Carbon-nanotube Based Membranes for Wastewater Treatment Technologies

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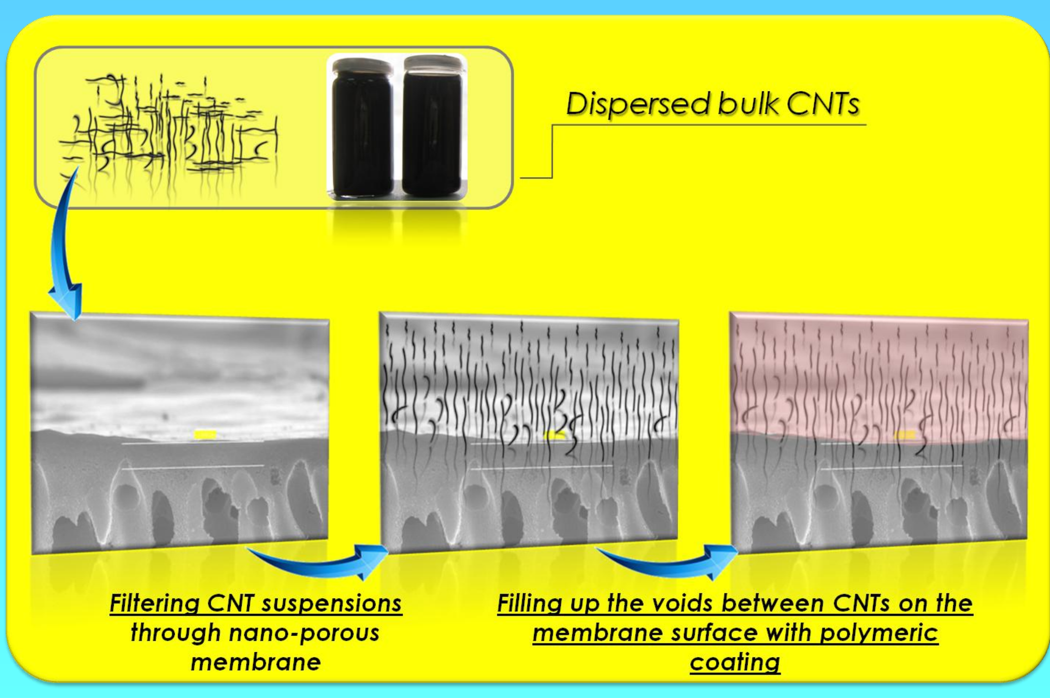
INTRODUCTION

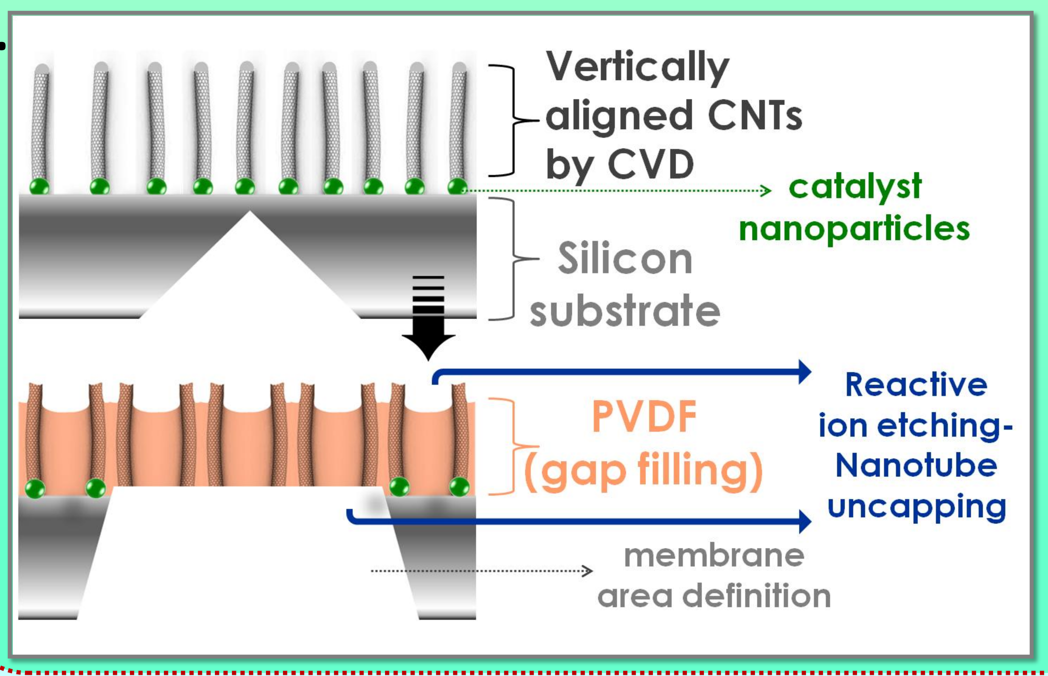
Membrane technology has become a dignified separation technology over the past decades. Several approaches have been discussed regarding the **use of carbon nanotubes (CNTs) during the membrane development processes.** The exceptionally high aspect ratios of CNTs at such quite small dimensions and the molecularly slick, chemically inert hydrophobic graphitic walls constitute collaterals for **transport applications**. Combined to their nano-scale internal diameters they compose a unique phenomenon of **speedy transfer and high selectivity.** In the literature, liquid flow through membranes composed of an array of aligned CNTs is reported to be four to five orders of magnitude faster than is predicted from conventional fluid flow theory.[1,2] This is attributed to the almost frictionless interface at the CNT wall. **The infiltration of CNTs into a porous polymeric membrane is anticipated to overcome the immanent limitation of counterbalance between flux and selectivity.**

OBJECTIVES

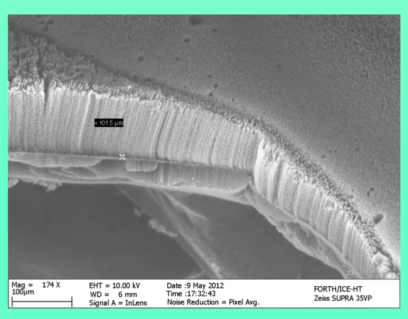
A. Development of novel **porous anisotropic polymeric membranes with the subsequent embedment of tailor-made CNTs in the thin selective layer of PES** (polyethersulfone) **ultra-filtration membranes** with innovative filtration methods aiming at the **rejection of low molecular weight organic compounds combined to high flux**.



B.

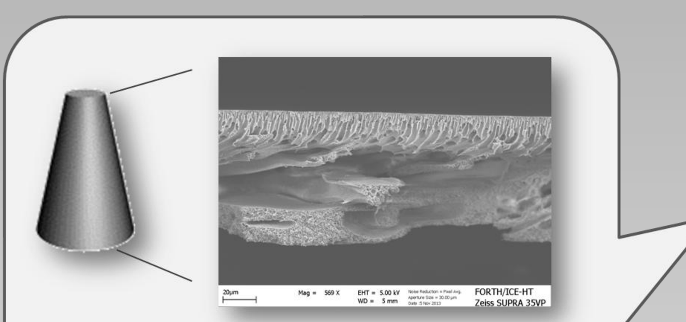


Vertically aligned CNT-forest incorporation into PVDF (polyvinylidene fluoride) **matrix for the development of CNT-separation membranes.**



MATERIALS

A. **Membrane Characteristics**



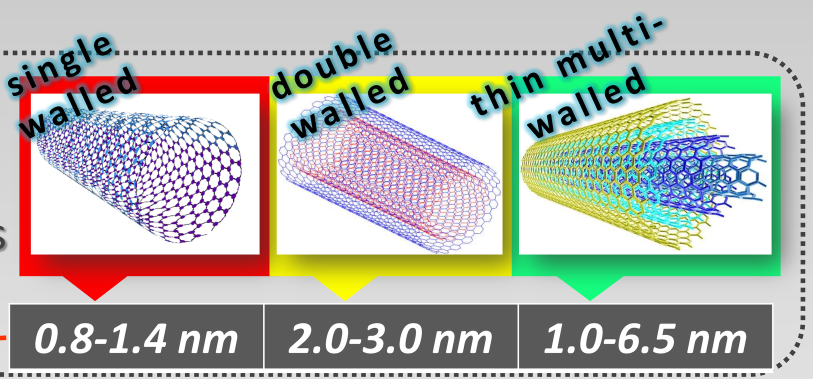
(SEM cross section image)

PES nano-porous UF membrane of conical-shape structure formed by phase inversion

Average pore size	~40 nm
Thickness	100 μm

PROPERTIES OF CNTs:

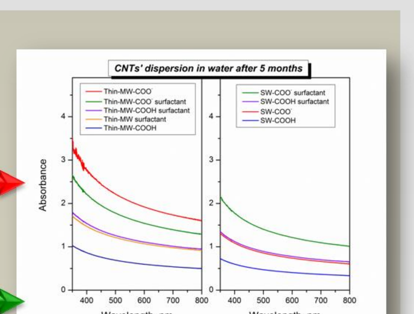
- High aspect ratio
- Chemically inert hydrophobic graphitic walls
- Internal diameters of nano-scale range



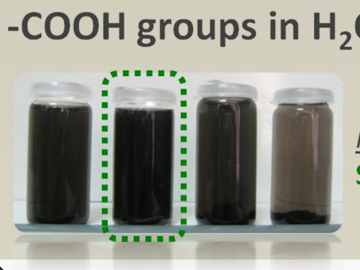
Study of CNTs' dispersion in water

Dispersion of ***Thin-MWCNTs*** functionalized with *-COOH* groups in H_2O

From left to right: Thin-MWCOO⁻, Thin-MWCOO⁻ (+surfactant), Thin-MWCOOH (+surf.), Thin-MWCOOH, Thin-MW (+surf.).



Dispersion of ***SWCNTs*** functionalized with -COOH groups in H_2O



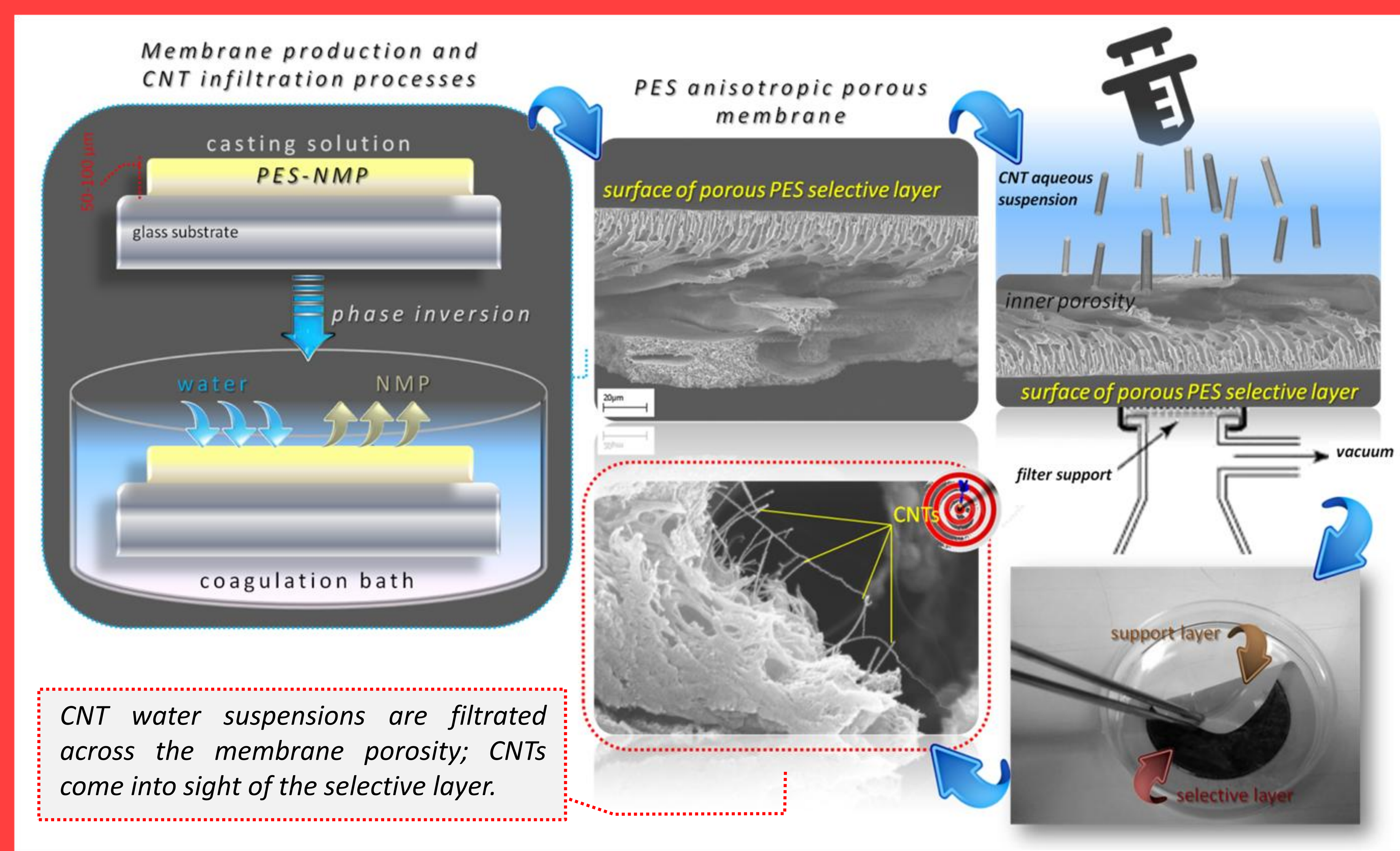
From left to right: SWCOOH (+surf.), SWCOO⁻ (+surf.), SWCOO⁻, SWCOOH.

Properties of CNTs

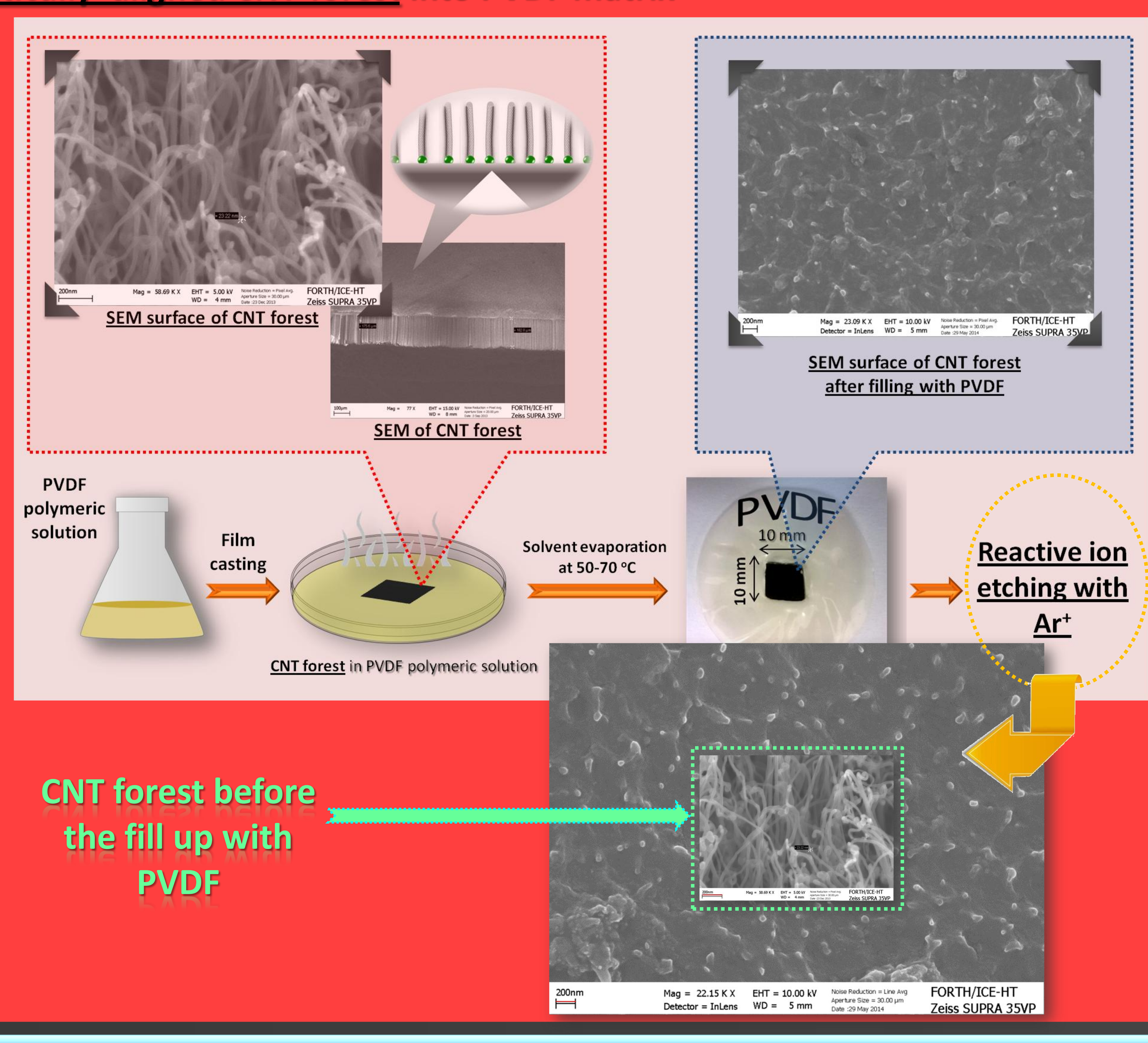
	SWCNT *Cheaptubes	SW-COOH	SW-COO⁻	Thin – MWCNT *Nanothinx	T– MWCNT-COOH	T– MWCNT-COO⁻
Carbon Purity (%)	>90	>90	>90	94	94	94
External Diameter (nm)	1-2	1-2	1-2	6 – 15	6 – 15	6 – 15
Internal Diameter (nm)	0.8 – 1.6	0.8 – 1.6	0.8 – 1.6	1.0 – 6.5	1.0 – 6.5	1.0 – 6.5
Length	5-30μm	≤ 1μm	≤ 1μm	≥ 10μm	≤ 1μm	≤ 1μm

EXPERIMENTAL

A. CNTs' embedment into tailor-made PES membranes

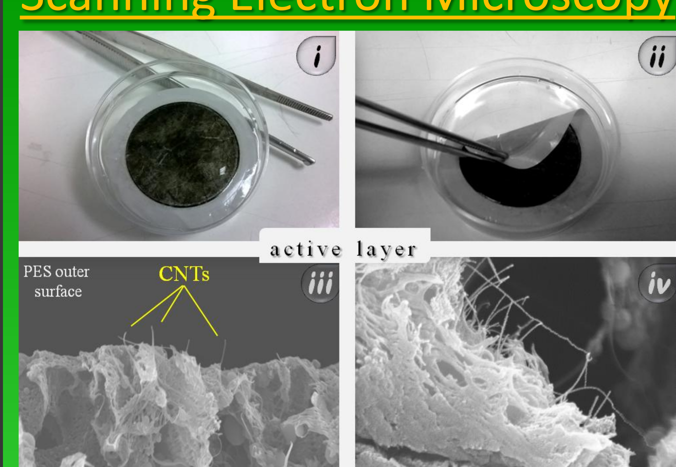


B. Vertically aligned CNT-forest into PVDF matrix



RESULTS

Scanning Electron Microscopy

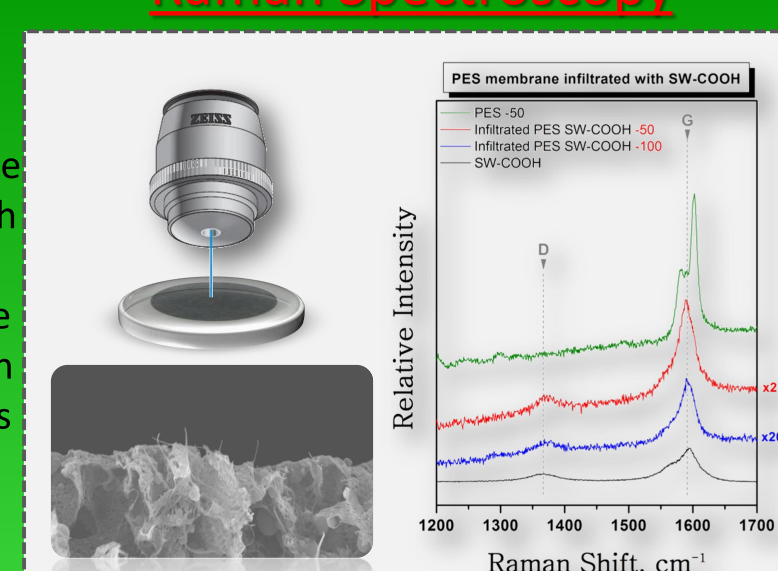


Images i, ii show the effect of CNTs' infiltration through the membrane. **Black area (i) is the selective area CNTs' embedded** as a result of their trans-infiltration through the support side, white area! *(ii)*.

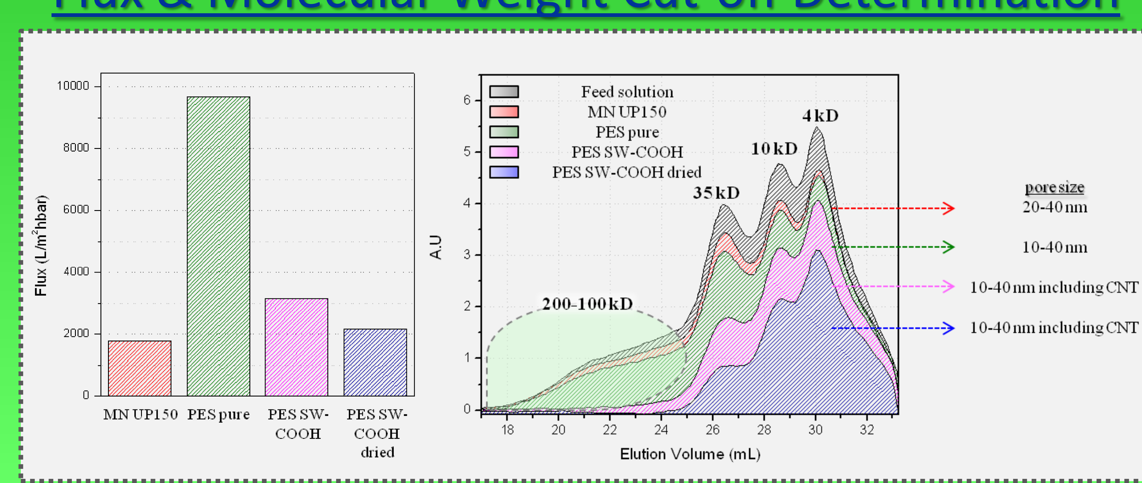
Images iii, iv: *SEM images of cross sections of the selective area of PES membranes infiltrated with CNTs, noticeable also on the outer surface.*

Raman Spectroscopy

Raman spectra collected from the selective layer indicate the presence of **SWCNTs**, although the infiltration was carried out from the support side. Raman penetration depth is as much about the thickness of that layer.



Flux & Molecular Weight Cut-off Determination



CONCLUSIONS

1. The embedment of CNTs into anisotropic porous polymeric membranes was achieved using a new/specific infiltration method that allows the CNTs both to be maintained well dispersed in the aqueous suspensions and to be shoved, steered and aligned towards to the membrane pores.
2. The conversion of a UF membrane to a NF one by the embedment of CNTs in the selective layer is not an easy task. There are many challenges that must be addressed, by some means with the development/application of innovative filtration methods.

AKNOWLEGMENTS

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REFERENCES

[1] J.Holt, H. Park, Y. Wang, M. Stadermann, A. Artyukhin, C. Grigoropoulos, A. Noy, O. Bakajin, Science 312 (2006) 1034-1037.
[2] A. Noya, H.G. Parka, F. Fornasieroa, J. K. Holta, C. P. Grigoropoulos, O. Bakajina, Nanofluidics in carbon nanotubes, Nanotoday 2 (2007) 22-29.