Carbon Nanotubes in Water Treatment and Sea Water Desalination

CNTs for Sorbents and Membranes

- Chemically stable
- High surface area
- Thermally stable
- Possibility of fabrication by self-assembly
- Immobilization in membranes and filters
- Wide range of compounds
  - Polar and non-polar

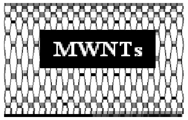
Roy, Addo Ntim, Mitra and Sirkar. *J. Membrane Sci*. **2011**
Sae-Khow and Mitra. Anal. Chem. 2010
Karwa, Iqbal, and Mitra, *Carbon* **2006,**
Mishra and Ramaprabhu *J. Phys. Chem. C* **2010**,

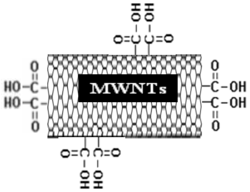
Gas Phase Sorption Capacities of CNTs

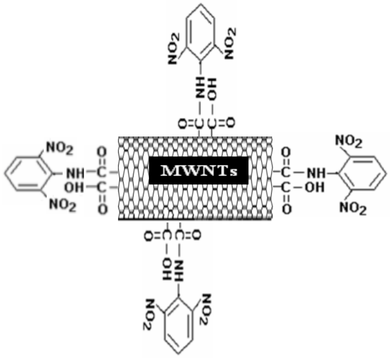
Relative Breakthrough Times (min)

	Polar			Non-Polar		
	DCM	Ethanol	Propanol	Hexane	Benzene	Toluene
Polar-CNT	16	35	30	5	6	10
Nonpolar-CNT	8	12	15	20	20	45
Carbopack	2	2	5	5	6	6

Mustansar, Saridara, Mitra, J. Chrom. and Analyst (2008)







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CNT Based Removal of Arsenic from Water

Arsenic in water

- Exists primarily as oxyanions with formal oxidation states of III and V
- Arsenite – As (III)
  - Dominates in sulfidic and methanic waters
  - Non ionic at the pH range of 4-10(H_3AsO_3)
  - High solubility
  - More toxic
- Arsenate – As (V)
  - Dominant form in oxic waters
  - Ionic at the pH range of 4-10 ($H_2AsO_4^-$ / $HAsO_4^{2-}$)
  - More reactive in solution

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Advanced case of arsenic poisoning, China, *photo courtesy of USGS.*

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Arsenic Adsorption on Iron oxide

- Oxides of iron, aluminum and manganese are potential sinks for arsenic in aquifer sediments
- Iron oxide-Arsenic complexation reactions
  - α -FeOOH + $H_2AsO_4^{-}$ + $3H^{+} \rightarrow FeH_2AsO_4 + 2H_2O$
  - α -FeOOH + H_3AsO_3 + $2H^{+} \rightarrow FeH_2AsO_3 + 2H_2O$
- Iron oxide coated materials for arsenic removal reported in literature
  - Sand, biomass, activated carbon etc

Addo Ntim and Mitra. J. Chem. Eng. Data (2011). 56 (5), 2077–2083
D. Pokhrel and T. D., Viraraghavan T., *Journal of . Hazardous. Materials,.* 2008, 150, 818–825.
V. K. Gupta, V. K. V.K., Saini and N. , V.K., Jain, N., *Journal of. Colloid Interface Science,.* 2005, 228, (1) 55–60

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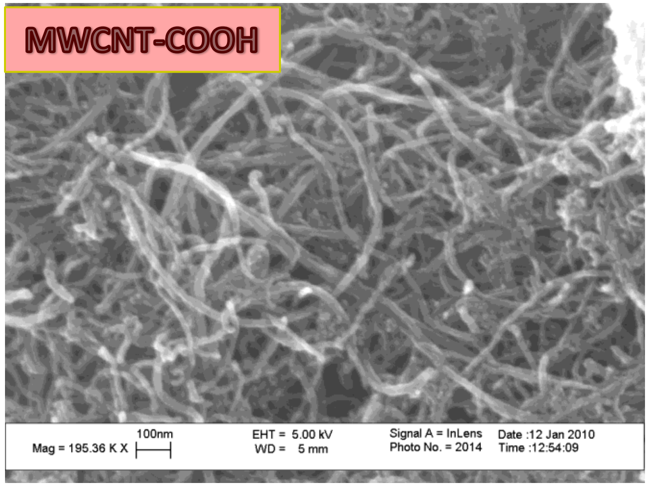
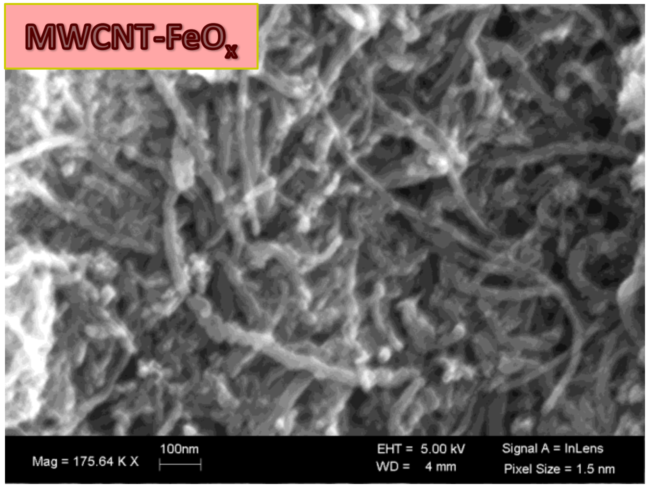
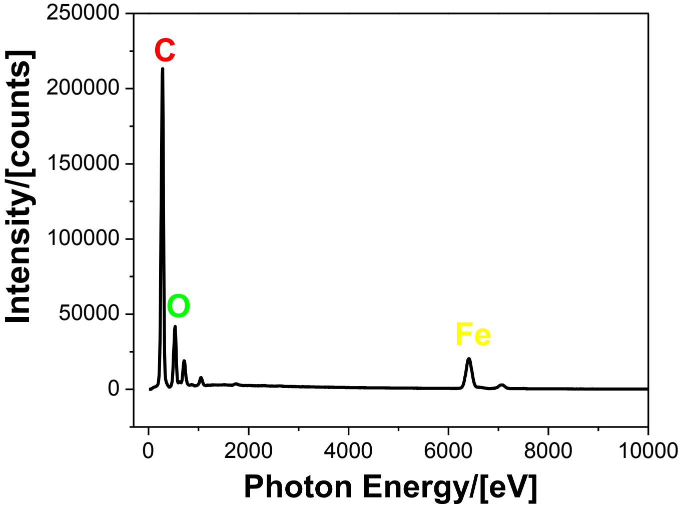
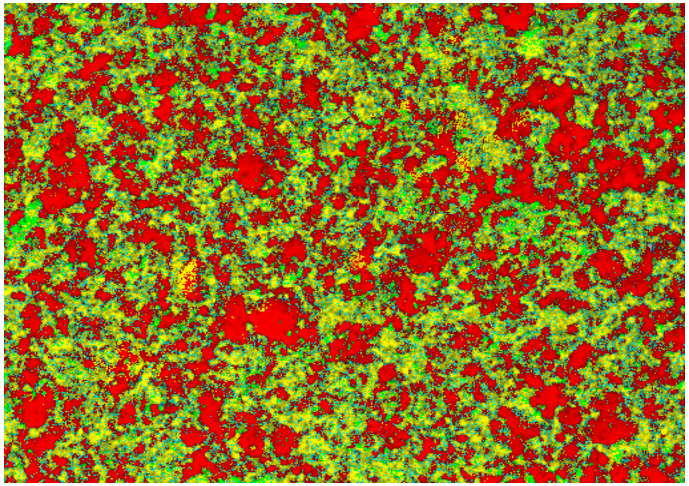
Synthesis of CNT-Iron Oxide Hybrid









Addo Ntim and Mitra. J. Chem. Eng. Data (2011). 56 (5), 2077–2083

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Comparison of the Arsenic Adsorption on Different Nanotube Forms

Adsorbents	Arsenic Removal (%)		*qe* (μg/g)	
	As(III)	As(V)	As(III)	As(V)
MWNT-FeO_x	99	100	1723	189
Original MWNT	10	23	9.9	23.2
MWNT-COOH	3	9	3.3	9.0
qe: micrograms of arsenic adsorbed per gram of adsorbent				

S. Ado Ntim and S. Mitra, Chem. and Engr. Data (2011)

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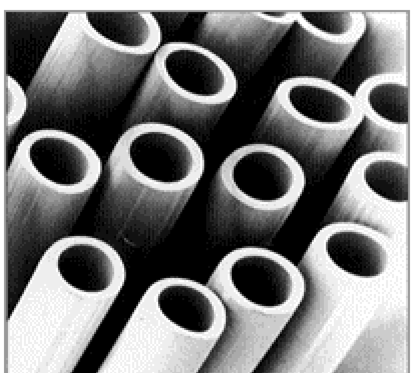
Carbon Nanotube Immobilized Membranes (CNIM)

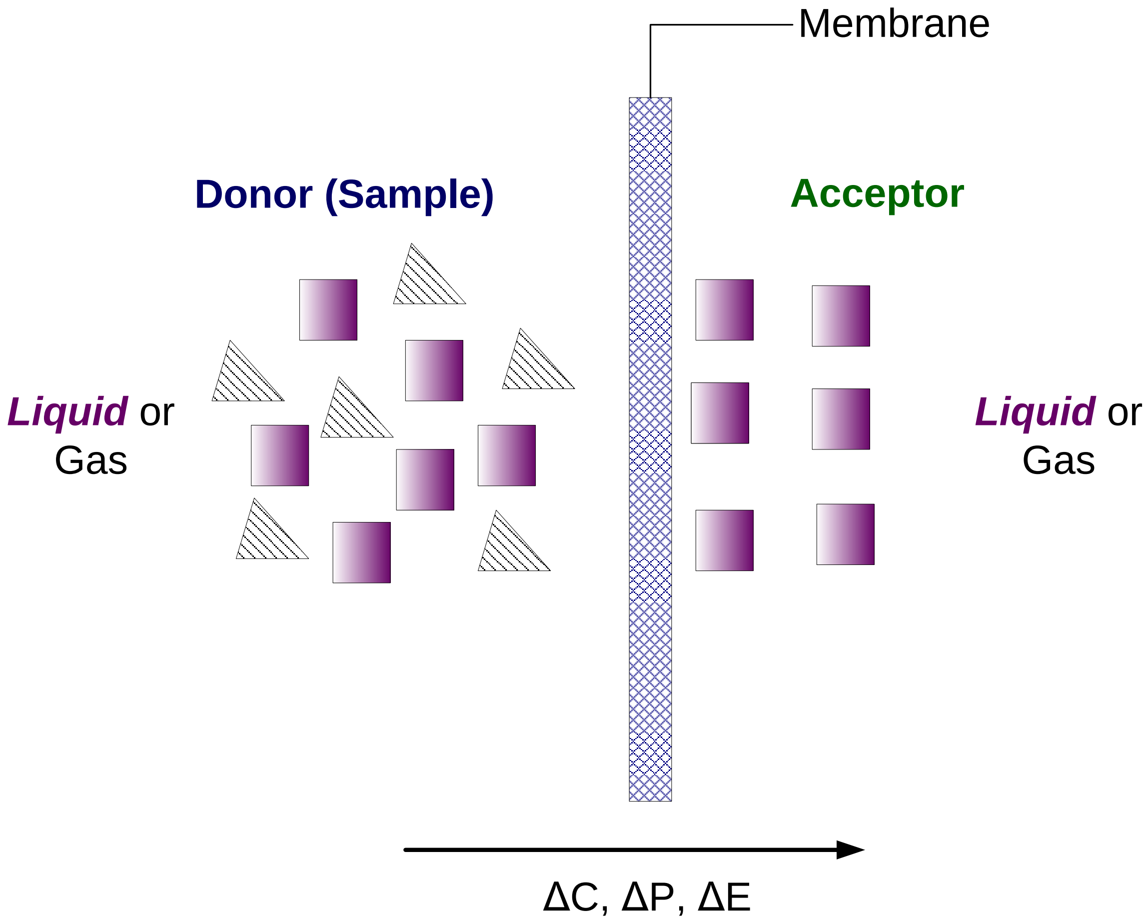
Applications of Membrane

- Turbidity & pathogen removal:
    - Microfiltration (MF)
    - Ultrafiltration (UF)
- Organic Removal: Nanofiltration (NF)
- Desalination: Reverse Osmosis (RO) or NF
- Dialysis – kidney failure and ion Removal
- VOCs removal: Pervaporation

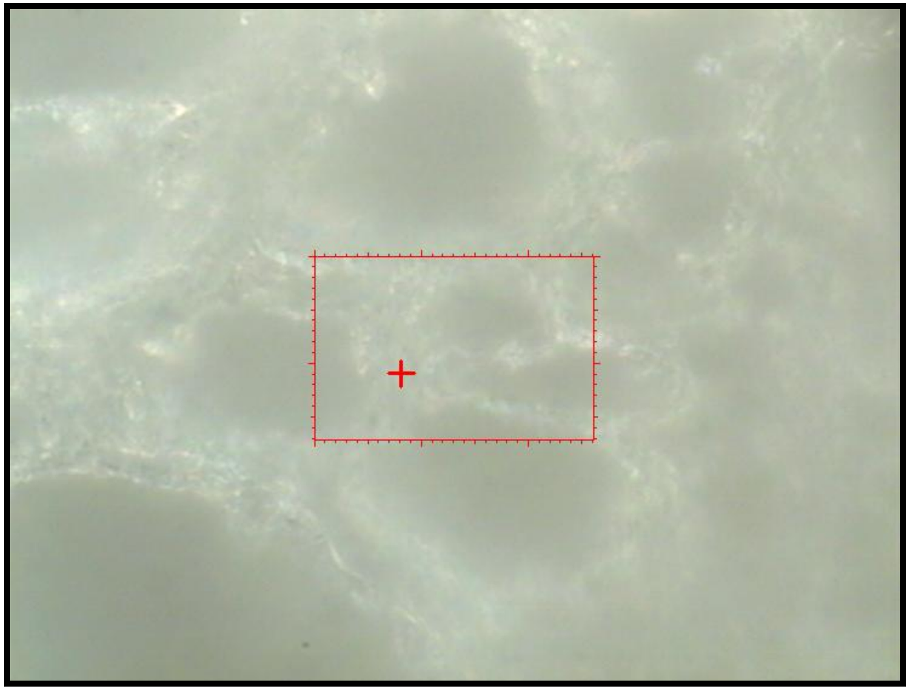


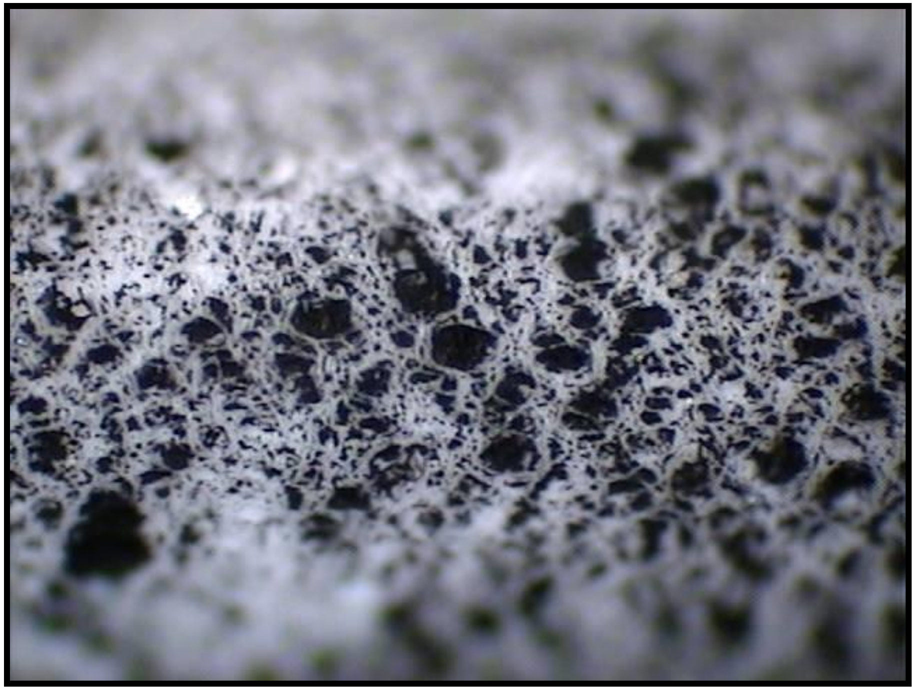
Cross Section 200 µm

Membrane Separation and Extraction



Carbon Nanotube Immobilized Membranes (CNIM)

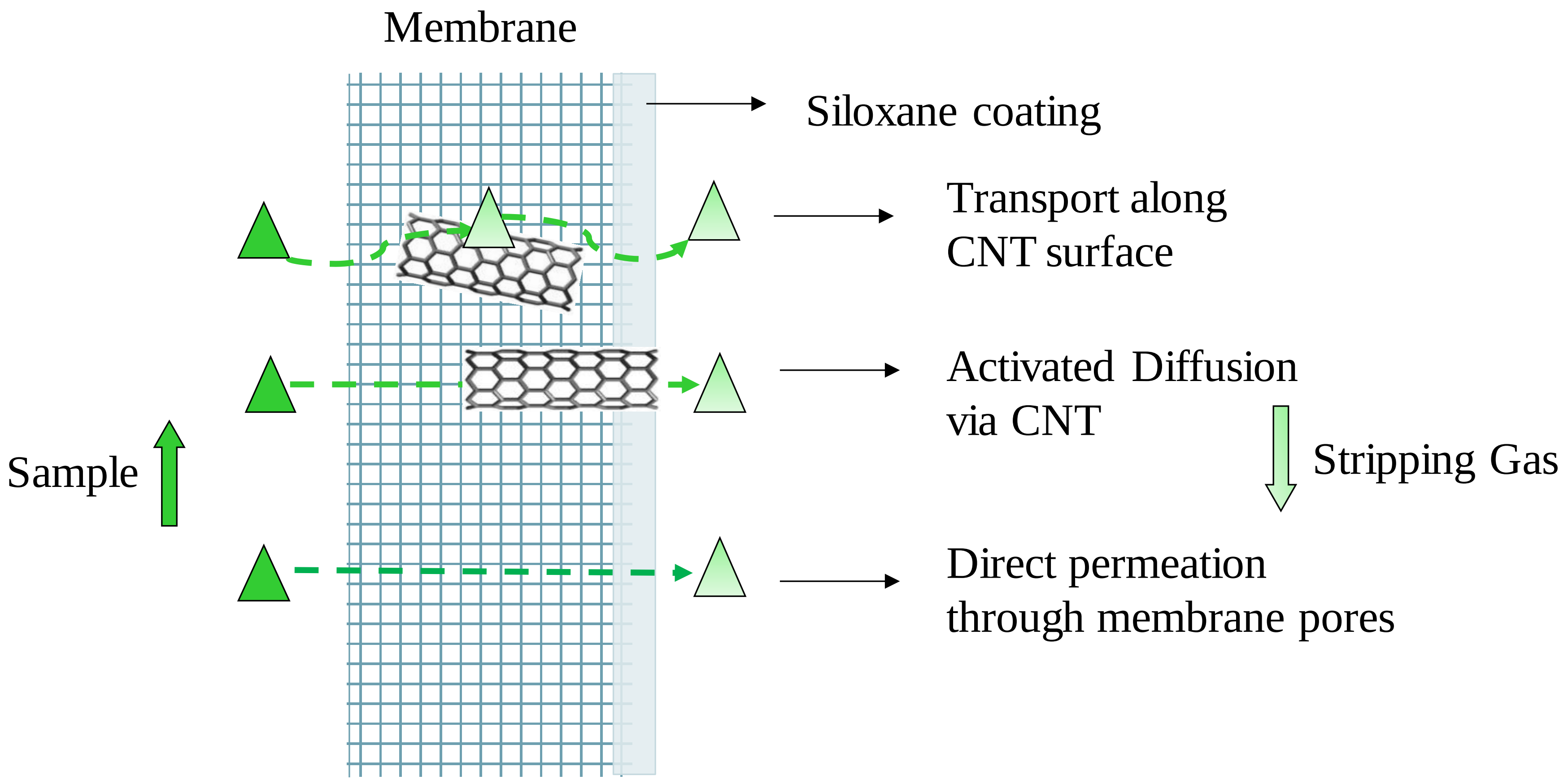




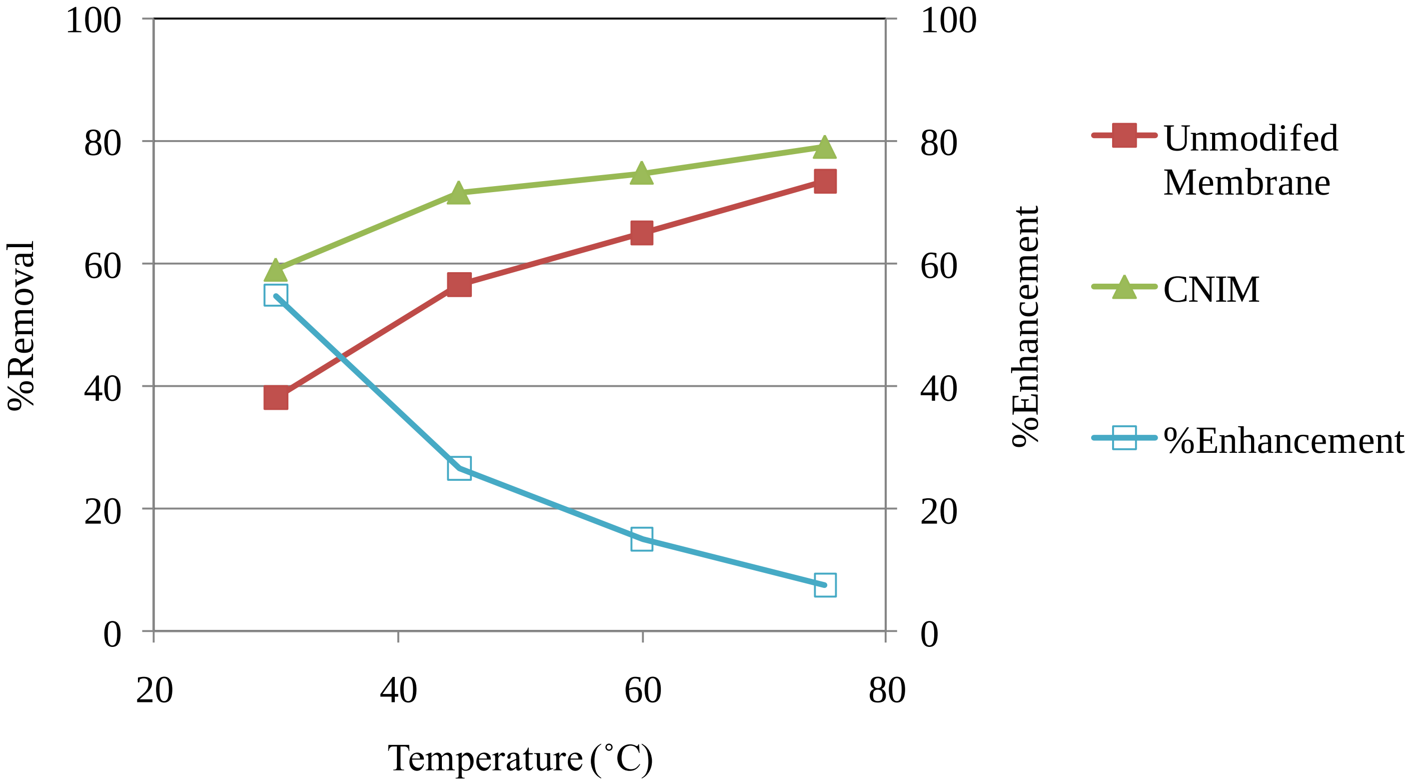
(Polymeric membrane on left and carbon nanotube immobilized membrane on right)

Removal of Volatile Organics from Water Using Carbon Nanotube Immobilized Membranes

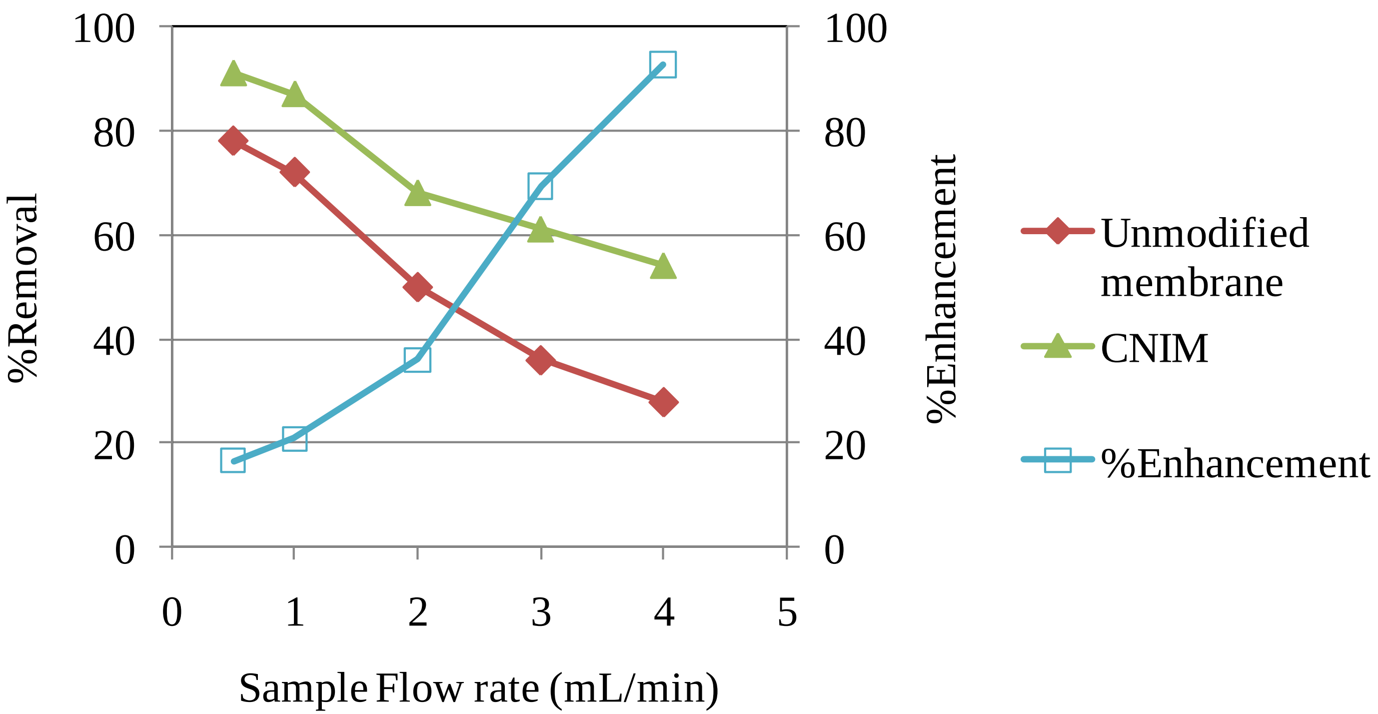
Removing VOCs from Water On CNIM



Pervaporation of Toluene



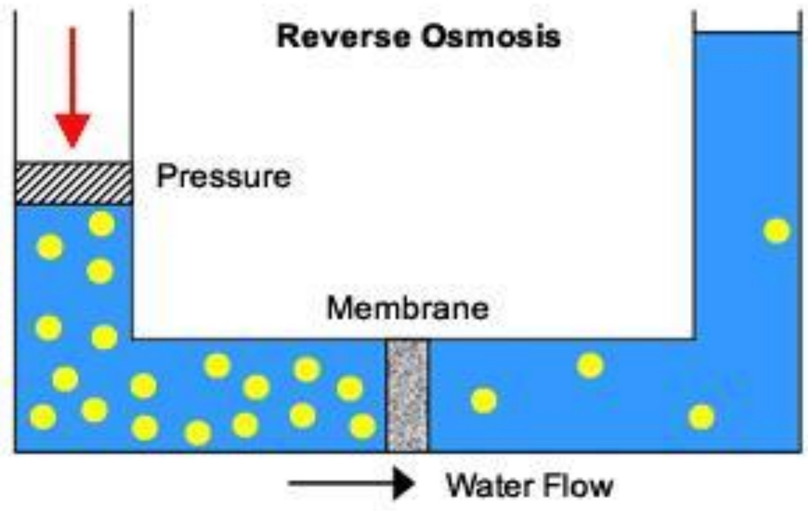
Pervaporation at Different Flow Rates for Dichloromethane



Sea Water Desalination on CNTs

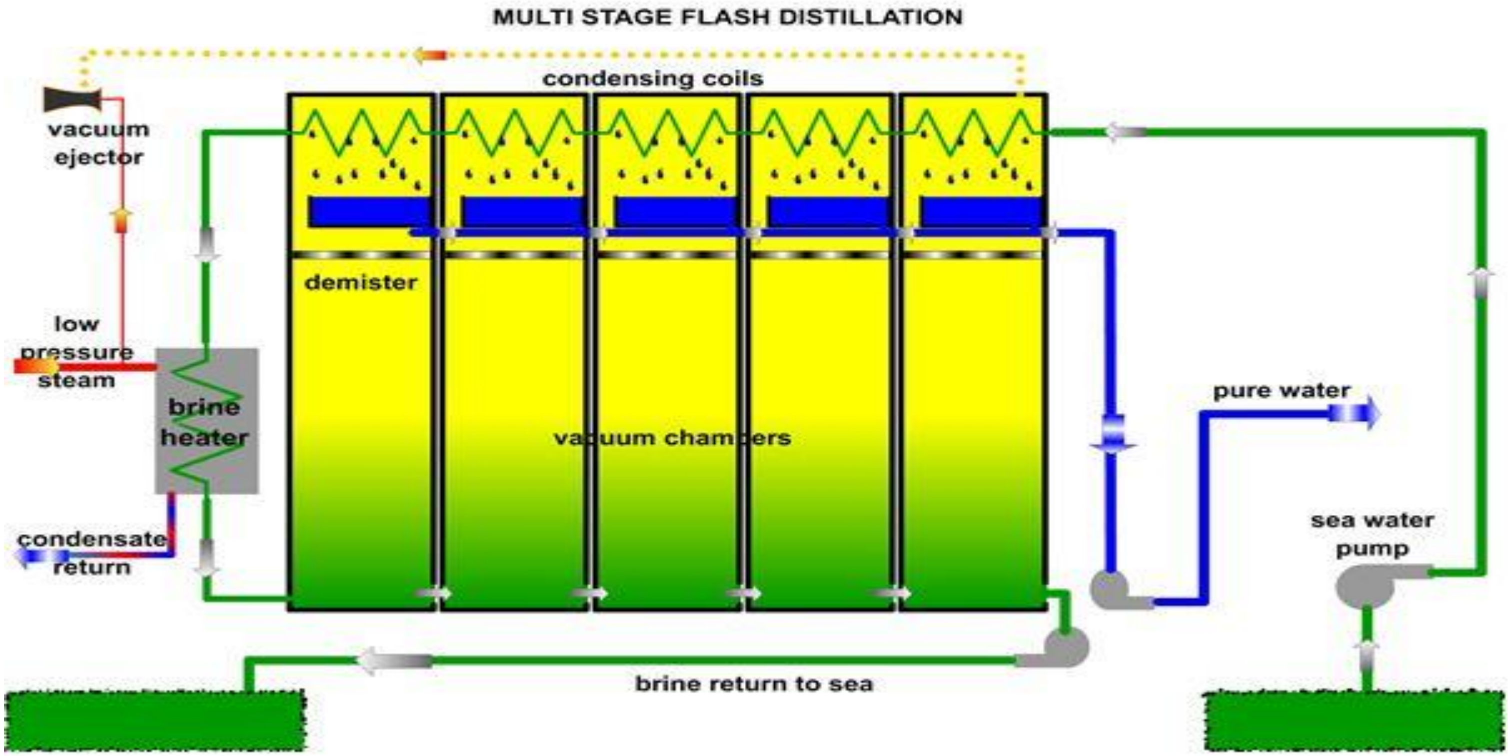
Desalination by Reverse Osmosis

- Membrane separates a dilute solution from a concentrated solution
- Solvent crosses from the dilute to the concentrated
- Solvent flow is prevented by applying an opposing hydrostatic pressure (390 psi for sea water)
- 30 to 250 psi for fresh and brackish water, 600-1000 psi for sea water.



www. watertreatments.com/desalination-water-treatment-filter-filtration-purify/reverse-osmosis-desalination-water-treatment-system

MSF Schematic

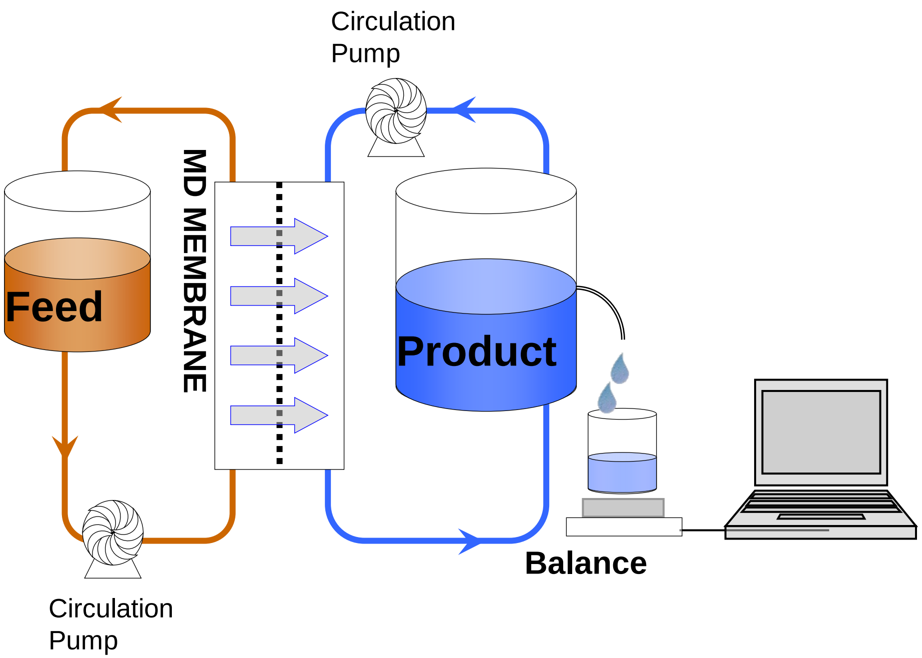


www.brighthub.com/engineering/mechanical/articles/29623.aspx.image=49823

Membrane Distillation

Membrane Distillation

- Heat the water solution (60-90°C) and it is partially transformed to water vapor
- The vapor will pass through the membrane and leave impurities behind
- Similar to a distillation, but occurs at lower temperatures



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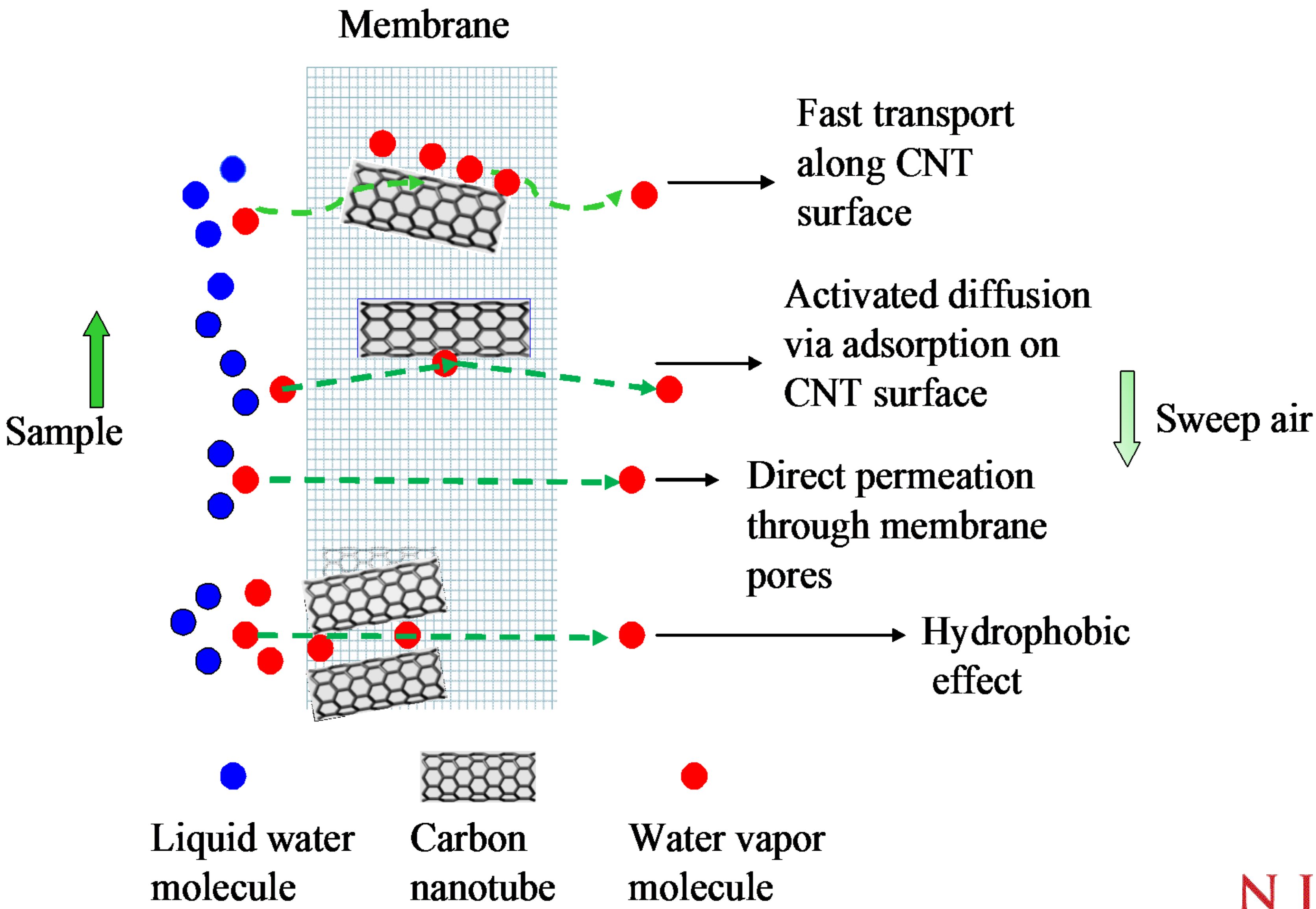
Membrane Distillation on CNIM



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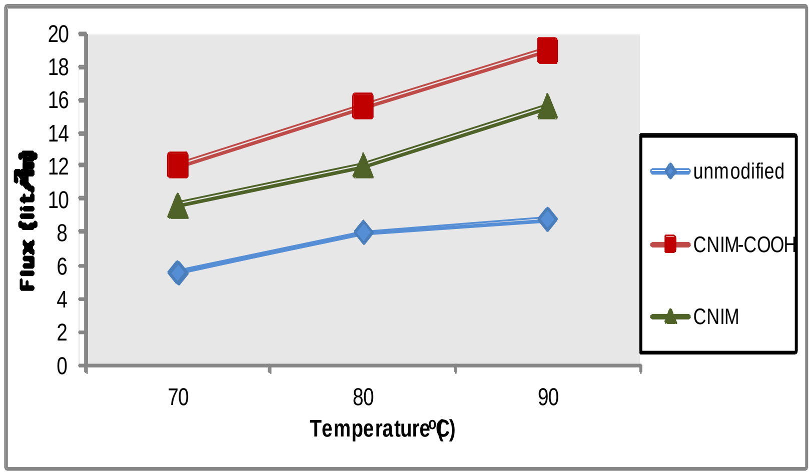
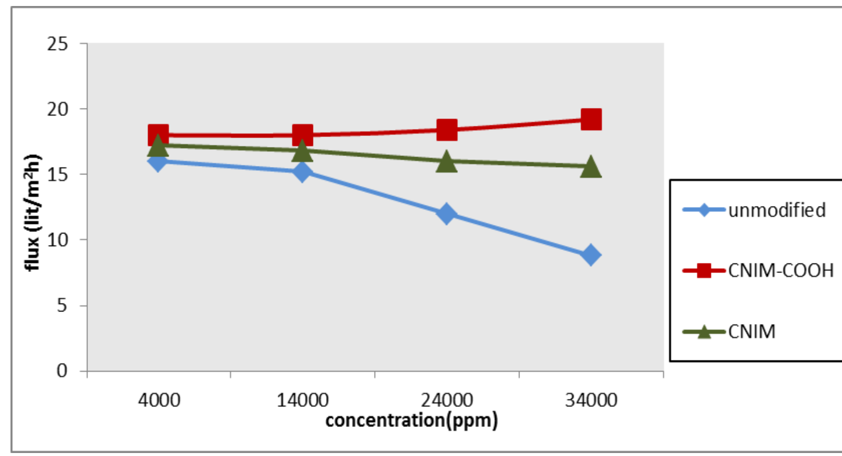
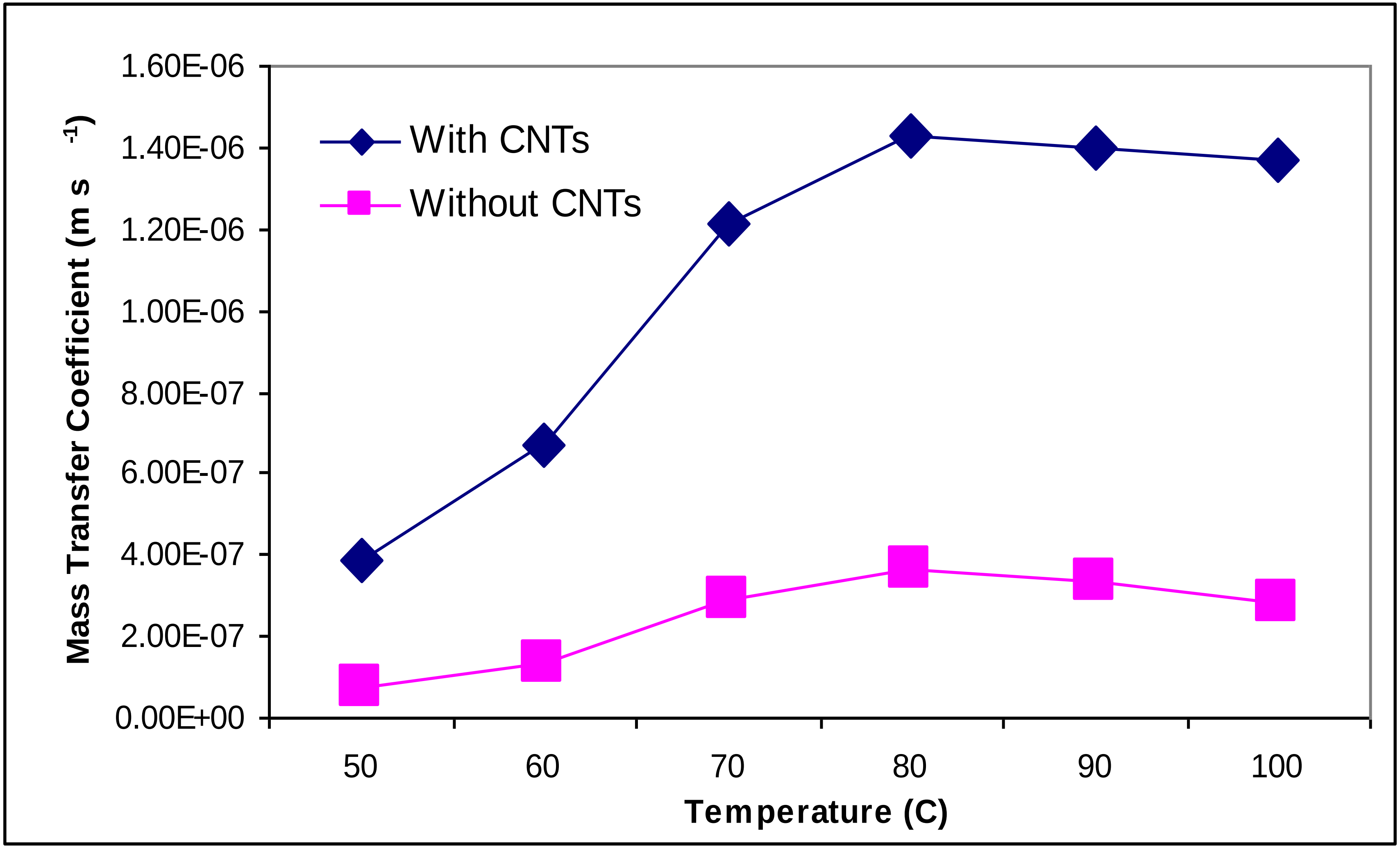
Water Vapor Flux During Sea Water Desalination on CNIM



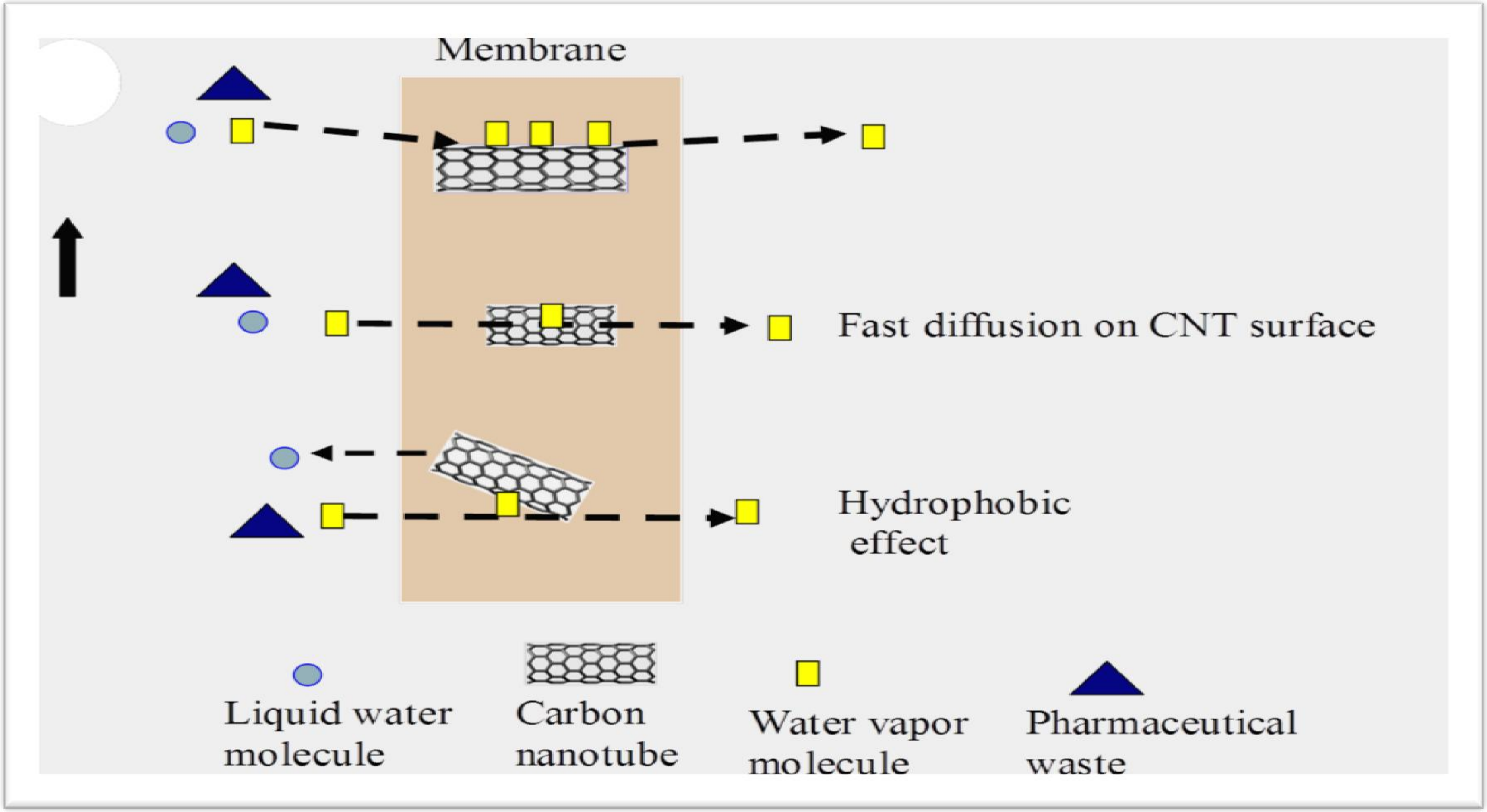


Effect of CNTs on Mass Transfer Coefficients



Concentrating Pharmaceutical Waste on CNIM

MD Preconcentration of Pharmaceutical Waste and Generation of Clean Water



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Enrichment for Different Pharmaceuticals Using CNT Based MD

Compound	CNIM EF	Plain EF	%Enhancement
Ibuprofen	14.4	5.9	244
Acetaminophen	9.7	3.6	269
Diphenhydramine	13.5	5.1	265
Dibucaine	11.4	3.6	317

Next Generation Membrane- CNIM

- High Flux
- Better Selectivity
- Lower Temperature Operation -economical
- Thermal Stability

- Application – Environmental Remediation, desalination, filtration, food processing ..…

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