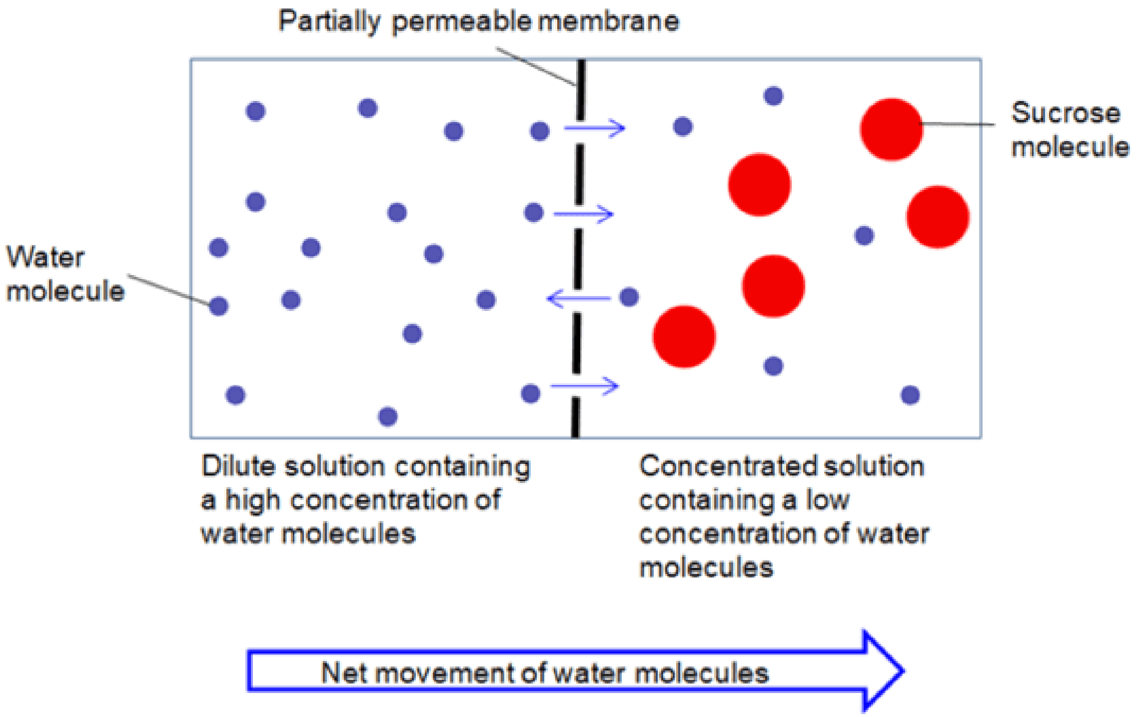
Introduction
Natural Desalination: «The Natural Water Cycle»

The Natural Water Cycle includes:

- Evaporation
- Transpiration
- Condensation
- Precipitation
- Run-off
- Infiltration
- Percolation

Introduction
Natural Desalination: «Natural Osmosis»

Osmosis is a biophysical phenomenon in which water (or another solvent) moves from a less concentrated solution to a more concentrated solution through a partially permeable membrane (in other words, it lets some particles pass, while blocking others).



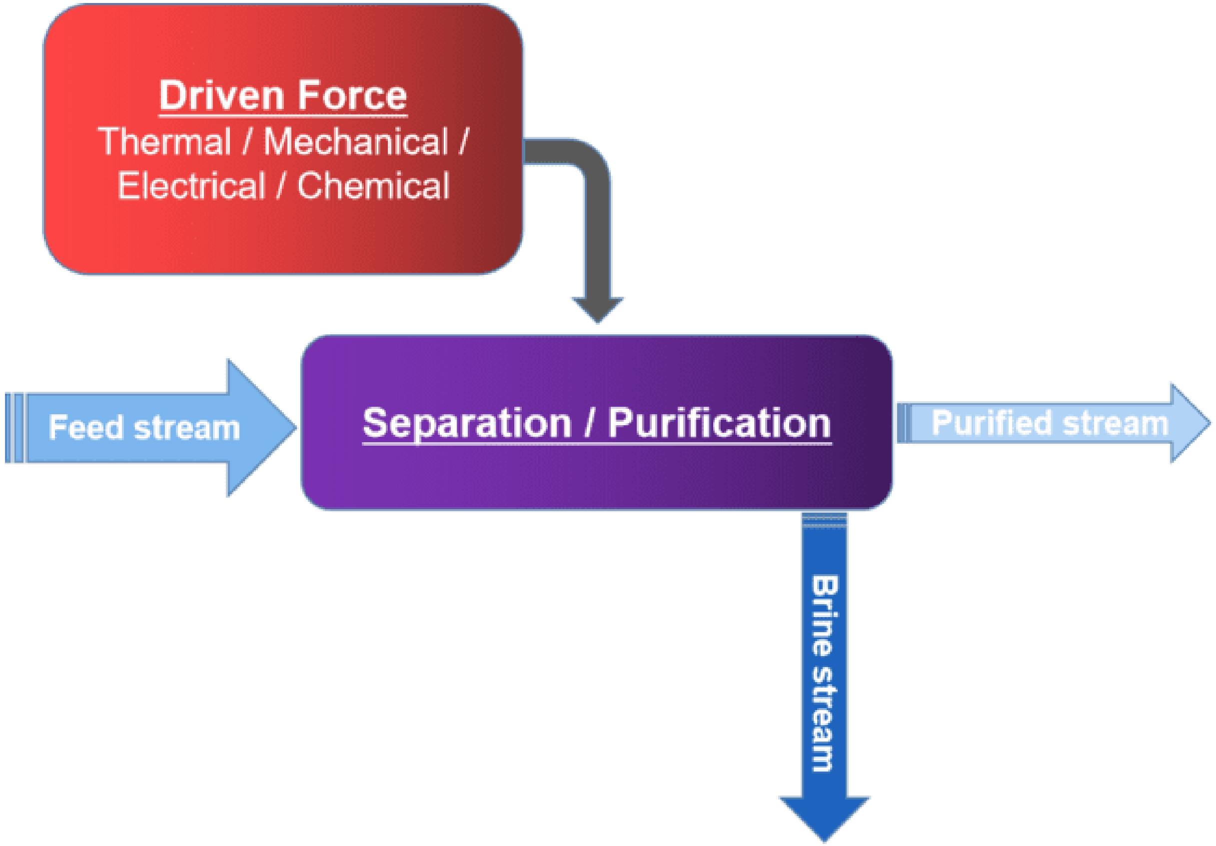
The solvent will maintain this migration until equilibrium in concentration is reached.

Introduction
Natural Desalination: «Natural Osmosis»

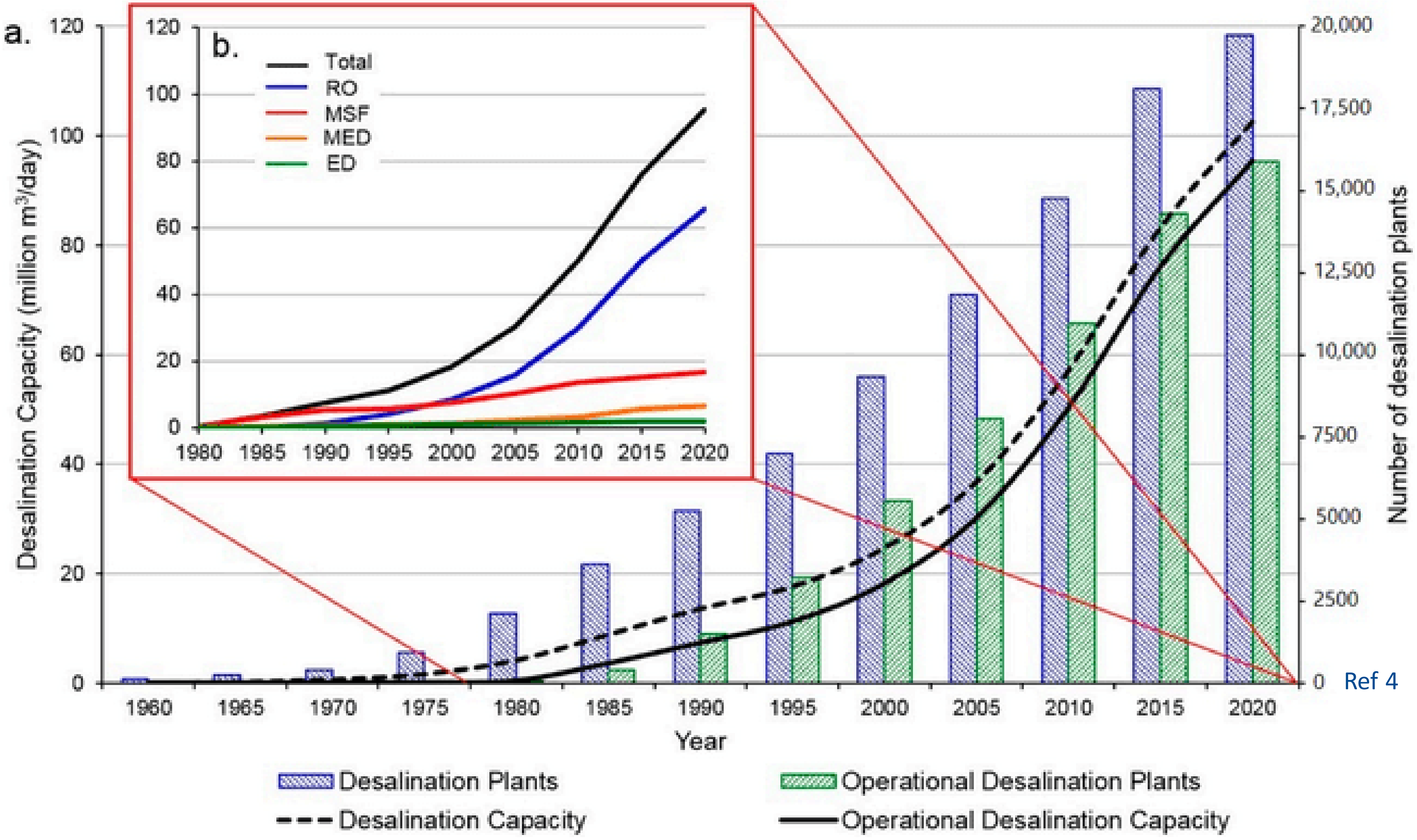
Forward osmosis is the predominant method of water transport across root cells of mangrove trees. It's a great example of a naturally occurring FO process. The cells utilize a highly concentrated internal solution of sugars to extract fresh water from the surrounding seawater.

Mangrove trees are a great example of a naturally occurring FO process.

- **Desalination Basic Concept:**



Introduction
Desalination Technologies: Global Statistics



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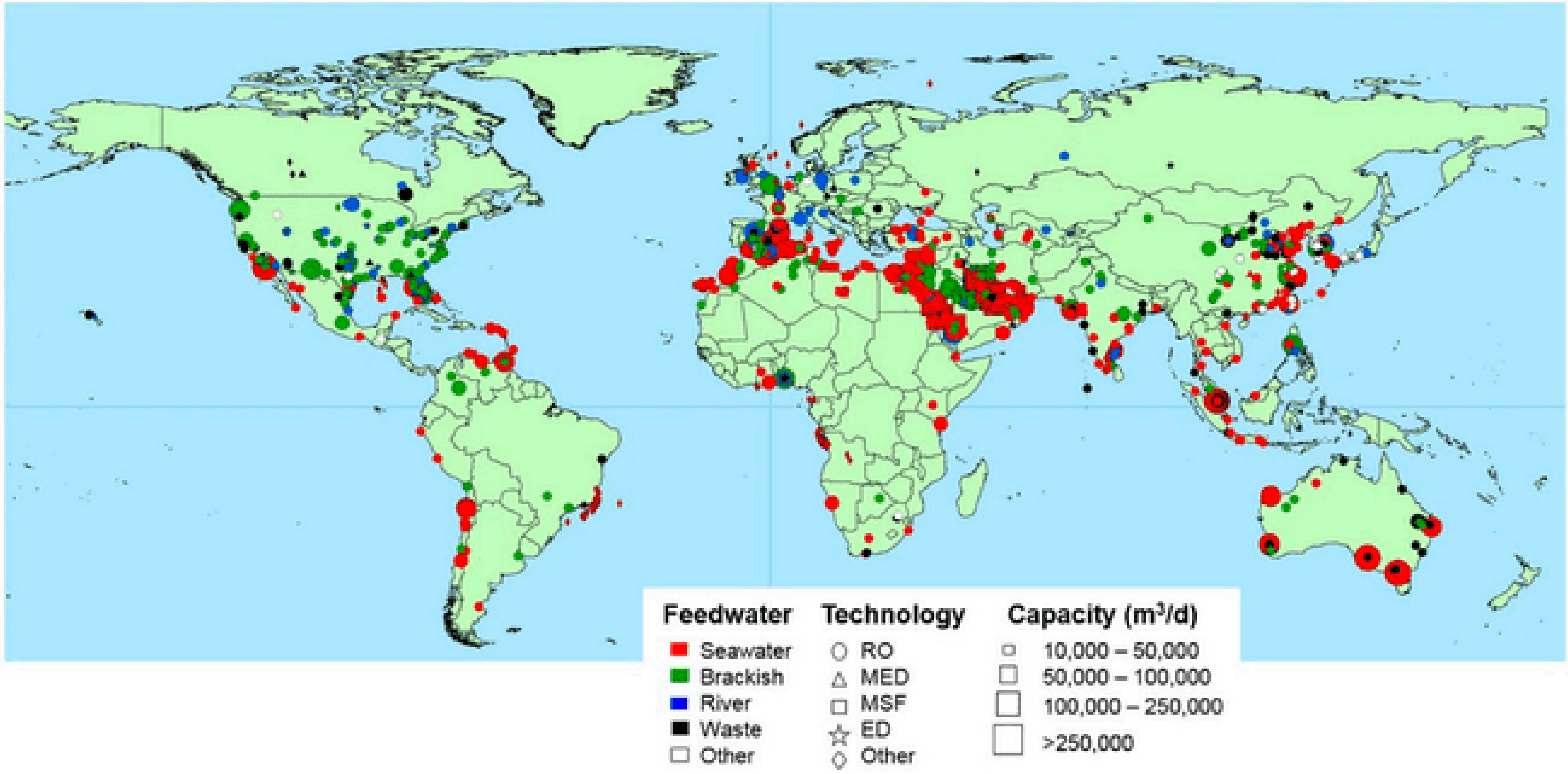
Introduction
Desalination Technologies: Global Distribution



Introduction
The Commercial Desalination Technologies «State-of-the-art»

Technology	Average Capacity [10^3 m^3/day]	Input	Recovery Ratio	Water Quality [ppm]	Energy Consumption		Water Cost [$/$m^3$]
					Electrical [kWh/m^3]	Thermal [kJ/kg]	
MED	0.6–30	SW	0.25	10	1.5–2.5	230–390	0.52–1.5
TVC	10–35	SW	0.25	10	1.5–2.5	145–390	0.87–0.95
MSF	50–70	SW	0.22	10	4–6	190–390	0.56–1.75
MVC	0.1–3	SW		10	6–12	no	2.0–2.6
SWRO	1–320	SW	0.42	400–500	3–6	no	0.45–1.72
BWRO	Up to 98	BW	0.65	200–500	1.5–2.5	no	0.26–1.33
ED	Up to 145	BW	0.9	150–500	2.64–5.5	no	0.6–1.05

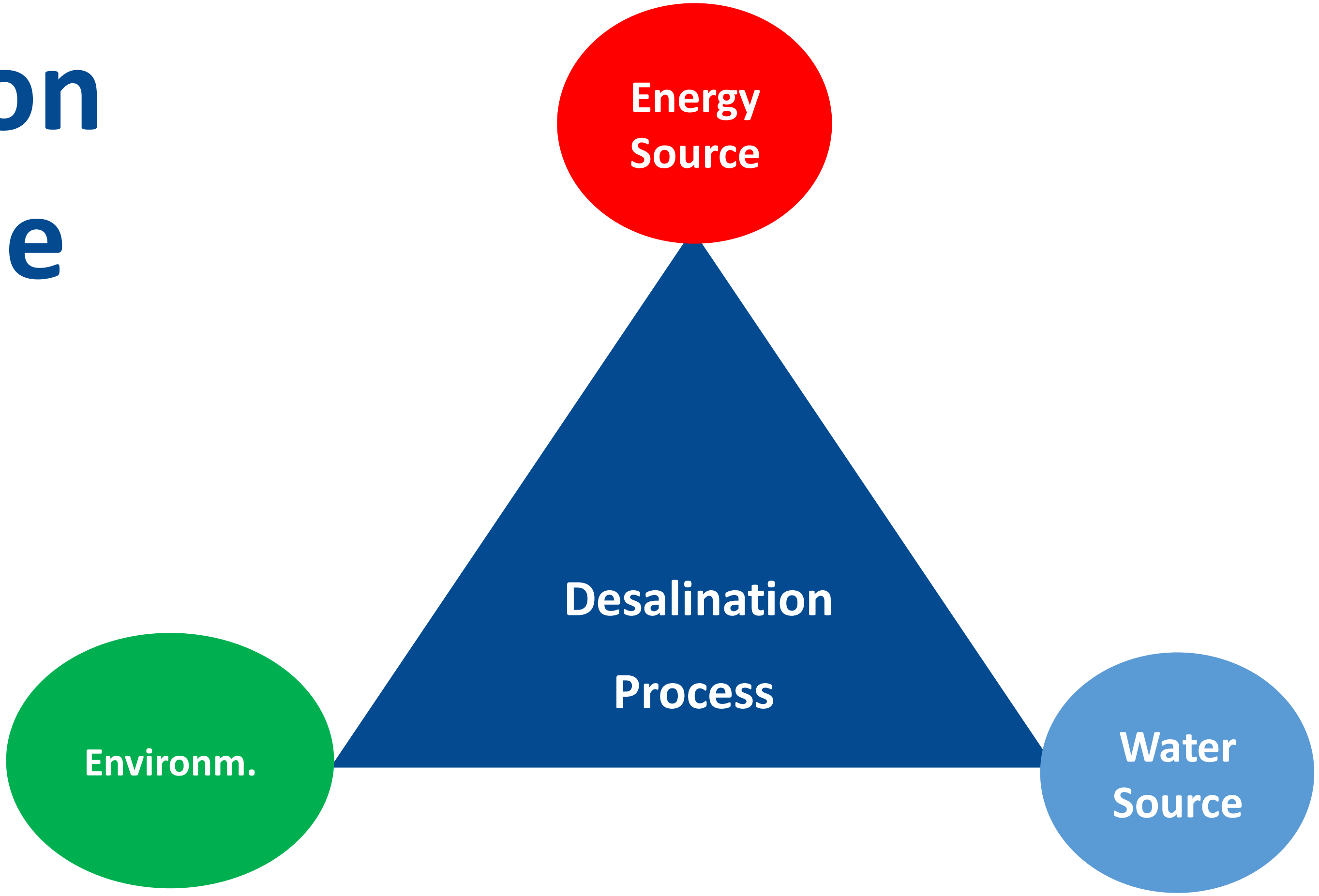
Ref 4

Introduction
Advantages and Disadvantages of the main Desalination Technologies

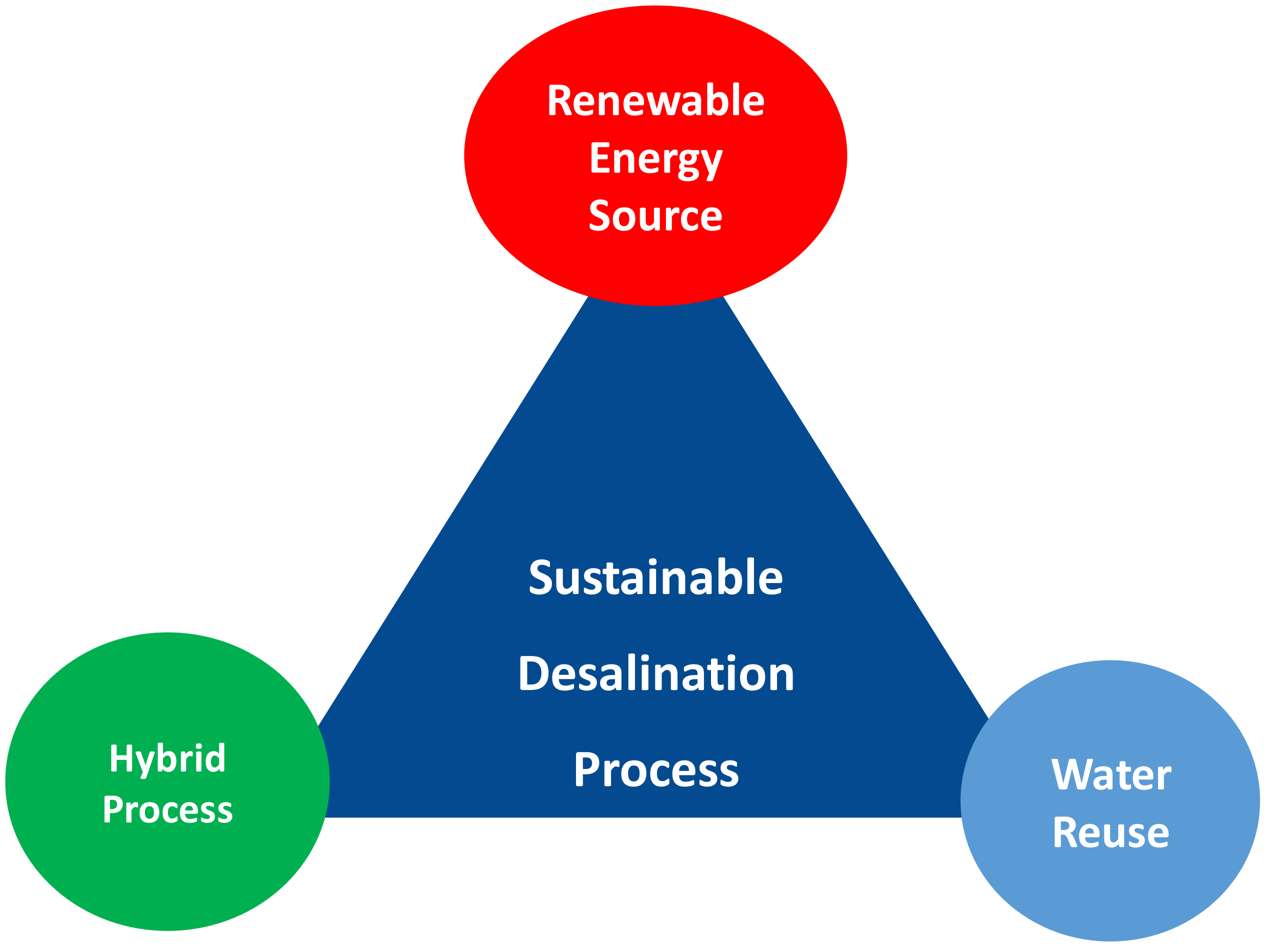
Technology	Advantages	Drawbacks	Status
MED	- High water quality - Low energy consumption	Scaling on the pipes	Commercial
MSF	- Maintenance operations to remove the scaling are simpler than in MED - High water quality - High rated capacity	- High energy demand - Huge investment - Corrosion problem - Slow start up - The entire plant is stopped for maintenance	Commercial
MVC	- High water quality - Low energy consumption	Low production capacity	Commercial
RO	- Only electrical demand - Low investments - Couplable with many renewable energy sources - Modular structure of plant	- Lower water quality - High costs for membranes and chemicals - Subject to biofouling	Commercial
FO	Low thermal energy	No drinking purpose (ammonia carbon dioxide) in industrial production	Special application (hydration bags) In development
NF	Low energy demand	Produces soft water (a diluted saline solution)	In development at the dual-stage unit for seawater
ED	- High purity of freshwater - Energy consumption proportional to salt concentration	- Only for brackish water (up to 2000 ppm) - Bacterial contaminants not removed by system	Commercial
CDI	Potentially more efficient than ED	Only for brackish water (up to 2000 ppm)	In development

Ref 4

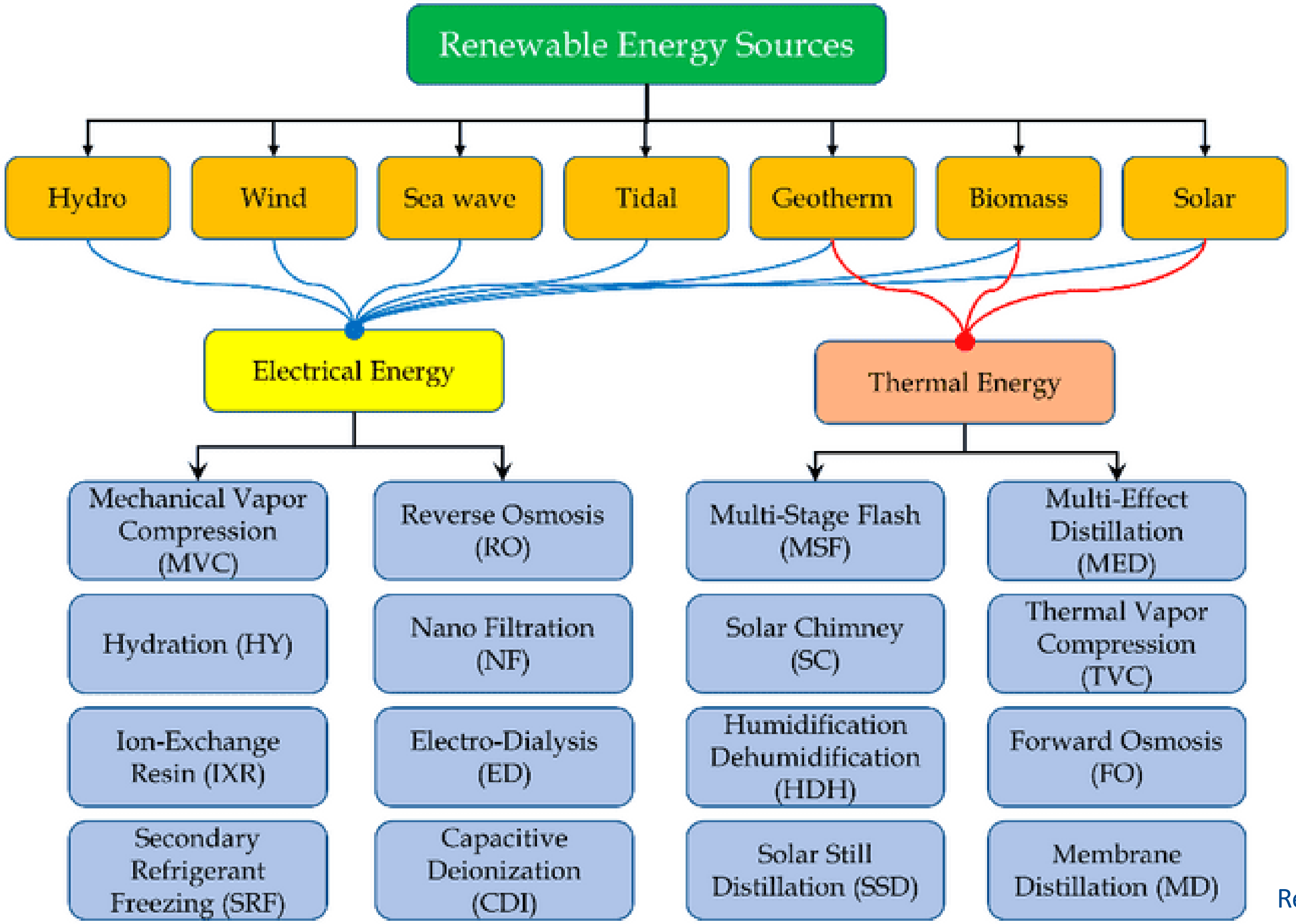
Is Desalination a Sustainable Process



Sustainable Desalination Process



Renewable Energy Sources and Possible Coupling with Desalination Technologies



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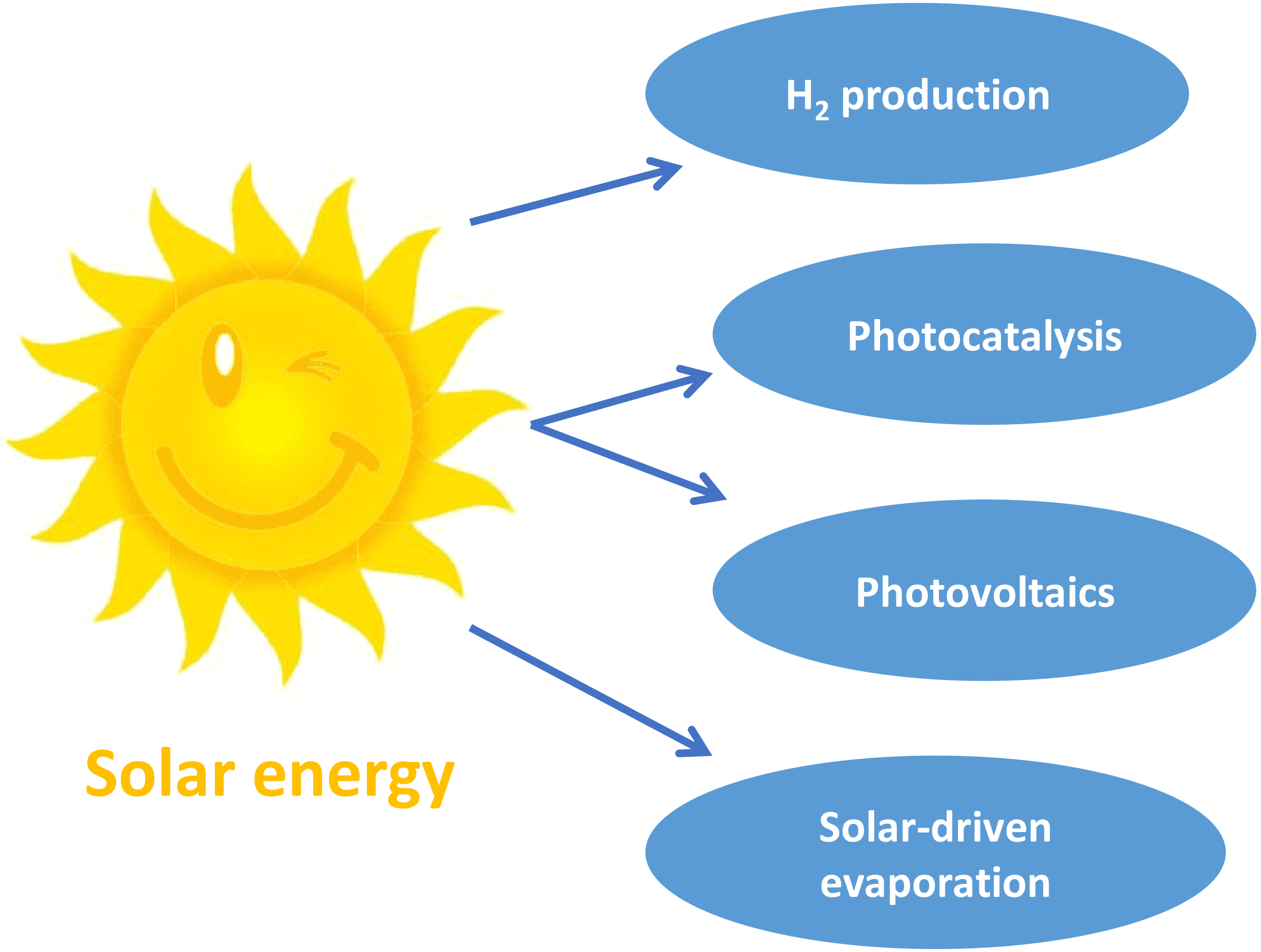
Introduction
Harnessing Solar Light for Direct Desalination Process / Brine solution

Widely distributed

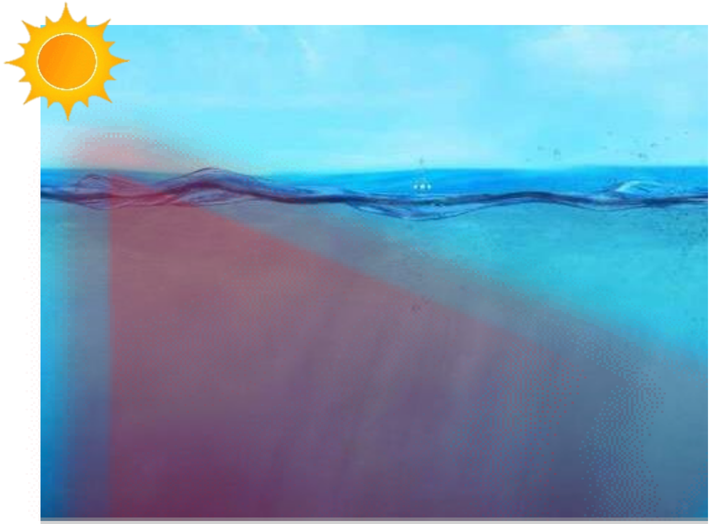
Clean

Large reserves

Sustainable



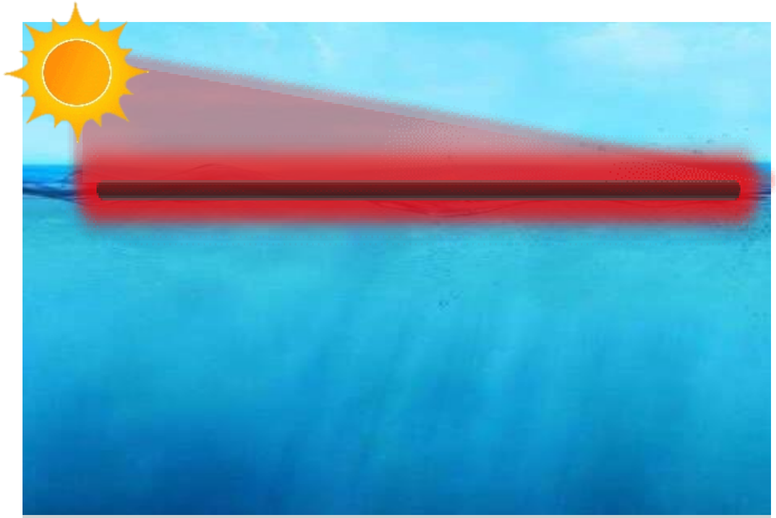
Solar-driven evaporation



Natural evaporation process

Bulk heating

Low Efficiency



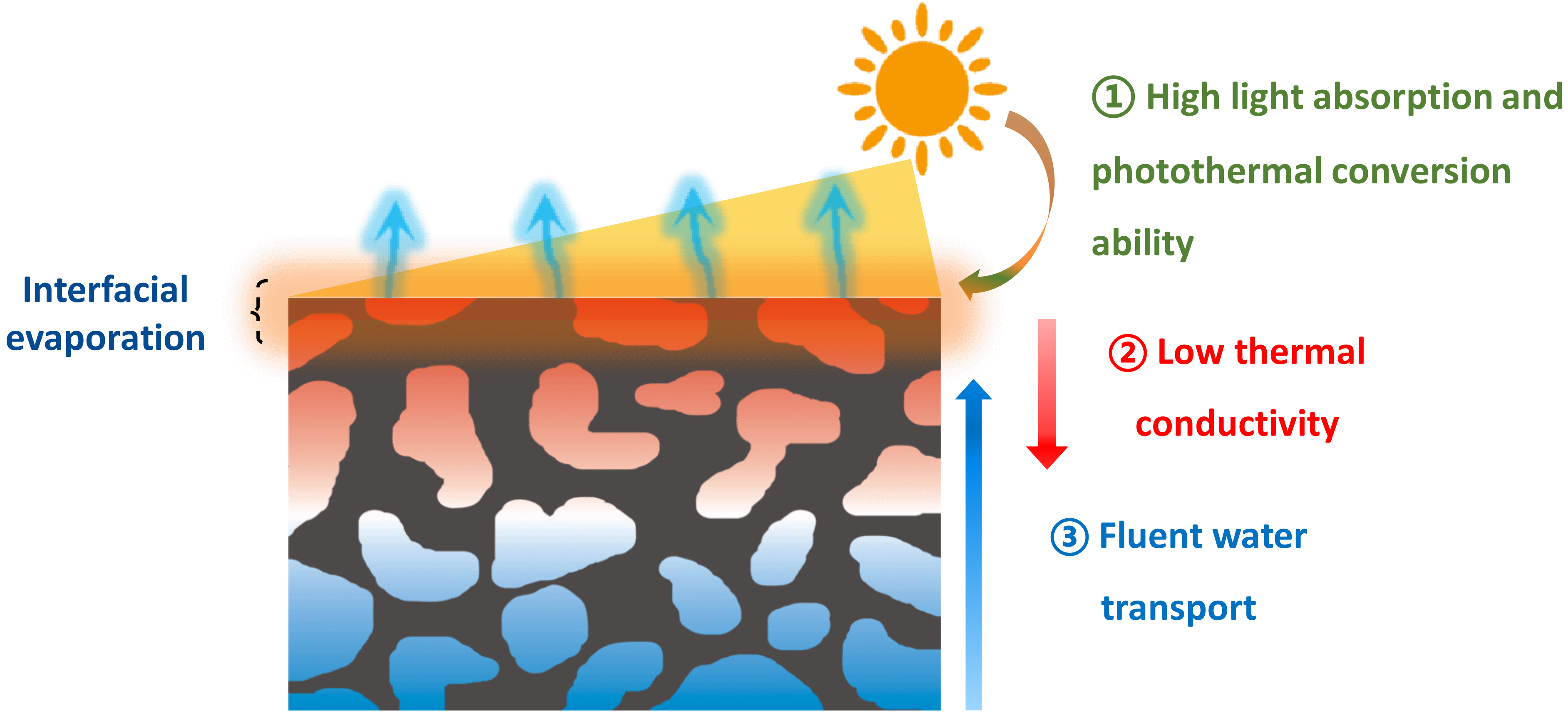
Photothermal Materials

Interface Heating

High Efficiency

Introduction
Harnessing Solar Light for Direct Desalination Process / Brine solution

Requirements



Materials

- **Carbon-based materials** (Graphene, **CNTs**, Carbon black......)
- **Noble metal nanoparticles** (Au、Ag、Pd......)
- **Metallic oxide** (Iron-based, Titanium-based......)
- **Polymer** (PANi、PDA、**PPy**......)

Purpose and Aim of the work

- We aim to design a novel photothermal membrane with dual applications for salts extraction and pure water cogeneration from brine via efficient solar light harvesting.
- The novel hybrid membrane will work on solving two main challenges; water scarcity via pure water production from brine using solar energy and brine discharge environmental problem by salts extraction without liquid discharge.
- We will grow up and optimize different kinds of photothermal layers using; polypyroll (ppy) via chemical vapor deposition (CVD), CNTs via vacuum-assisted filtration and mixed matrix design of ppy & CNTs.

- Evaporation rate and solar conversion efficiency will be determined.

Wider Objectives

1. Designing a novel photothermal membrane for salts extraction and pure water cogeneration from brine.
2. Optimizing the rational design of photothermal layer using ppy and CNTs on commercial substrates (PVDF & Fabrics).
3. Utilizing the novel photothermal membrane separation technology to achieve mining of metals and Efficient Sustainable Desalination from brines and seawater.

Specific Objectives

- Optimizing chemical vapor deposition of ppy layer on the commercial substrates.
- Optimizing deposition of CNTs on the commercial substrates via filtration technique.
- Facial deposition of ppy/CNTs as integrated design layer on the commercial substrates.
- Improved transmembrane flux with respect the pristine membrane without the deposited materials.
- Increasing membrane stability during simultaneous salts extraction and vapor generation.

Methodology

A) Chemical Vapor Deposition (CVD) of Pyrrole

M^nX_n :

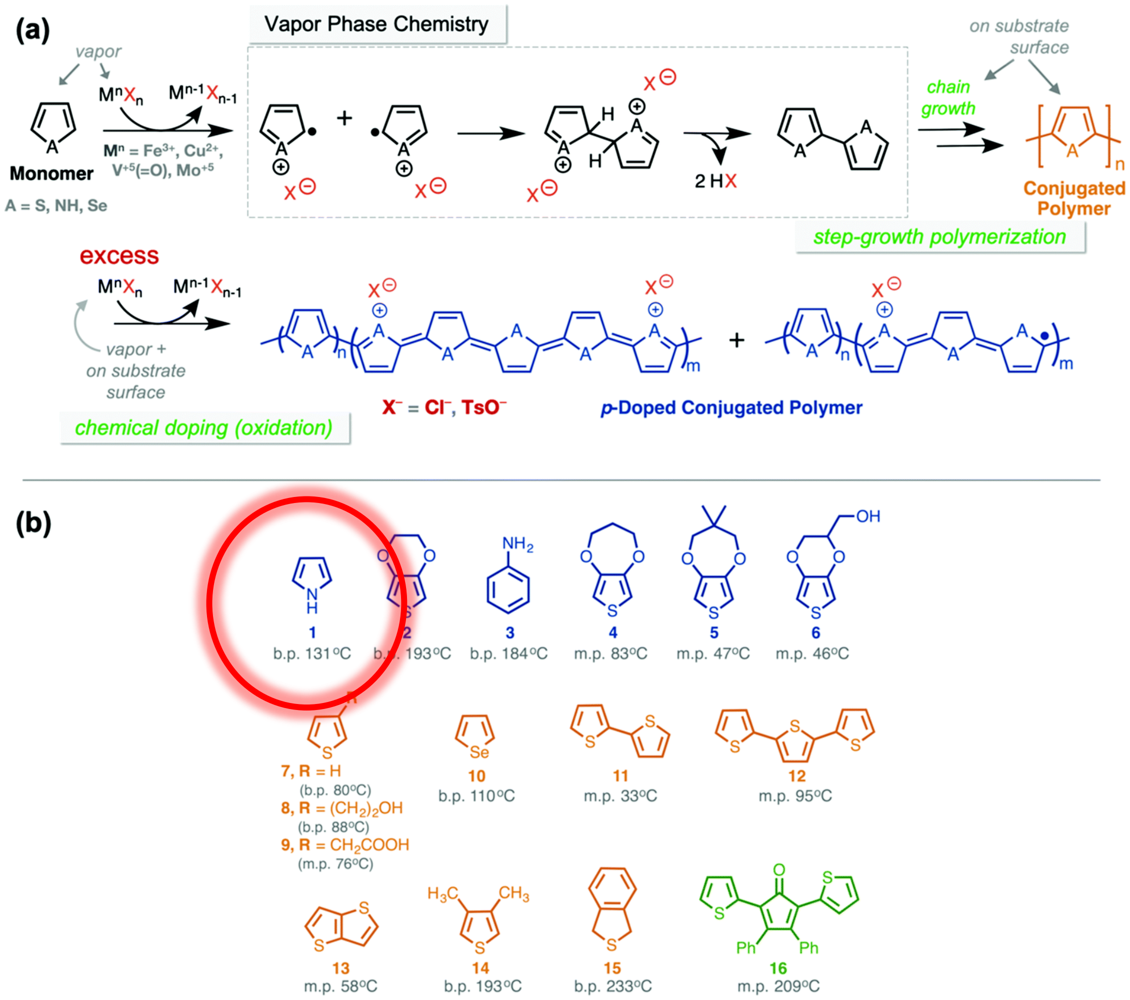
$FeCl_3$

$CuCl_2$

$KMnO_4$

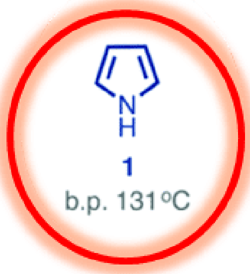
$(NH_4)_2S_2O_8$

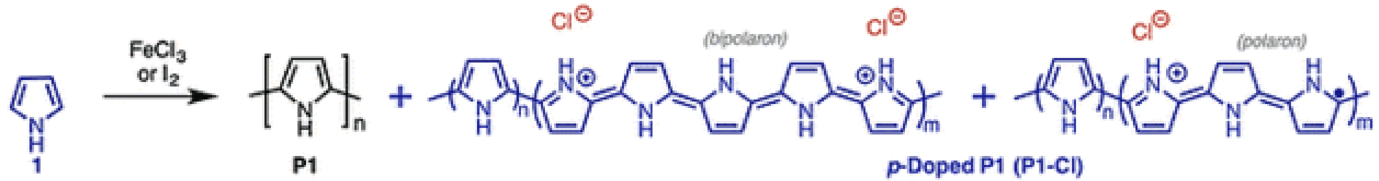
$Na_2Cr_2O_7$



Methodology

A) Chemical Vapor Deposition (CVD) of Pyrrole





(i) Optimizing Oxidants

M^nX_n :

$FeCl_3$

$CuCl_2$

$KMnO_4$

$(NH_4)_2S_2O_8$

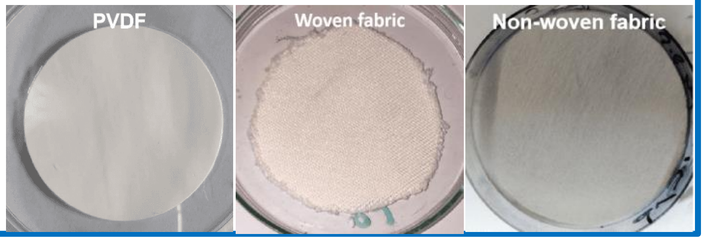
$Na_2Cr_2O_7$

(ii) Optimizing Substrates:

PVDF

Woven Fabric

Non-woven Fabric

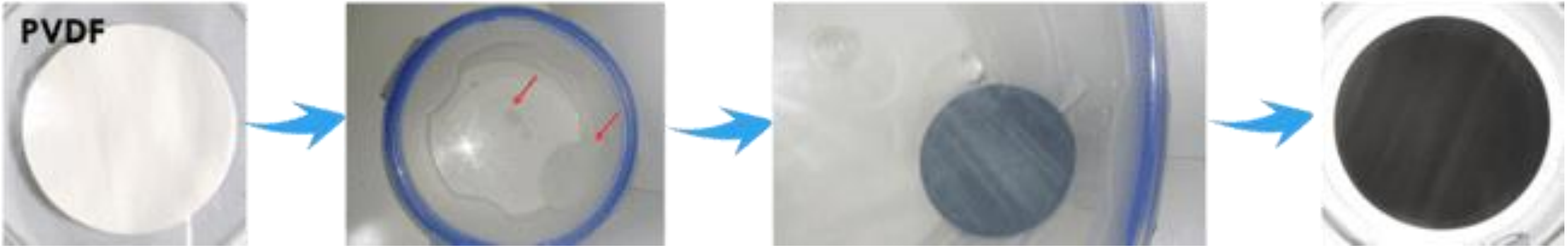


Methodology

A) Chemical Vapor Deposition (CVD) of Pyrrole

(iii) Optimizing Geometry of the Reactor

The reactor geometry is one of the crucial parameters that affect on CVD polymerization and scale-up the process.



Methodology

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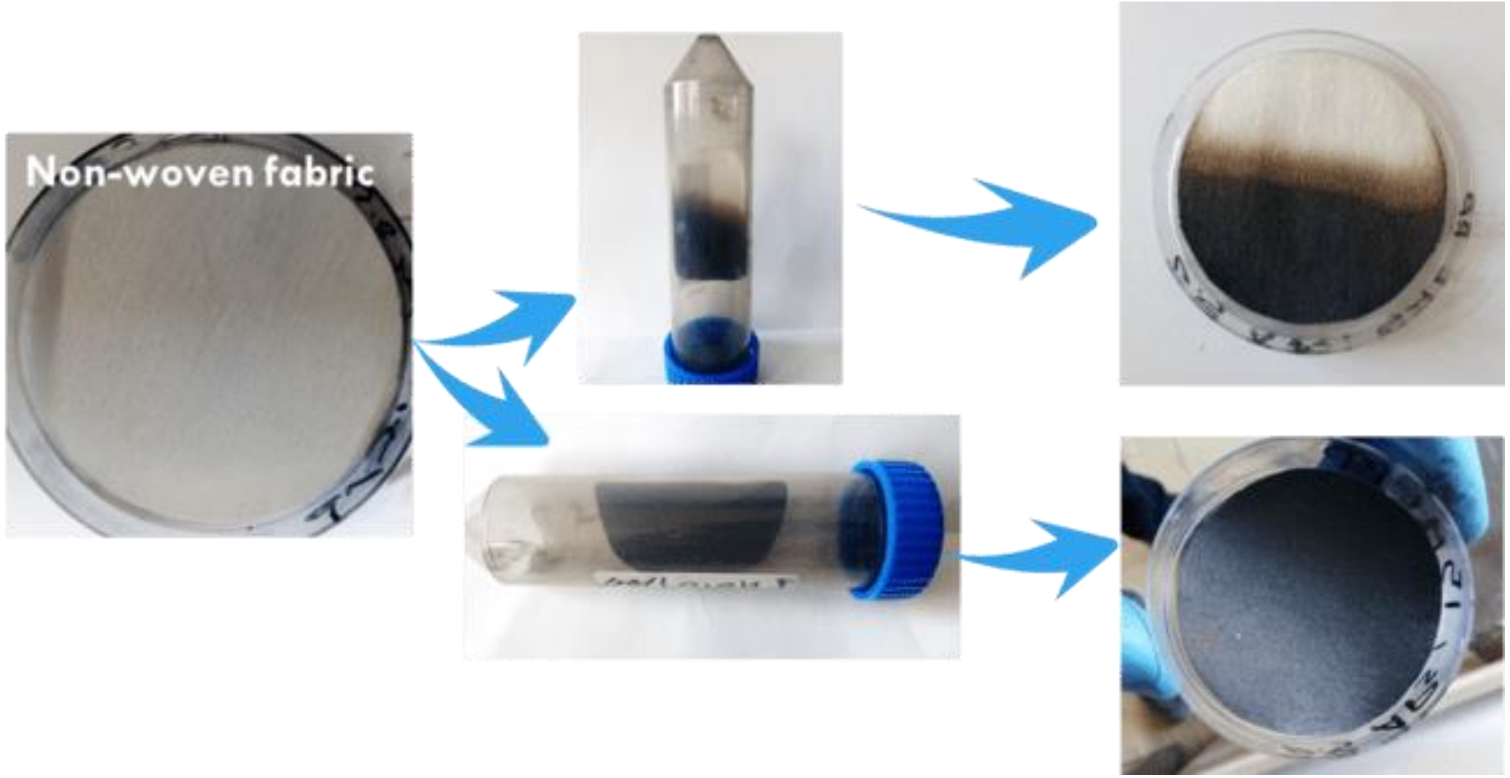

Methodology

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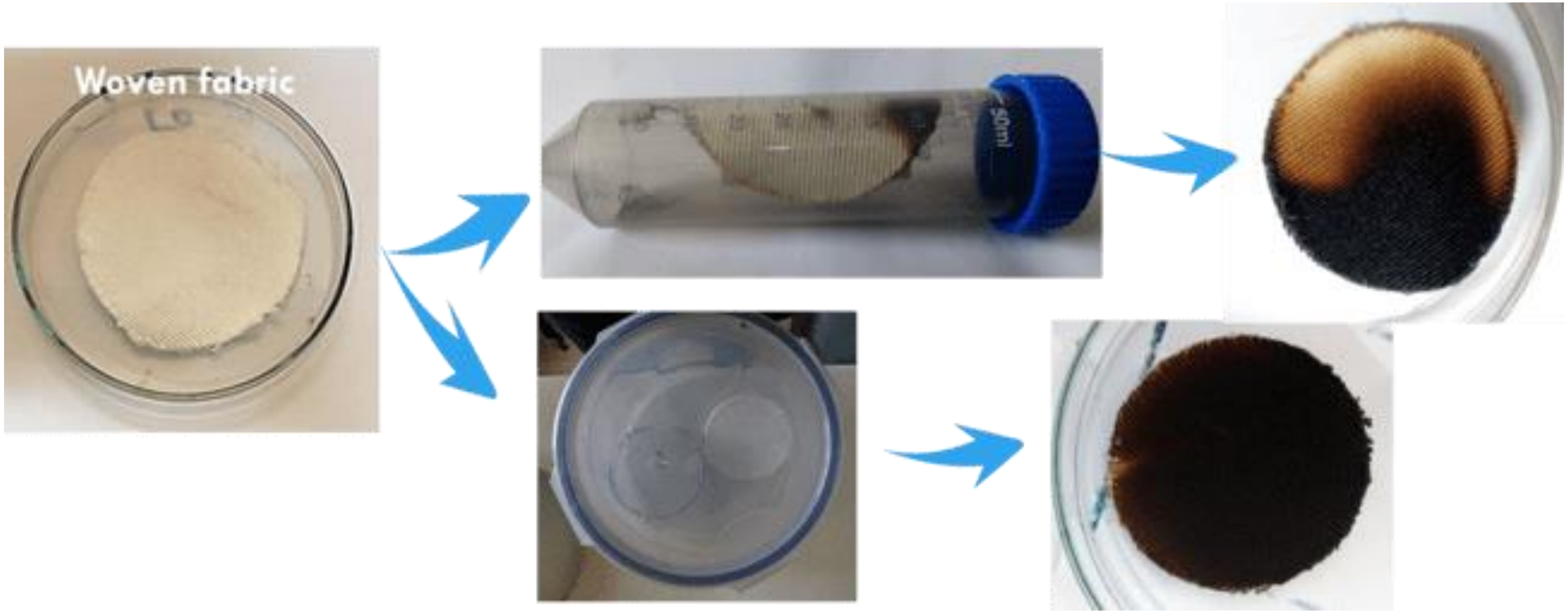


Methodology

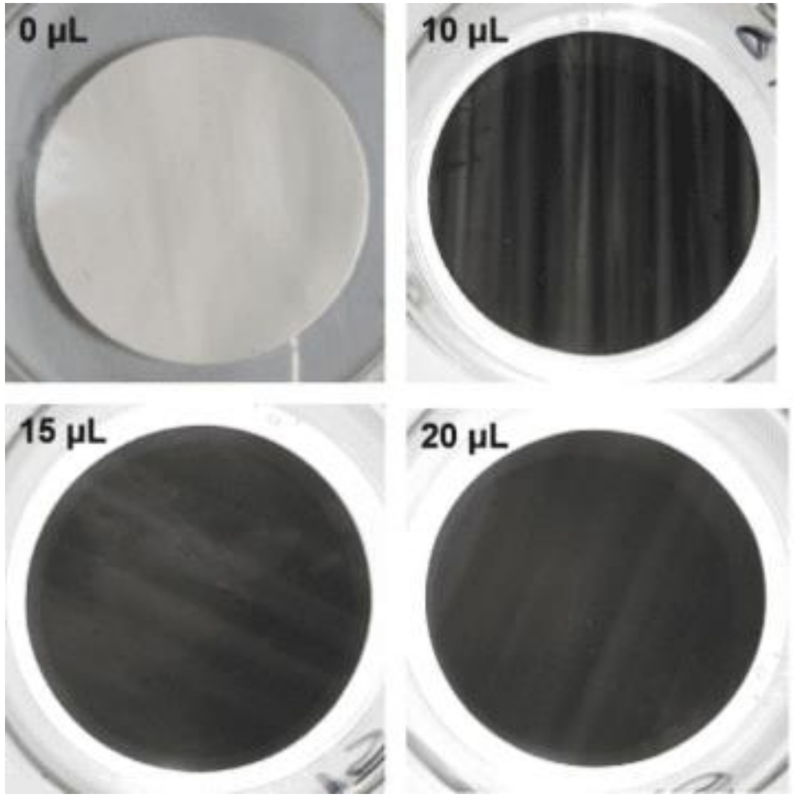
A) Chemical Vapor Deposition (CVD) of Pyrrole

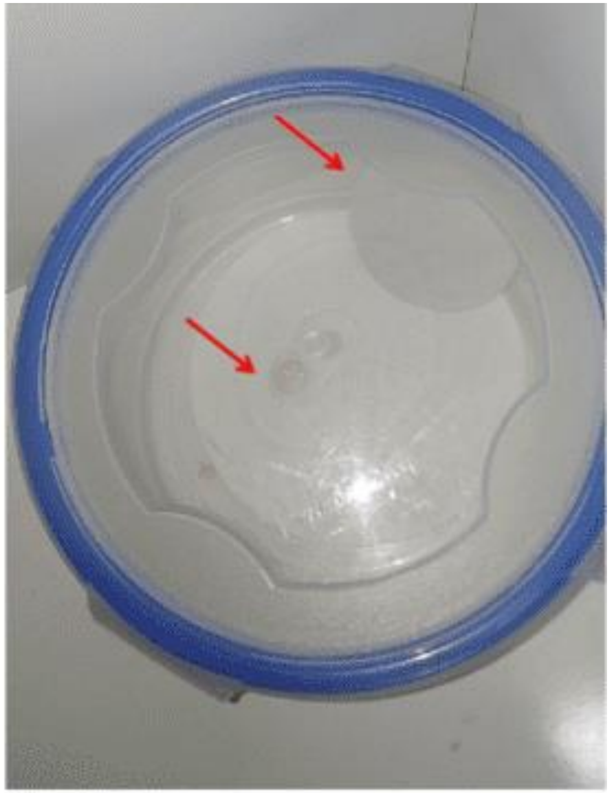
(iii) Optimizing Geometry of the Reactor

Scale-up the CVD polymerization process.

Results

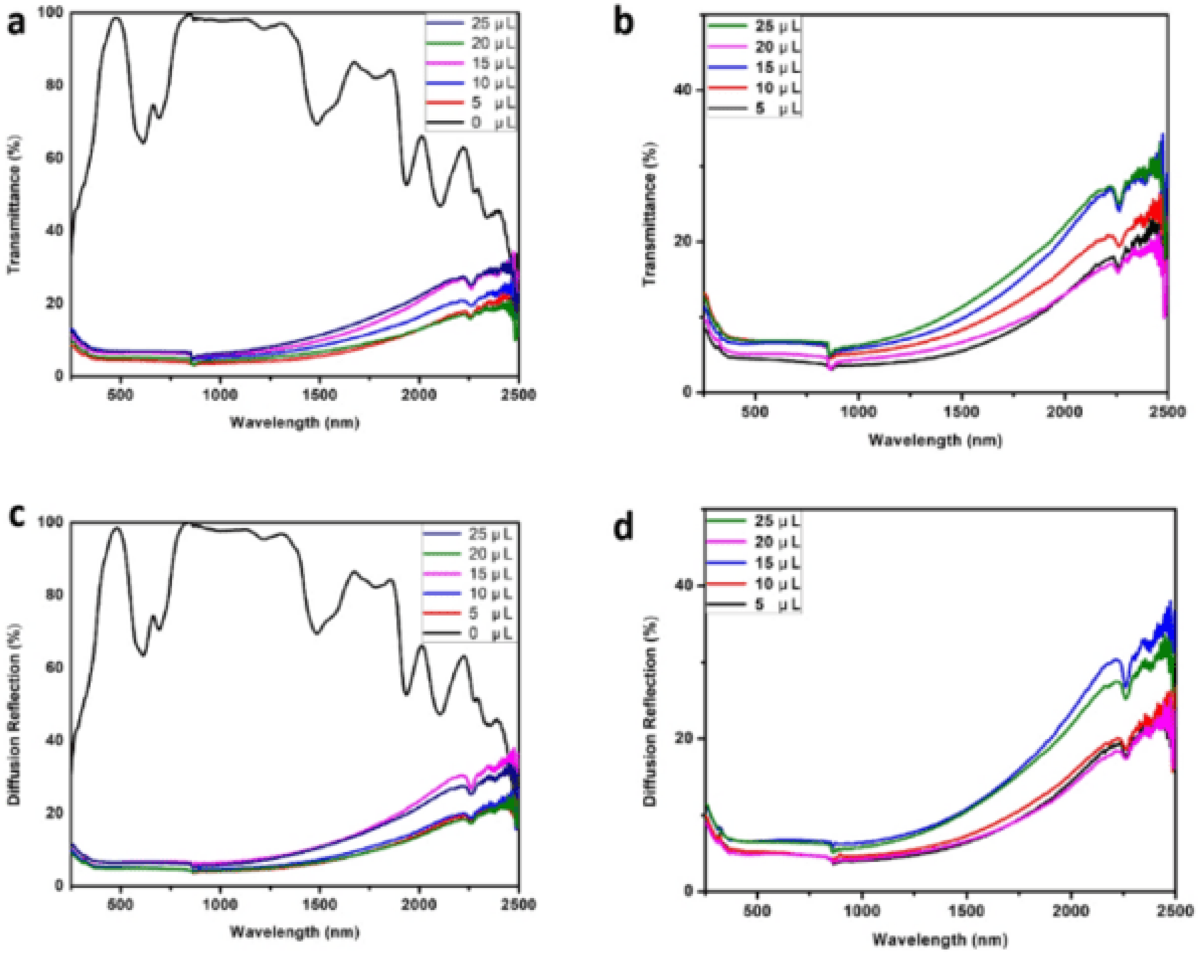
Different concentrations of pyrrole deposited on PVDF membrane (left), and the CVD polymerization method (right)





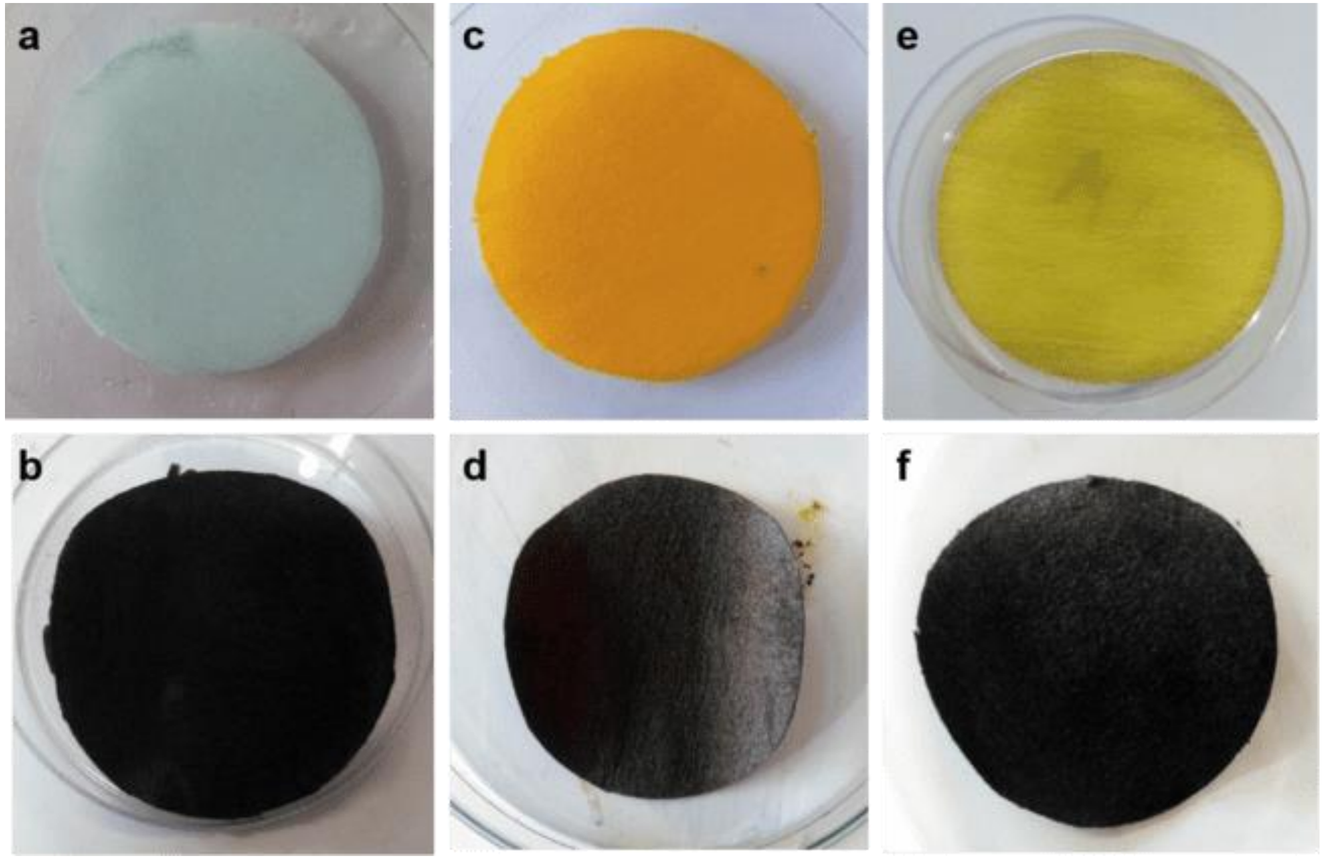
Results

UV-Vis-NIR spectra of photothermal layer with different concentration of pyrrole on the top surface of commercial PVDF membranes: Transmittance (a & b), and Diffusion (c & d)



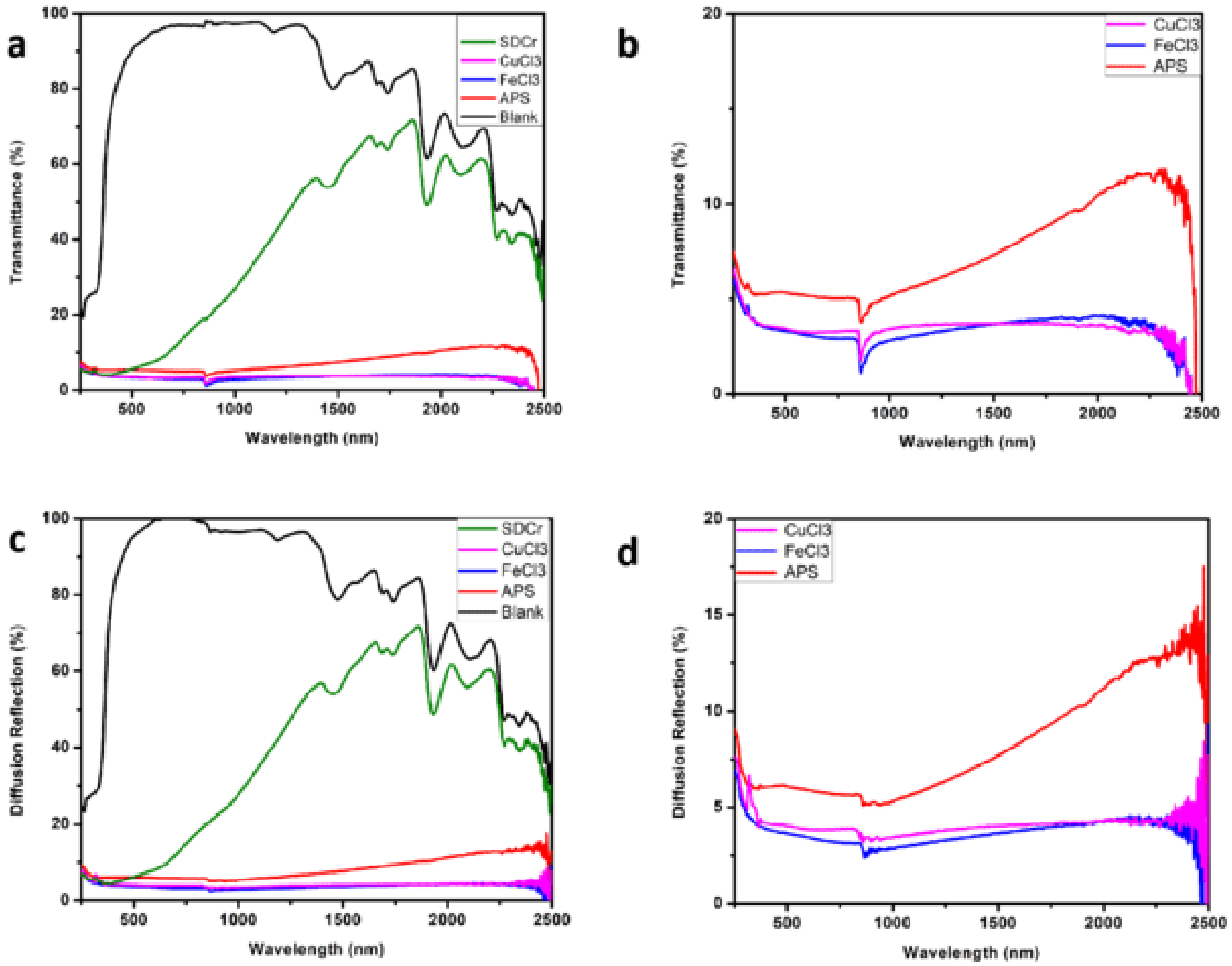
Results

Different oxidizing agents with concentration 0.5 M of non-woven fabric (before and after CVD; $CuCl_2$ «a & b»; $Na_2Cr_2O_4$ «c & d»; $FeCl_3$ «e & f», followed by 20 µL pyrrole deposition

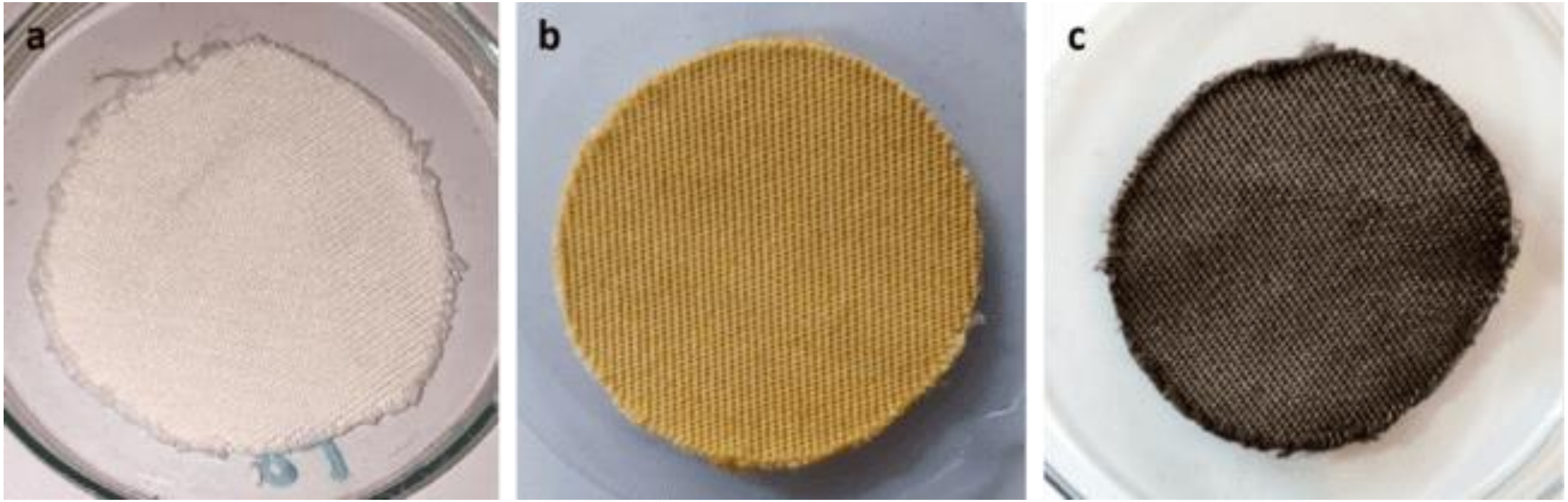


Results

UV-Vis-NIR spectra of photothermal layer with different oxidizing agents (0.5 M) for the non-woven fabric for ppy deposition using 20 µL of pyrrole: Transmittance (a & b), and Diffusion (c & d)

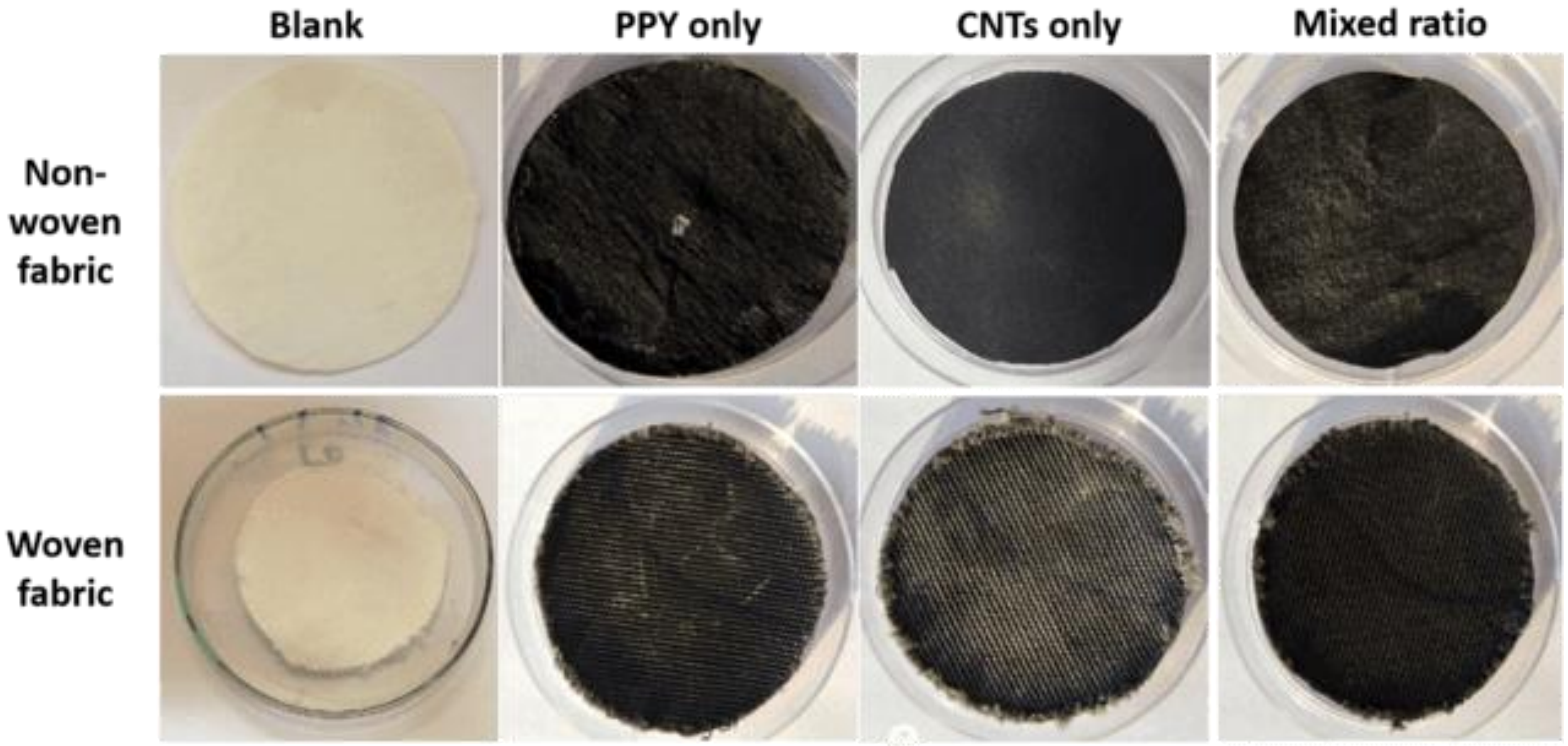


Results



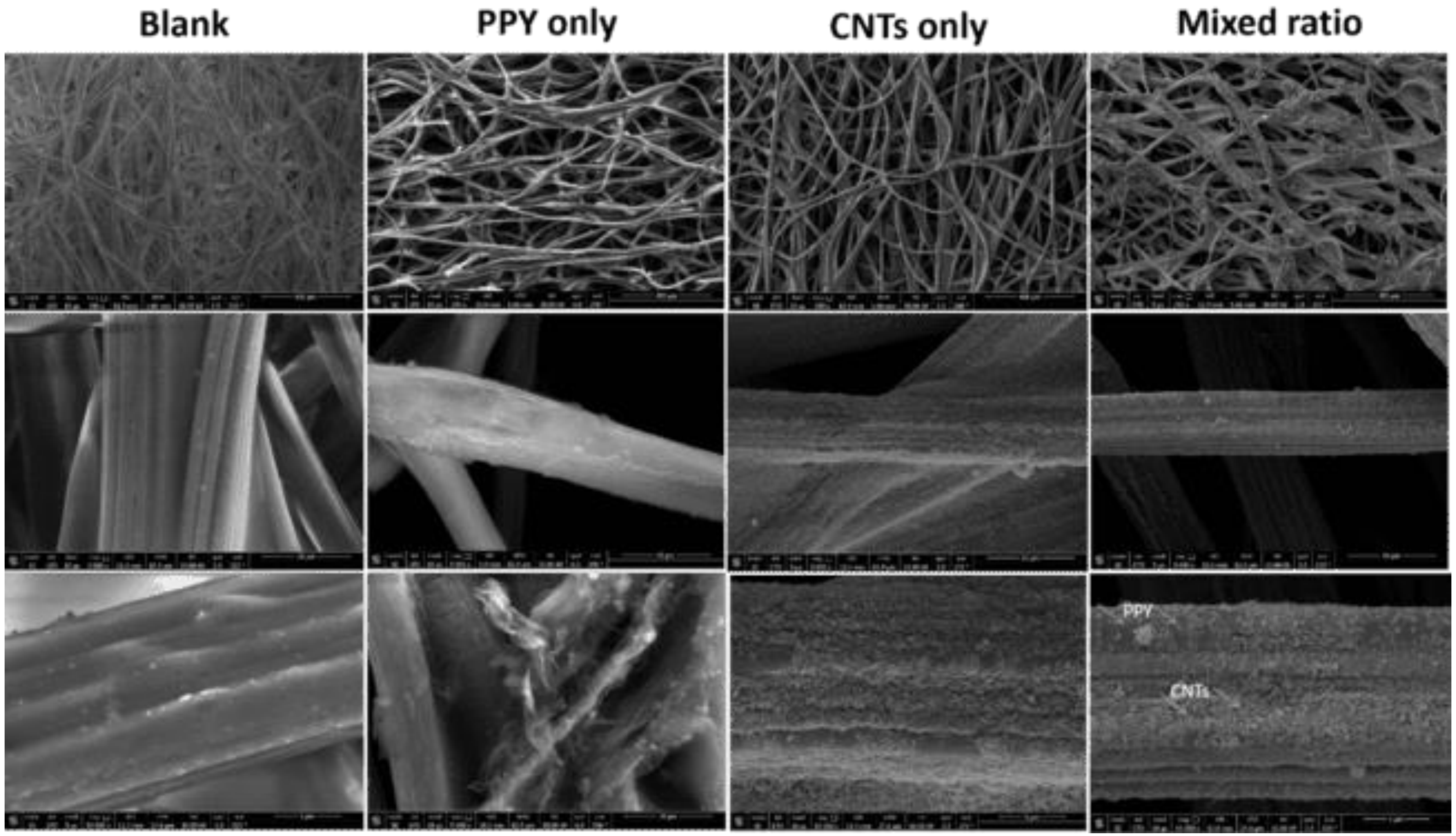
$FeCl_3$ oxidizing agent with concentration 0.5 M of woven fabric blank (a), before (b) and after (c) CVD using 20 µL of pyrrole

Results



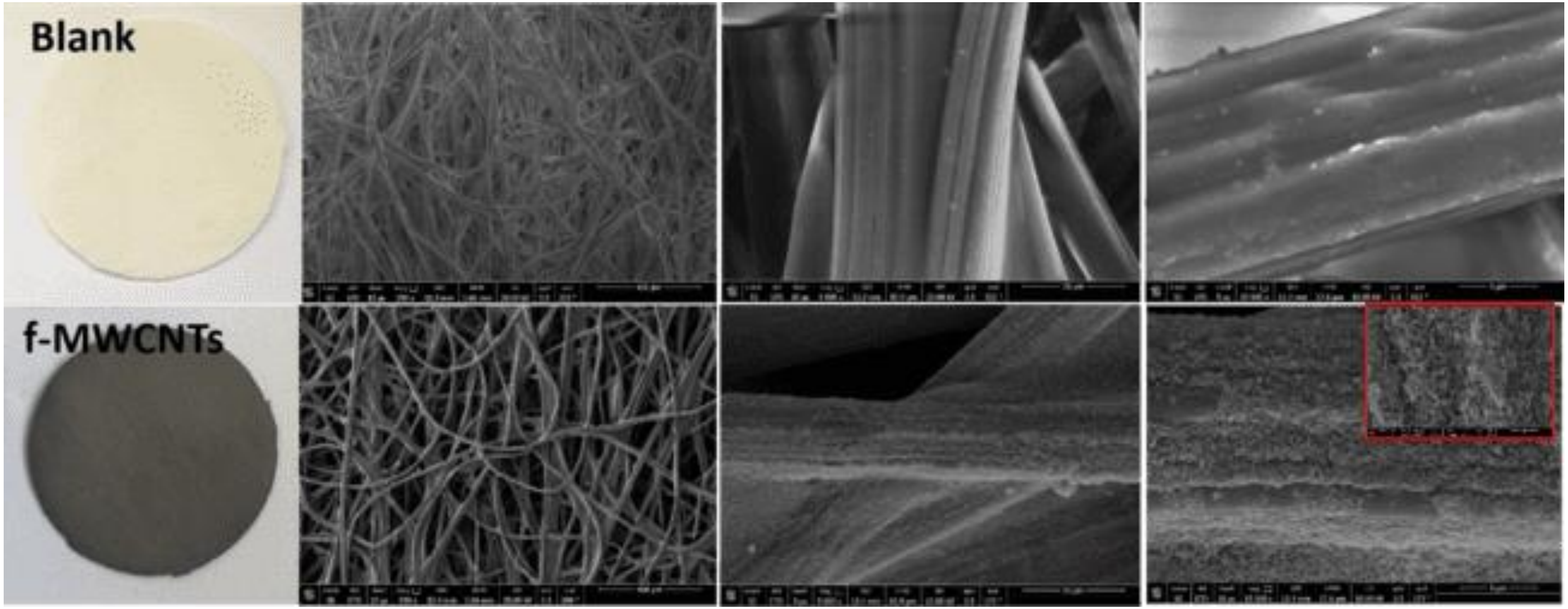
Blank
PPY only
CNTs only
Mixed ratio
Non-woven fabric
Woven fabric

Results



SEM images of the non-woven fabric with and without the deposited photothermal layers at different magnifications

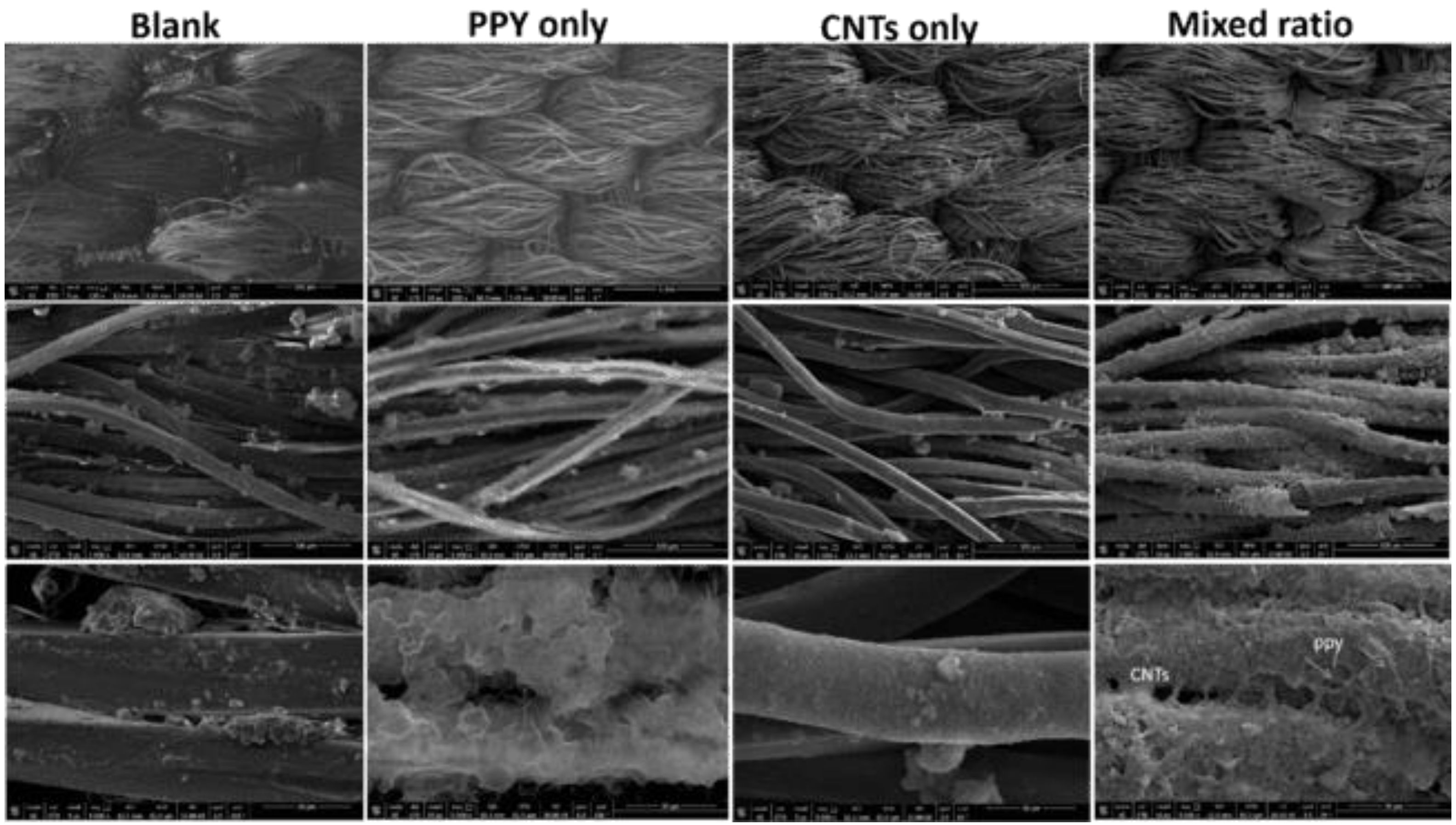
Results



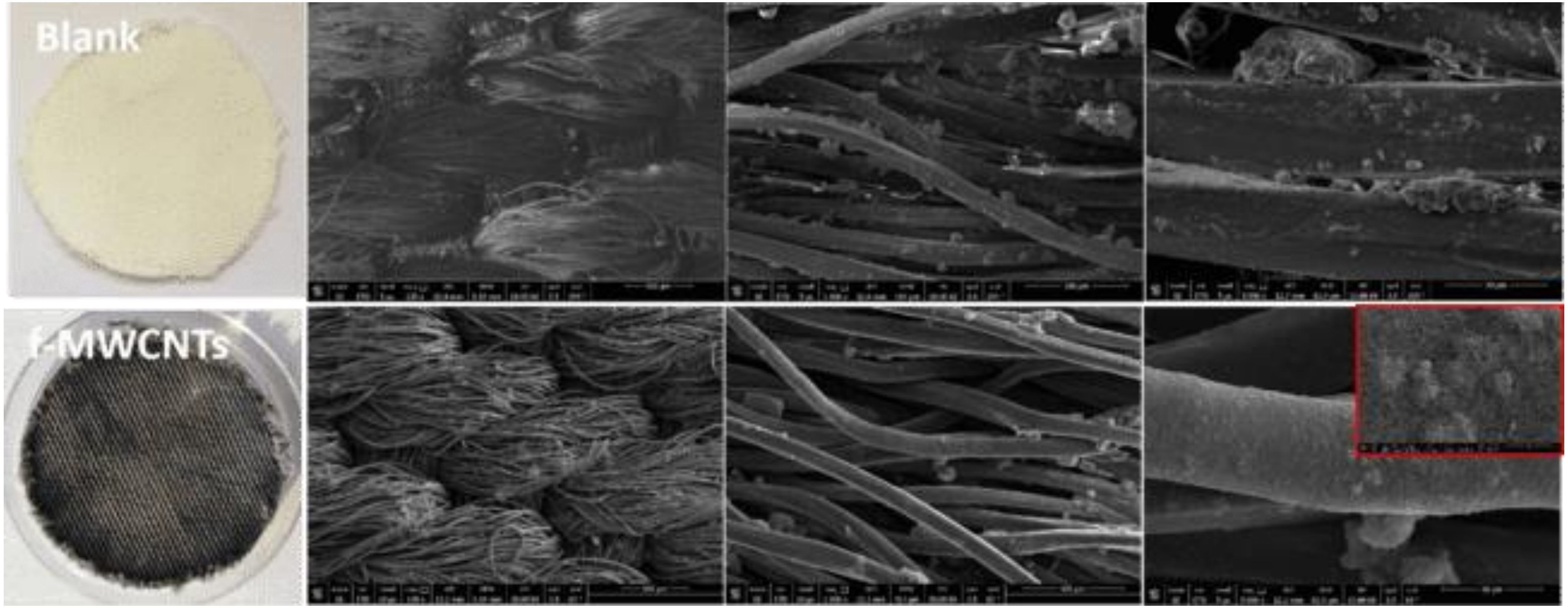
SEM images of the non-woven fabric with and without the deposited f-MWCNTs photothermal layers by wet-impregnation technique at different magnifications

Results

SEM images of the woven fabric with and without the deposited photothermal layers at different magnifications

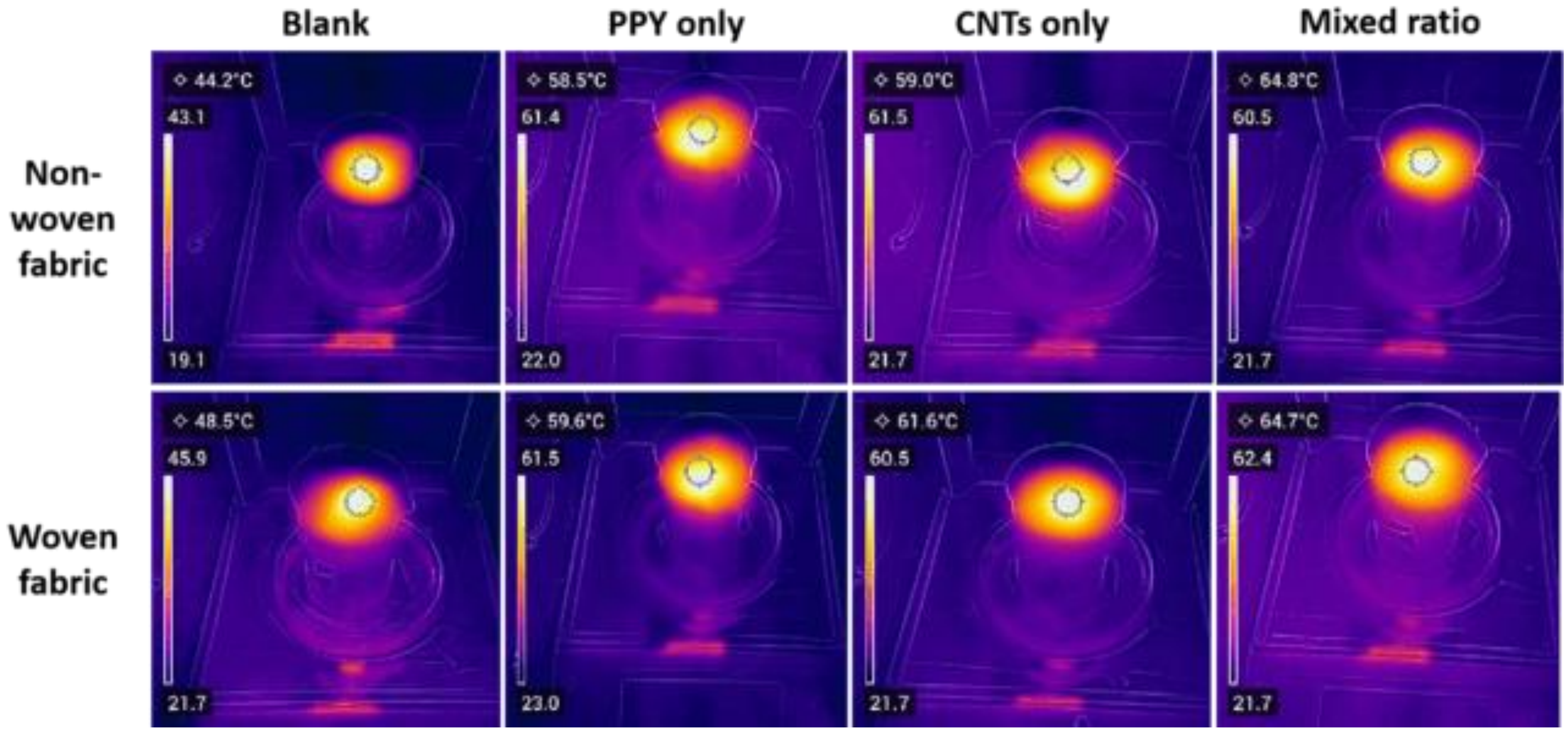


Results



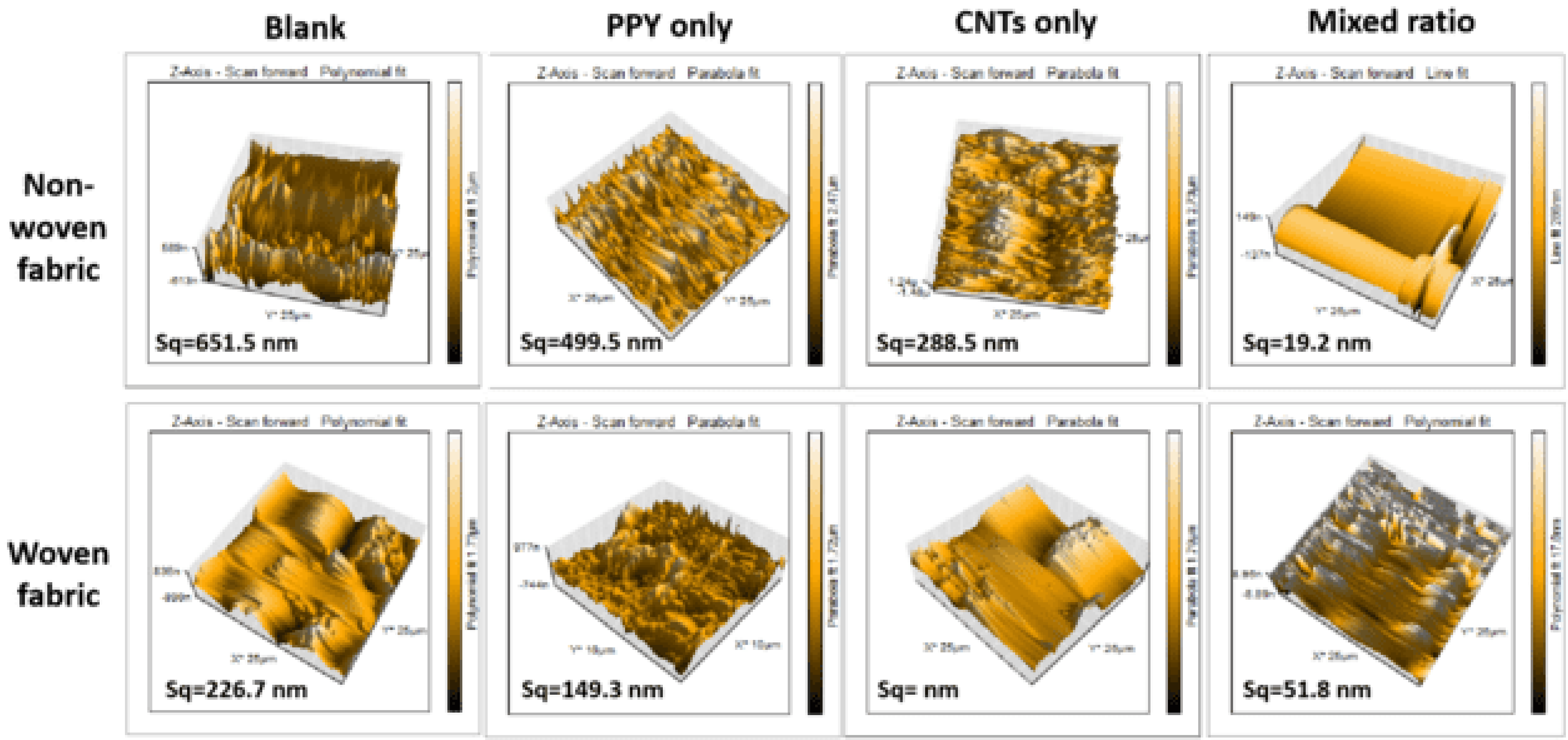
SEM images of the woven fabric with and without the deposited f-MWCNTs photothermal layers by wet-impregnation technique at different magnifications

Results



The IR images of the photothermal membranes under simulated solar light irradiation for 15 min in contact with 3.5% NaCl solution

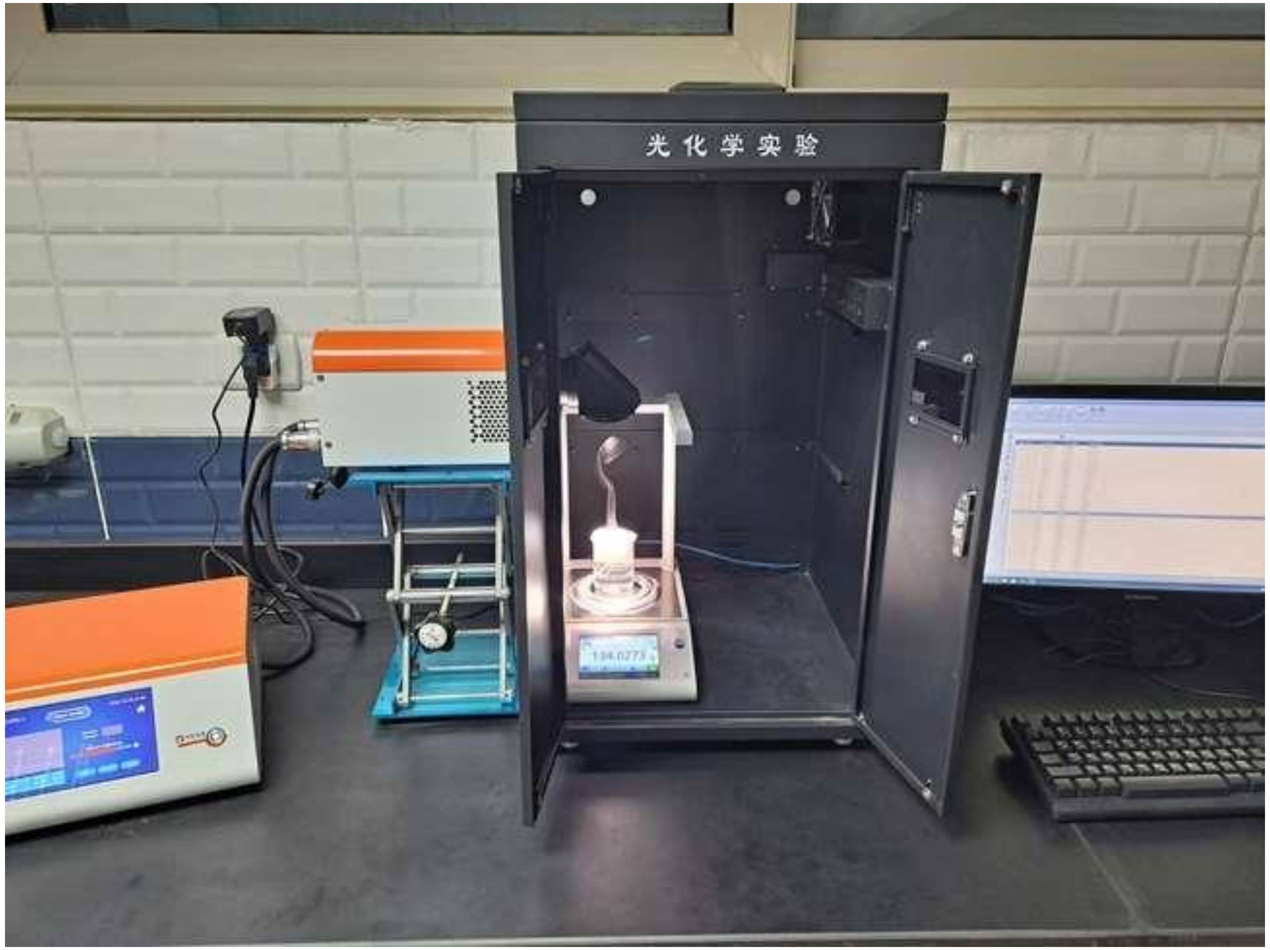
Results



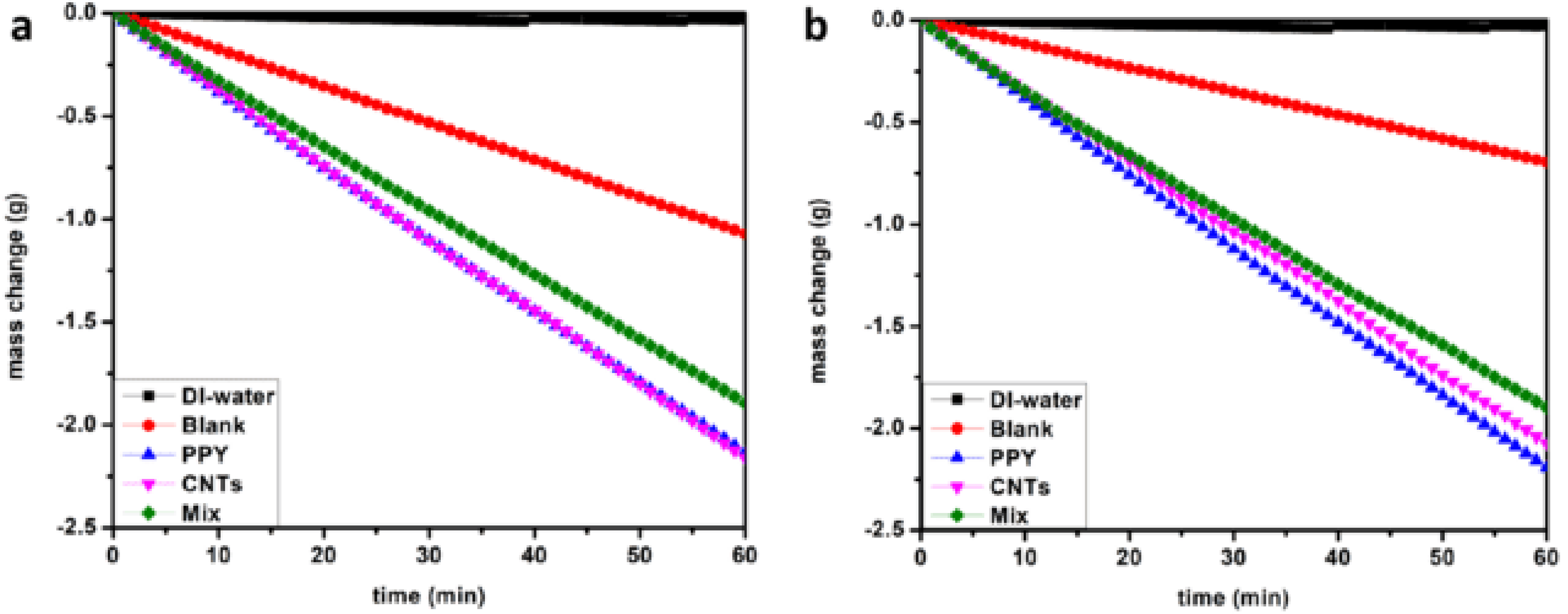
Surface analysis of the prepared photothermal layer by the Atomic Force Microscope (AFM)

Performance Evaluation of Photothermal Membranes

Solar simulator device with the control unit connected to the PC with a particular software to monitor the mass change of the analytical balance during the experiment.

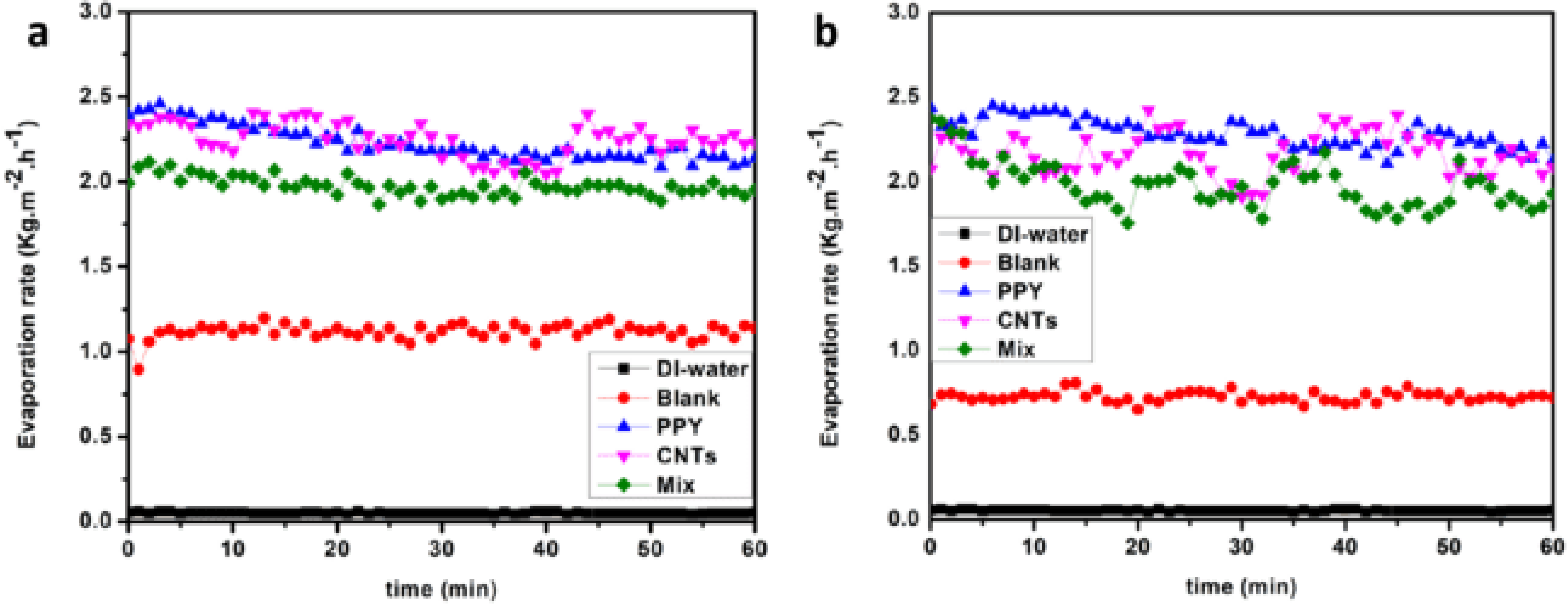


Performance Evaluation of Photothermal Membranes



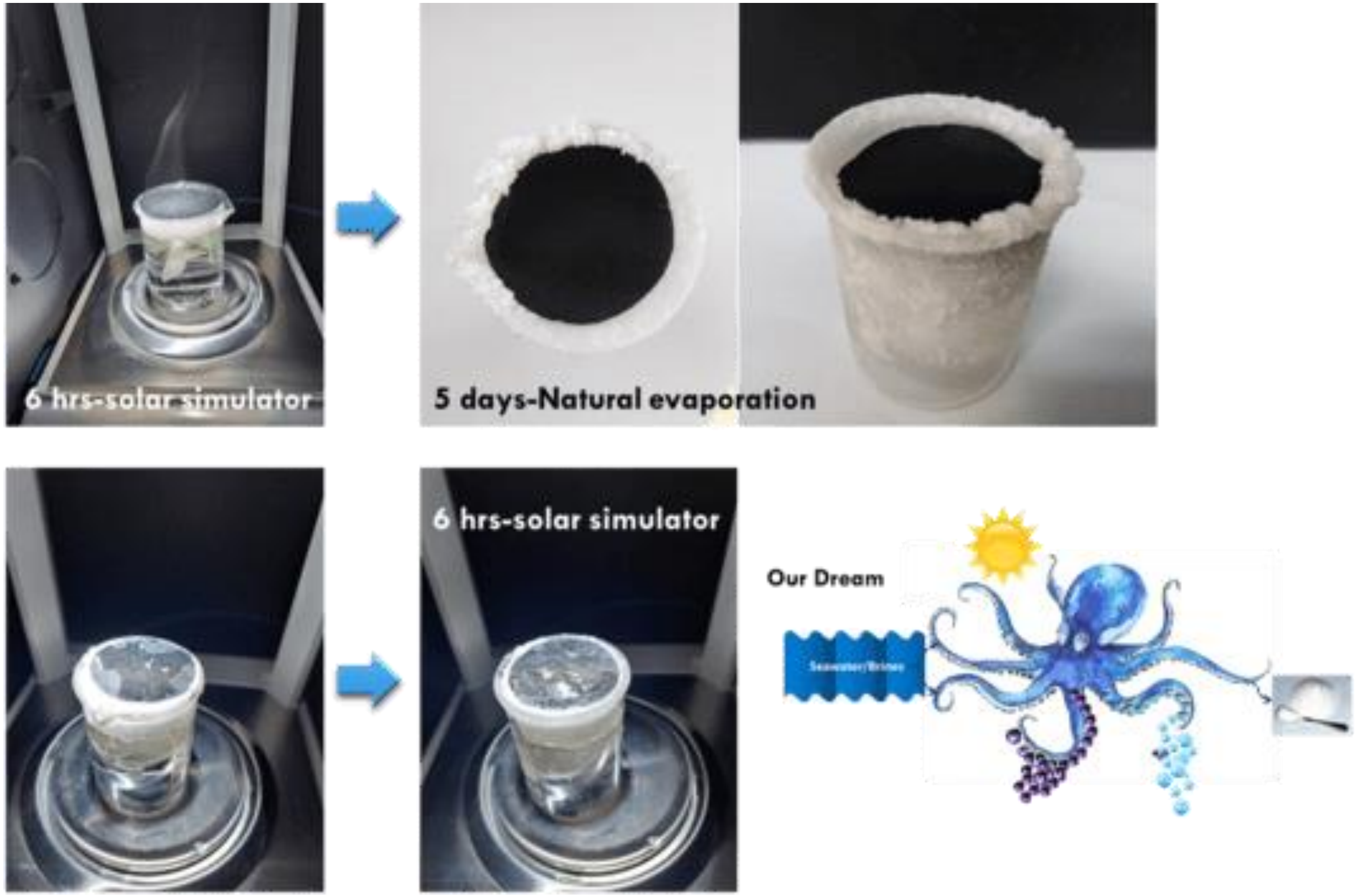
The mass change for the developed photothermal layer on the non-woven fabric (a), and woven fabric (b)

Performance Evaluation of Photothermal Membranes

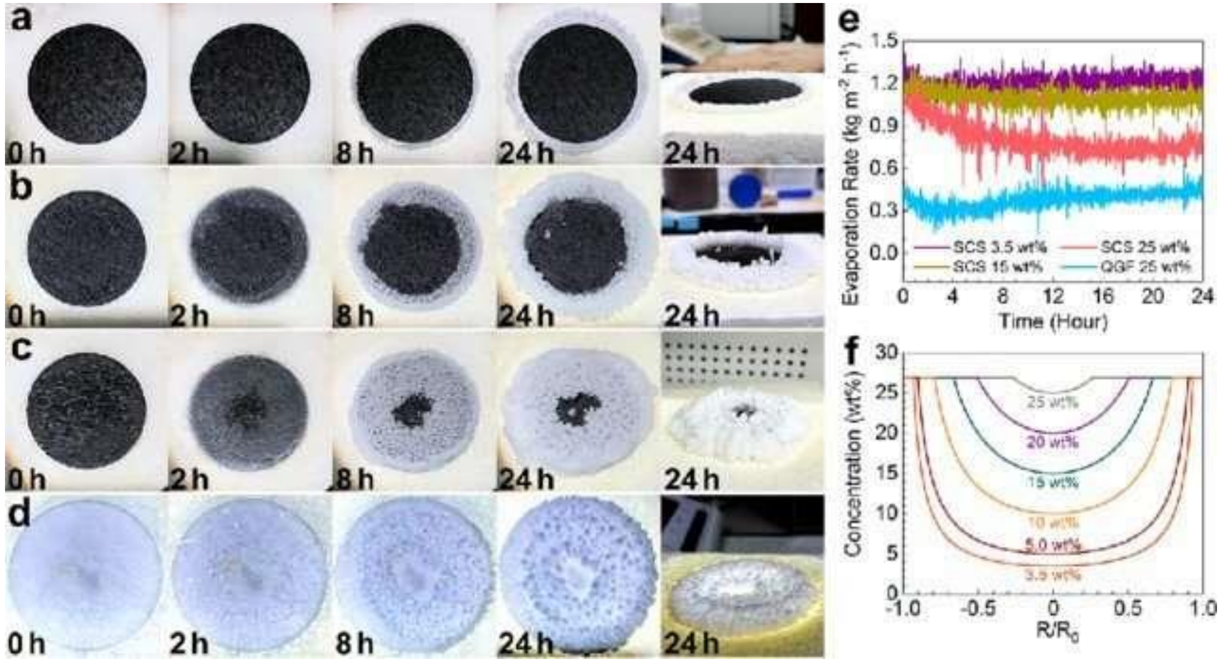


The evaporation rate for the developed photothermal layer on the non-woven fabric (a), and woven fabric (b)

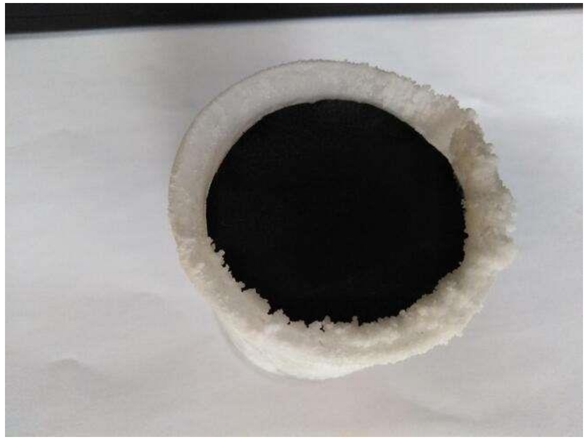
Attempts of simultaneous salts harvesting and vapor generation from 3.5% NaCl by Photothermal Membranes



Solar-driven evaporation: Freshwater Regeneration and salts extraction from seawater - achieving zero liquid discharge

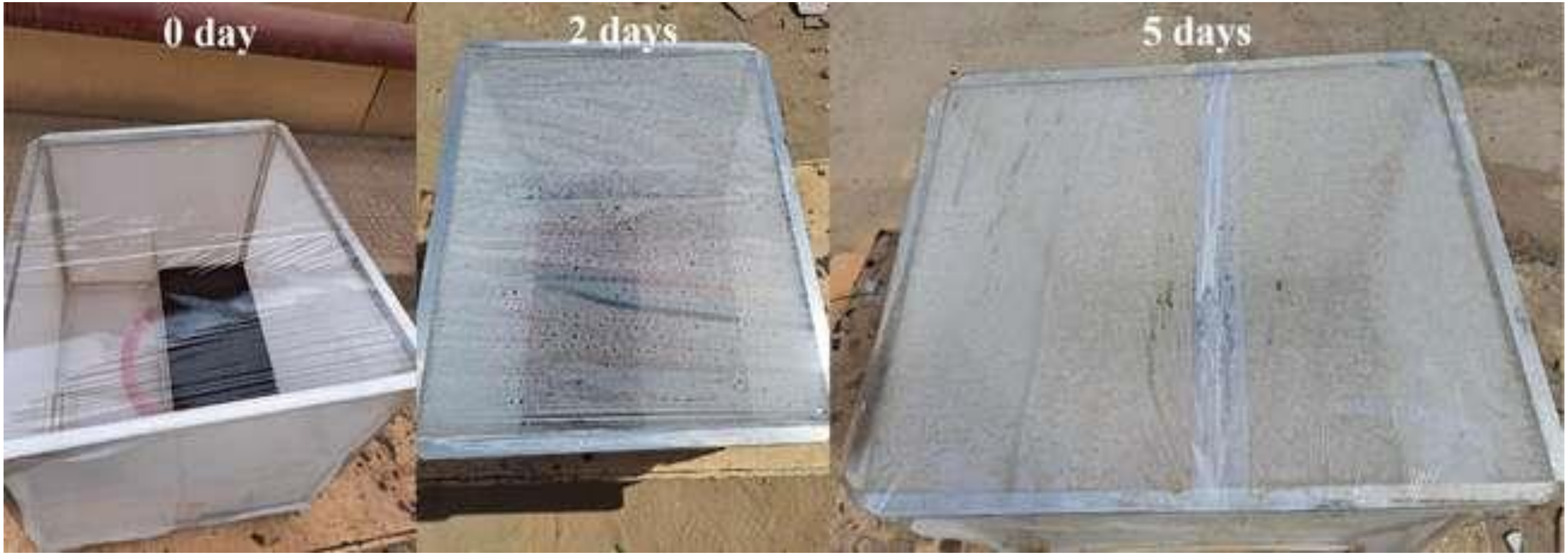


Environ. Sci. Technol. 2018, 52, 20, 11822–11830



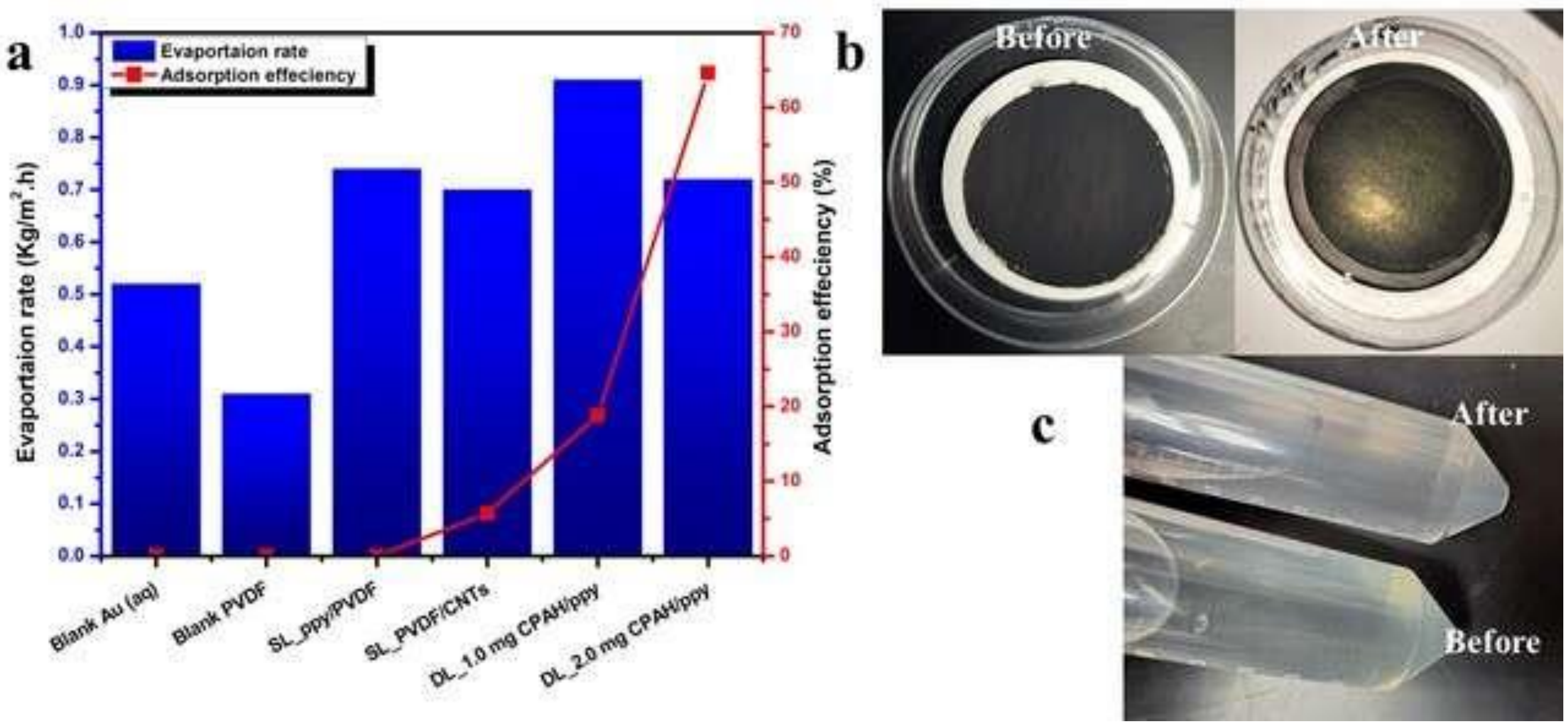
Ack. Funded work by STDF-YRG, call 10, ID 43224, PI: H. M. Abdel-Ghafar

Sustainable and spontaneous membrane desalination (direct solar-interfacial evaporation)

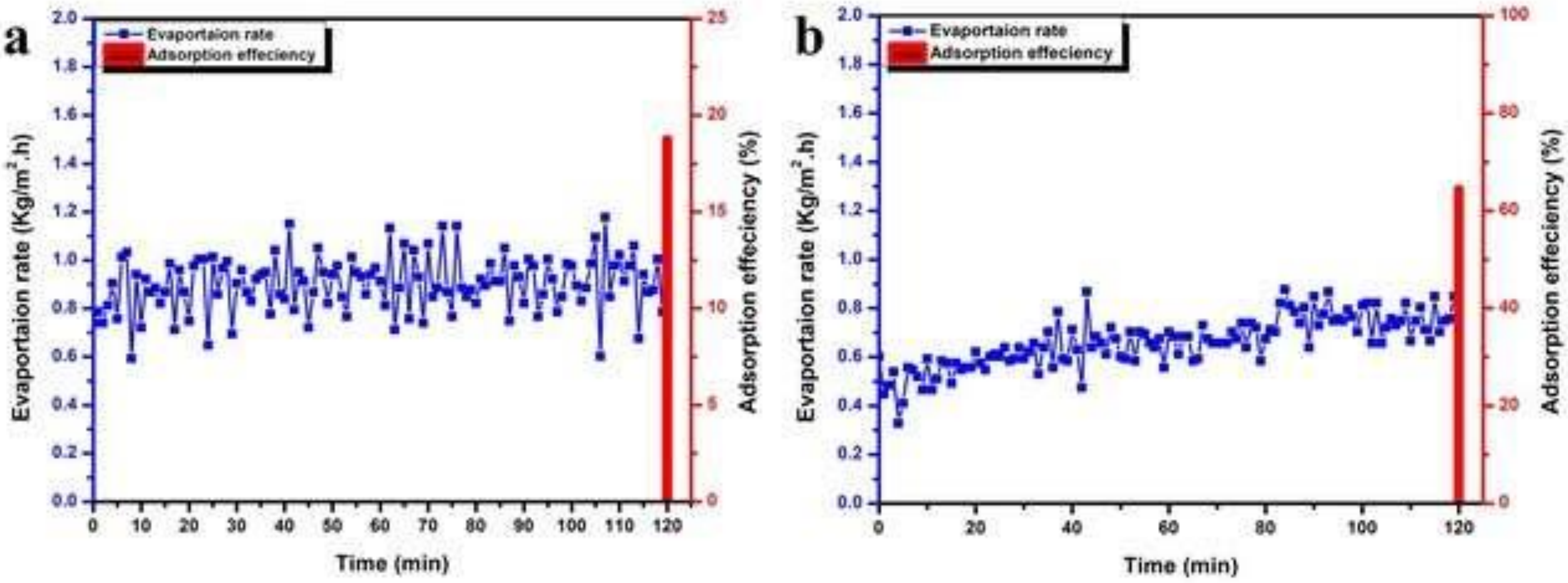


Sustainable and spontaneous membrane desalination simultaneously with salts harvesting

(a) the simultaneously determined evaporation rate (Kg/m^2.h), and adsorption efficiency (%), (b) a photograph of the DL_2.0 mg CPAH/ppy membrane before and after the experiment, and (c) the aqueous 50 mg/L of Au solution before and after the experiments.



The extended evaporation rate for 120 min with the resultant adsorption efficiency for the (a) DL_1.0 mg CPAH/ppy, and (b) DL_2.0 mg CPAH/ppy photothermal membranes.



Conclusion

- The developed photothermal membranes achieved comparable evaporation rate ranged from 2.0 to 2.5 $Kg/m^2.h$.
- The light absorption of the developed photothermal layers exceeded 95%.
- The developed non-woven fabric with 20 µL ppy achieved the simultaneous vapor generation with salts harvesting – without any salts accumulation on the membrane pores.

Conclusion

- The developed CNTs-PAA/PVDF photothermal membranes able to extract precious metals, especially Ag and Au at lower, 2.5 ppm, and higher concentration, 50 ppm, from different synthetic solutions.

Research Sponsors

Acknowledgment: This work was funded by the Science and Technology Development Fund (STDF), Project ID. 43224, Egypt.

References:

- [1] https://www.australianenvironmentaleducation.com.au/education-resources/the-natural-water-cycle/
- [2] https://www.zmescience.com/science/what-is-osmosis-0634/
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- [5] D. Bilger, S. Z. Homayounfar, T. L.. Andrew, A critical review of reactive vapor deposition for conjugated polymer synthesis, J. Mater. Chem. C, 2019,7, 7159-7174.

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