Co-financed by Greece and the European Union

ECOTECH – NCSR Demokritos

NAMED 2nd Meeting

- **For the development of the pilot unit we have two engineering designs, namely:**

- **(I) a design based on the preliminary design presented in the submitted proposal, which requires the development of four membranes (NF high Mg^{2+} rejection, NF high Na^{+} rejection, FO and MD modules, all of them up scaled to 0.5 m^3/day.**

- **(ii) a design based on the preliminary design presented in the submitted proposal, which requires the development of only three membranes (NF high Mg^{2+} rejection, NF high Na^{+} rejection and FO, up scaled to 0.5 m3/day (there is no need for MD development).**

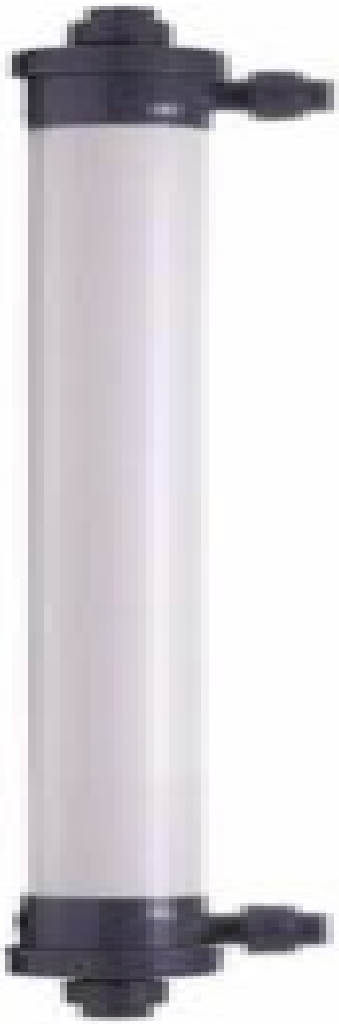
- develop to TRL 6 of “next-generation” membranes.
-
- **Forward Osmosis (FO) membranes** based on recent advances of nanotechnology, namely:

- (a1) PIM/SWCNT (German side?) and

- (a2) development of high flux single wall carbon nanotube (SWCNT) FO hollow fibre membranes by partner(Greek side).
-
- Development to TRL 6 of “next-generation” **nanofiltration hollow fibre , NF_{Mg}** high Mg^{2+} rejection (Greek side).

-
- **Development to TRL 6 of “next-generation” high flux membrane distillation (MD) membranes:**
- **(d1) PIM? (German side?)**
- **(d2) dual layer hollow fibre hollow fibre membranes hollow fiber membranes by partners(Greek side).**

- **Upscale the best membranes to 0.5 m^3/day.**
- **We need modules of the order of 0.5 m^3/day.**
- **Design, development, operation and optimization of innovative combinations of the best NF_1/NF_2/FO/MD.**



- **ECOTECH has upgraded the design, we have two designs, one $NF_1/NF_2/FO/MD$ and a second $NF_1/NF_2/FO$, reducing the number of the membranes that need to be developed down to three.**

- **Feasibility study for the selected pilot unit**

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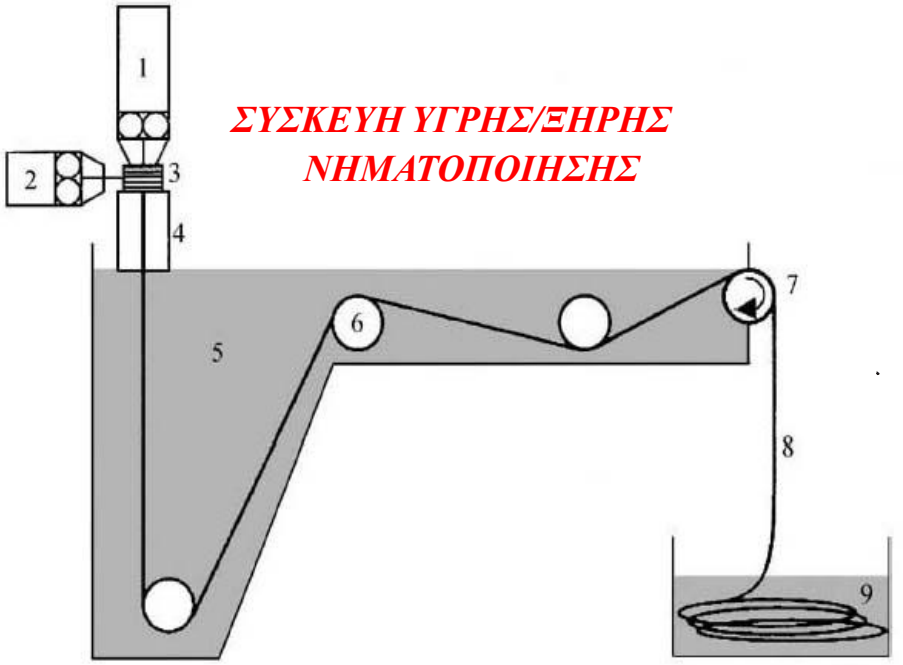
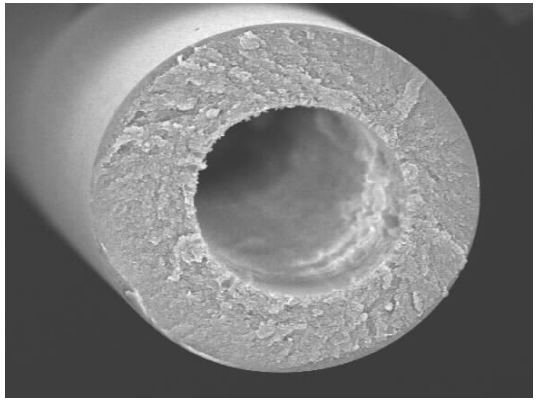
hollow fiber
MEMBRANE DISTILLATION carbon membranes

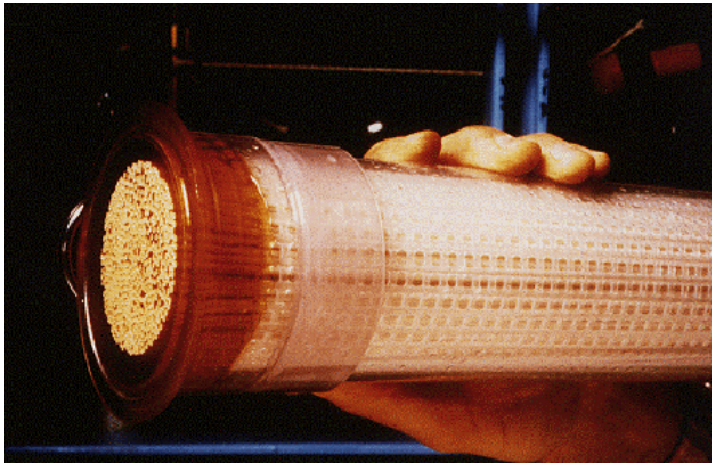


ΣΥΣΚΕΥΗ ΥΓΡΗΣ/ΞΗΡΗΣ ΝΗΜΑΤΟΠΟΙΗΣΗΣ

1. **Πολυμερές – Διαλύτης**
2. **Μη Διαλύτης**
3. **Spinneret**
4. **Air Gap**
5. **Λουτρό Θρόμβωσης**
6-7. **Τύμπανα Μεταφοράς - Συλλογής**
8. **Πολυμερική Κοίλη Ίνα**

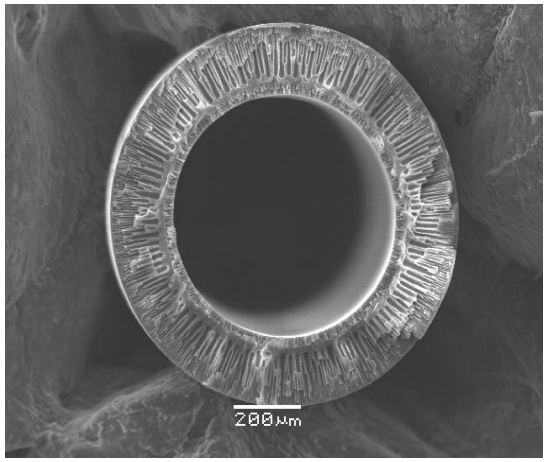


Φωτογραφία SEM

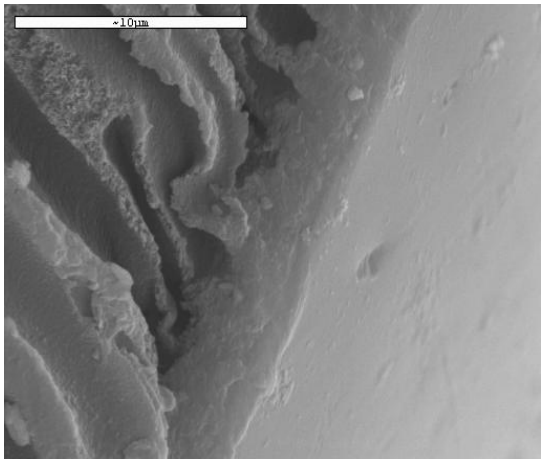


Module Κοίλων Ινών για Διαχωρισμό Αερίων

SEM PICTURES OF PRODUCED HOLLOW FIBER MEMBRANES



CROSS SECTION



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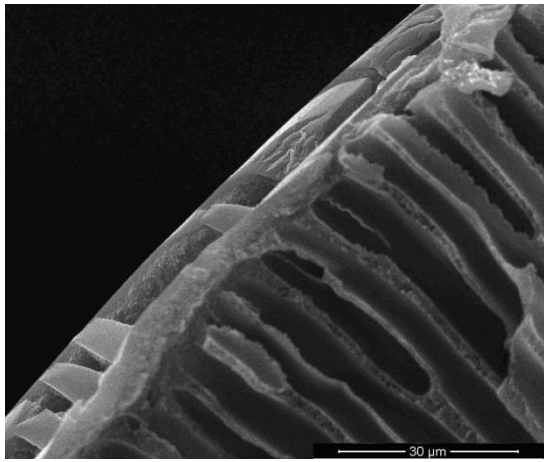

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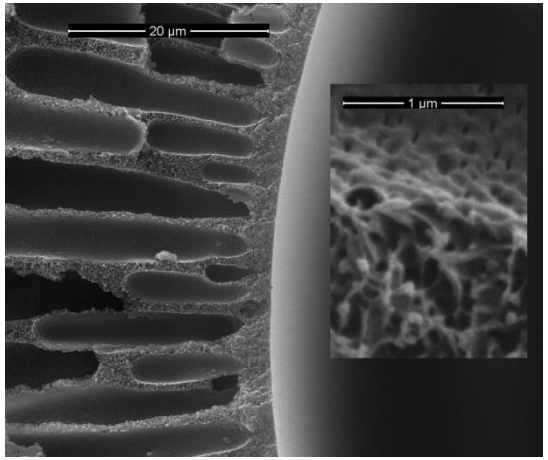

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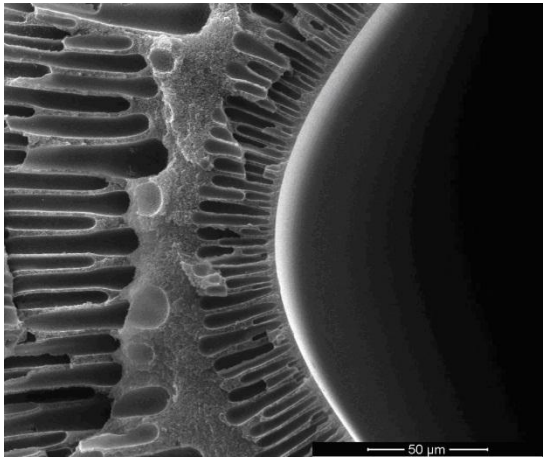

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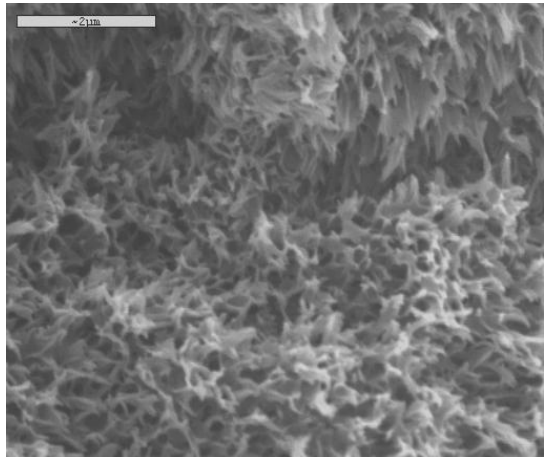


INNERT

MD up scaled module to 0.5 M^3/day MD

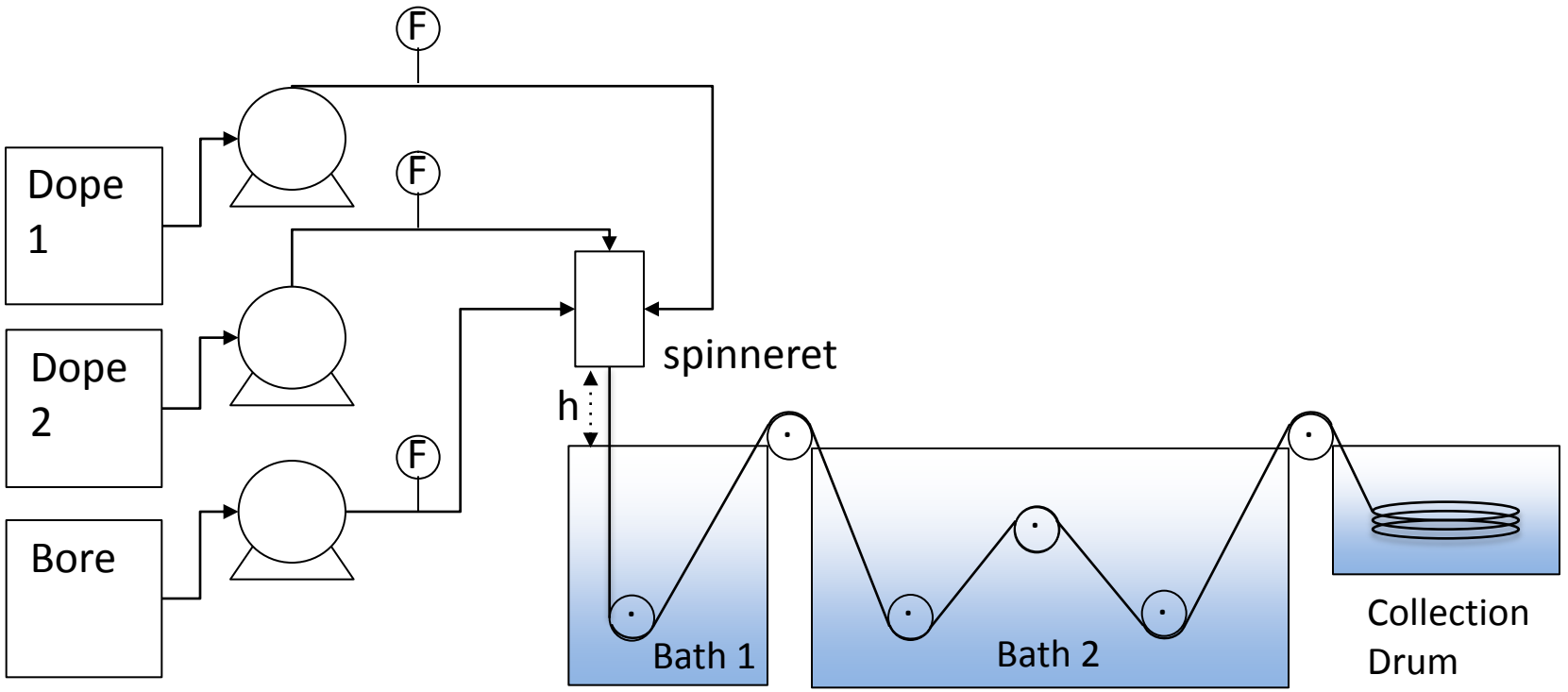
1. MD (Membrane distillation) Carbon hollow fiber fragile, not readily scalable

- **2. A better alternative is the readily scalable double layer PVDF/PEI (hydrophobic/hydrophilic) hollow fiber membrane**

Membrane Fabrication – Hollow Fiber and Flat

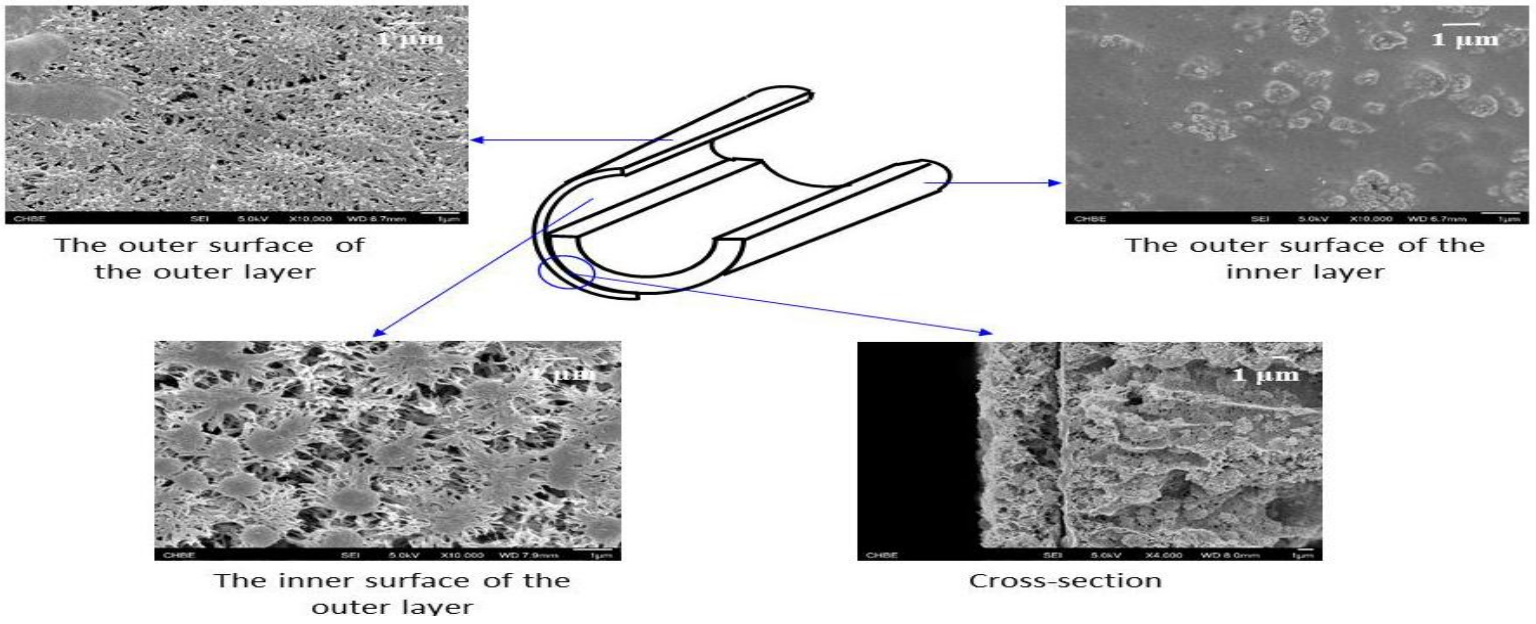
Goal: To fabricate flat and hollow fiber membranes for a MD, FO and NF application.

Dry-wet hollow fiber spinning set-up



Membrane Fabrication – For MD application

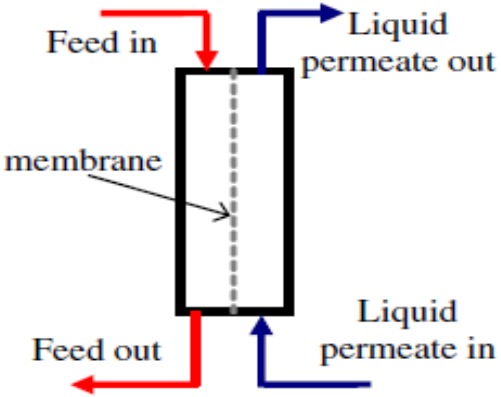
Goal: PVDF/PEI (hydrophobic/hydrophilic) dual hollow fiber membrane with alumina nanoparticles.

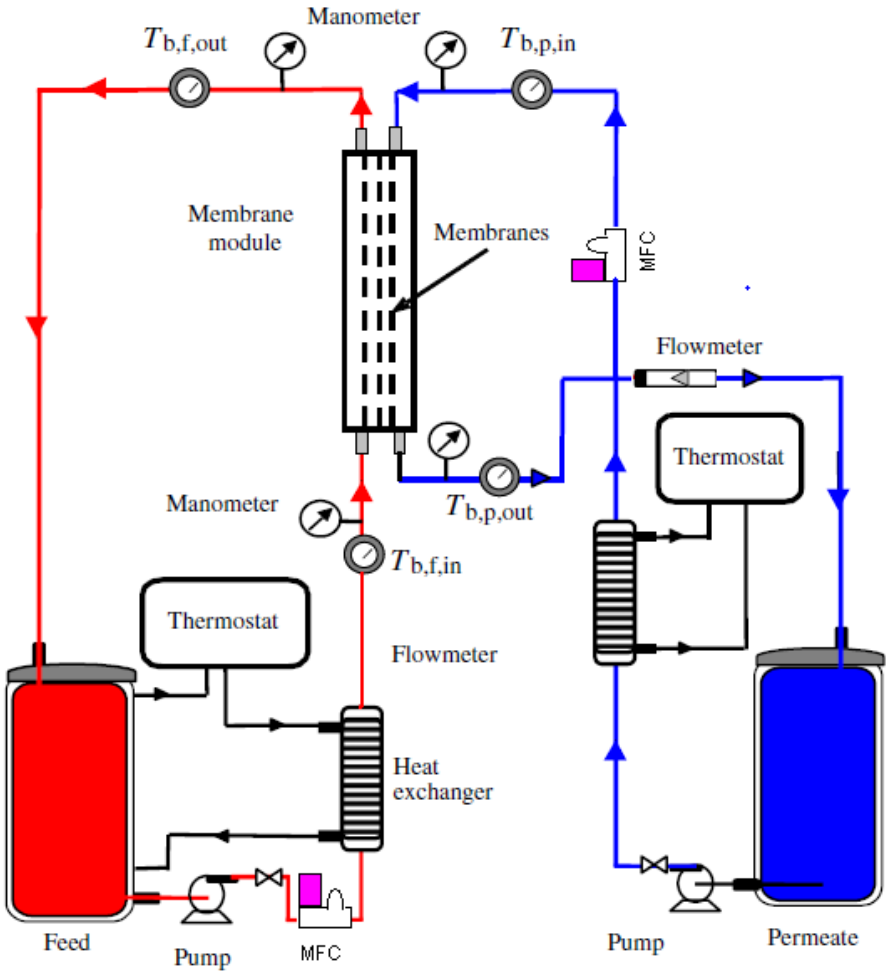


Membrane Fabrication – For FO and NF application

Goal: PES polyelectrolyte layering hollow fiber membrane with GA cross-linking, this creates a positive charge on the inner surface of the membrane that increases the rejection of salts.

Direct Contact Membrane Distillation - DCMD



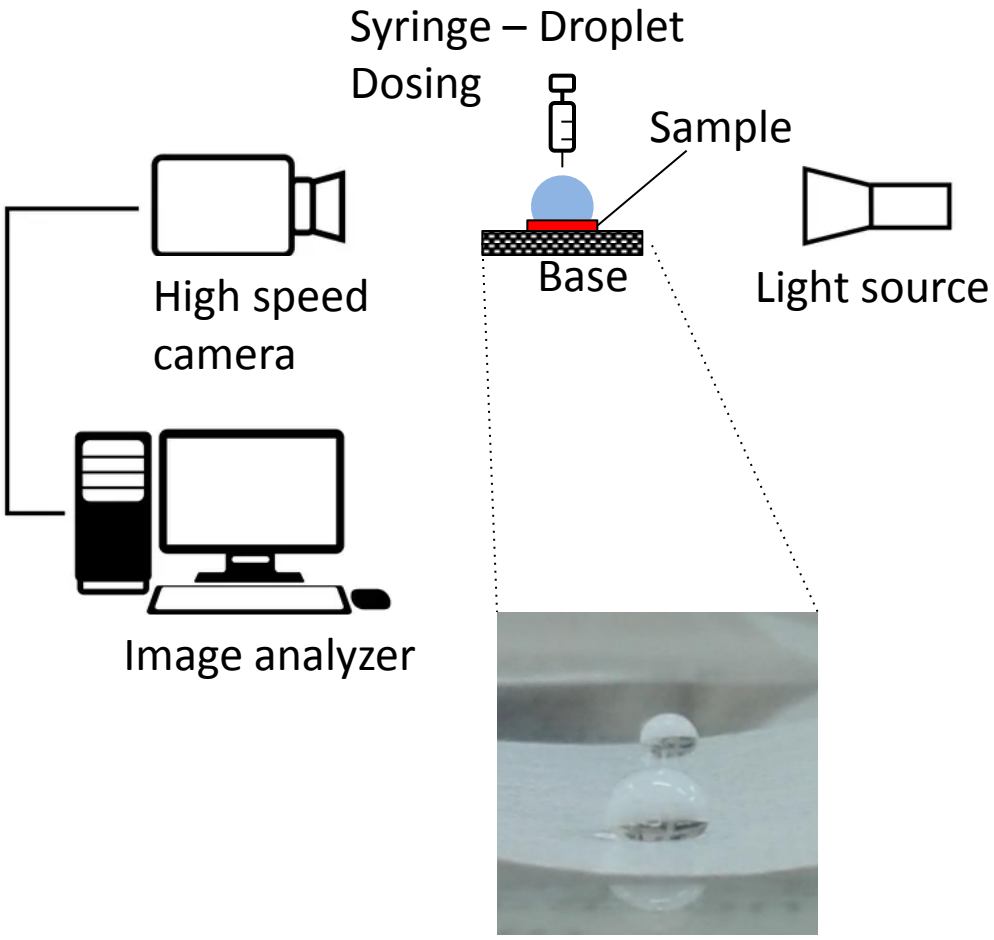


Commercial Membranes tested in the MD system

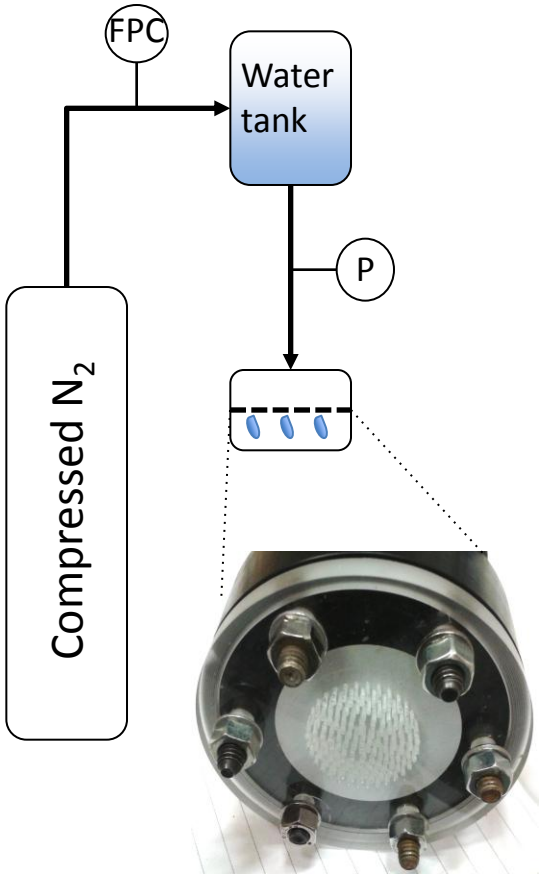
	M1B	M2B	M3L	M4L	M5L
Company	Filtres-Fiorini	Merck	Millipore	Filtres-Fiorini	Whatman
Type	Flat	Flat	Flat	Flat	Flat
Material	PTFE	PVDF	GTTP	NYLON	NYLON
Diameter [mm]	47	47	47	47	47
Pore size [µm]	0,22	0,22	0,2	0,22	0,2
Hydrophobicity	Hydrophobic	Hydrophobic	Hydrophilic	Hydrophilic	Hydrophilic

Characterization of Membranes

Water Contact Angle – WCA



Liquid Entry Pressure – LEP



Results from MD testing

Hydrophobic membranes proved too hydrophobic, no vapour was observed to pass through pores.

Hydrophilic membranes are not suitable for MD, the system resembles a FO operation.

Next plan 1: Membrane modification of surface to decrease hydrophobicity.

Next plan 2: Membrane modification of surface to increase hydrophobicity.

Membrane Modification - Method

Goal: To reduce hydrophobicity of hydrophobic membrane surface.

Step 1:
PTFE flat membranes were immersed for 24 hrs in various PVA solutions:
1 wt%, 0,5 wt% and 0,1 wt%.

Step 2:
Momentarily dipped in ethanol (bad solvent for PVA).

Step 3:
Immersed in GA (glutaraldehyde) solution for cross-linking of PVA for 24 hrs.

Step 4:
Washed with distilled water and dried.

Step 5:
Immersed in distilled water at high temperature (~65°C) for 24 hrs.

Step 6:
Stored dry at room temperature.

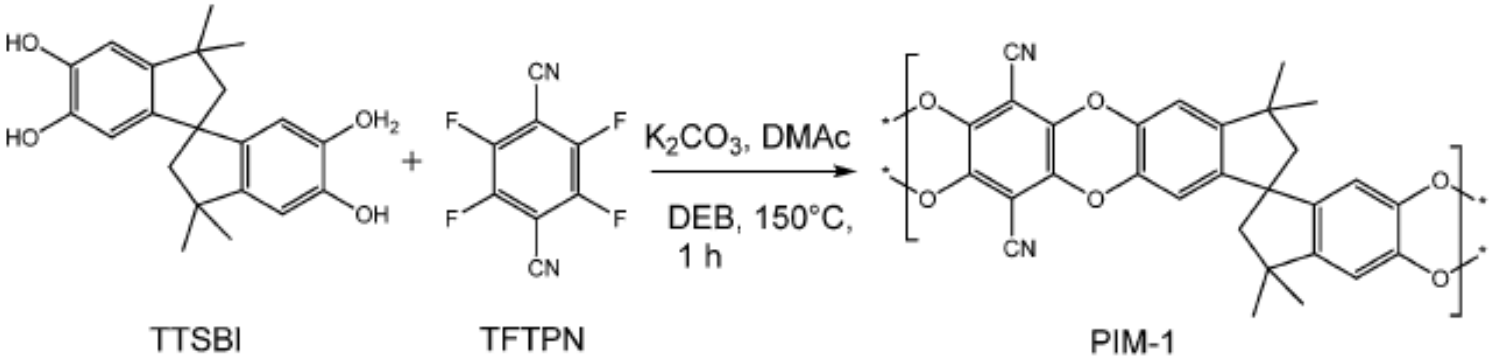
Results from PVA modification

The membrane modified with PVA 0,1% had a decreased contact angle and LEP but remained hydrophobic.

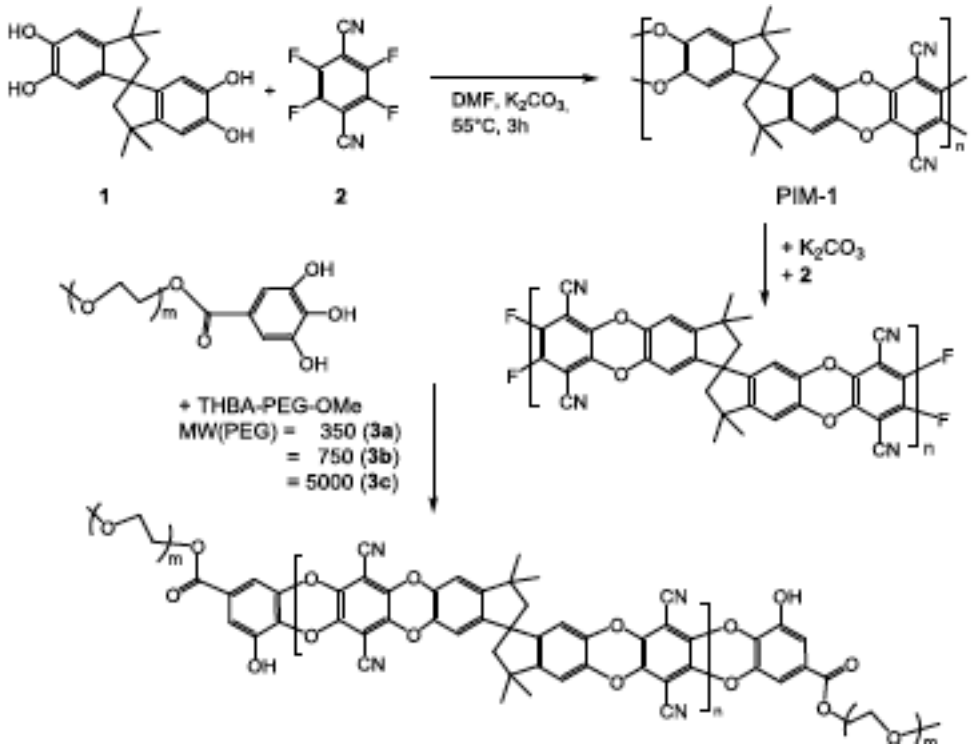
While, the membranes modified with PVA 1% and PVA 0,5% became hydrophilic.

Next step: To coat membranes with PVA solutions of 2% and 0,05% and test the modified membranes' performance in the MD system.

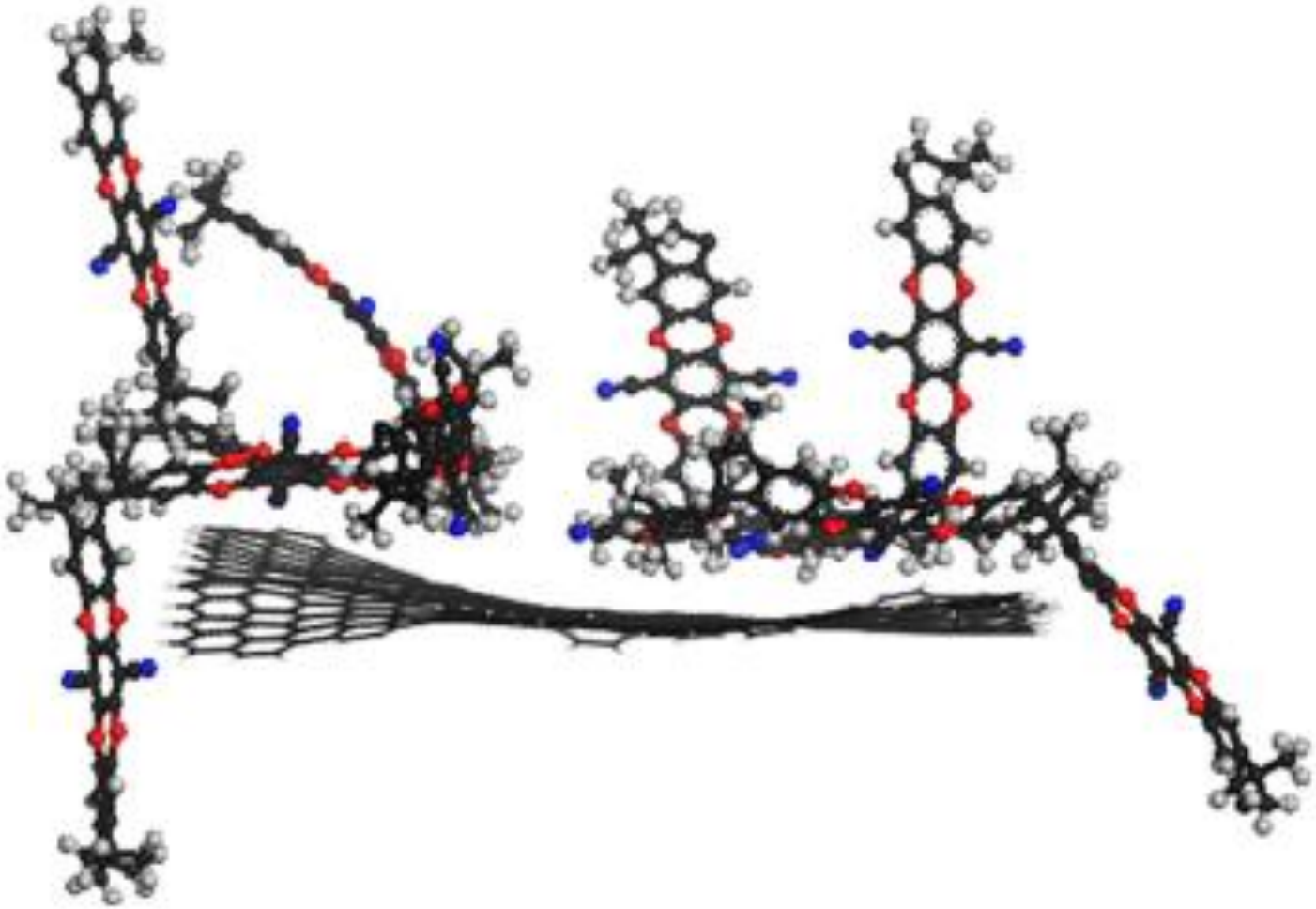
PIM-1


HO
HO
OH
OH
+
CN
F
F
F
F
CN
K_2CO_3, DMAc
DEB, 150°C,
1 h
CN
O
O
O
O
CN
O
O
TTSBI
TFTPN
PIM-1

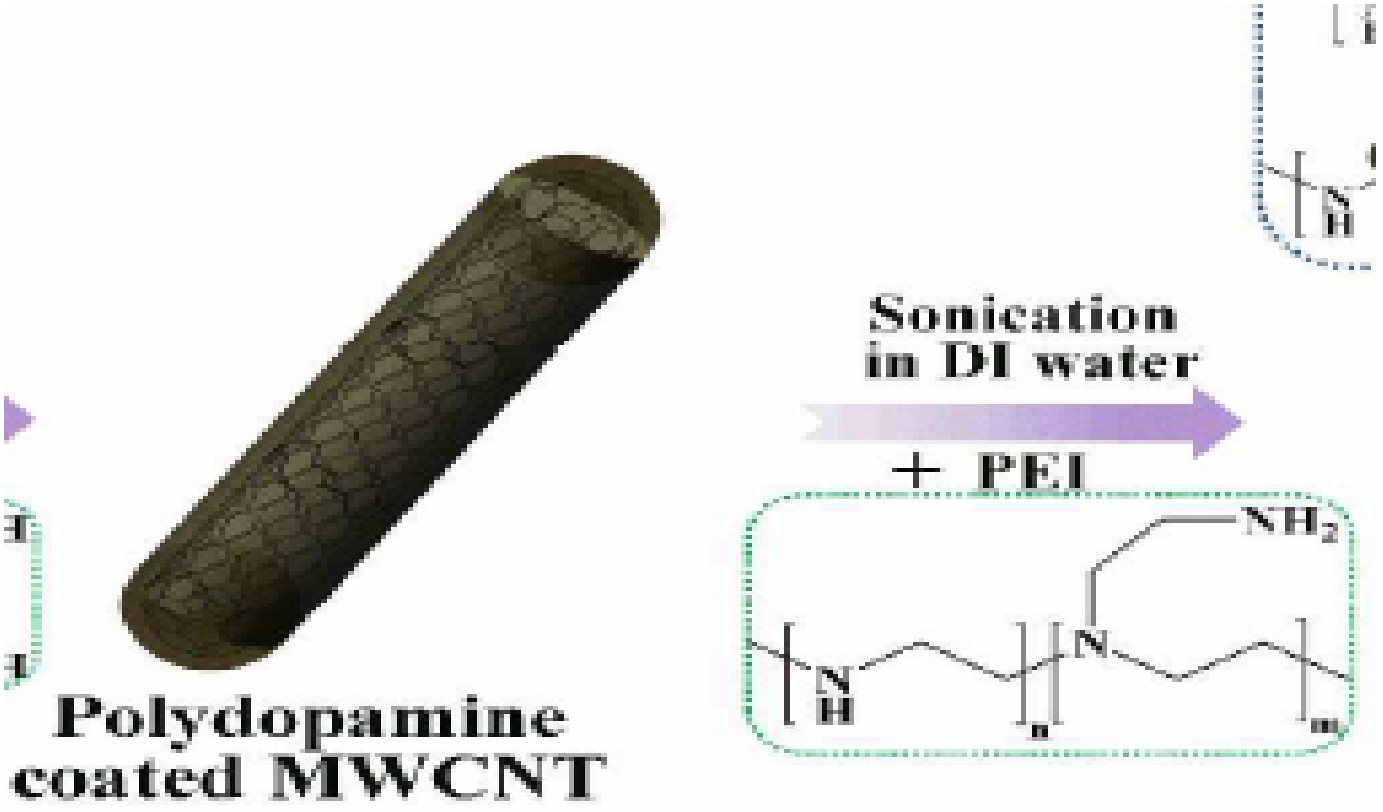
PERVAPORATION OR NANOFILTRATION OR FO?



PIM1-GO up scalable PVDF hollow fiber FO membranes

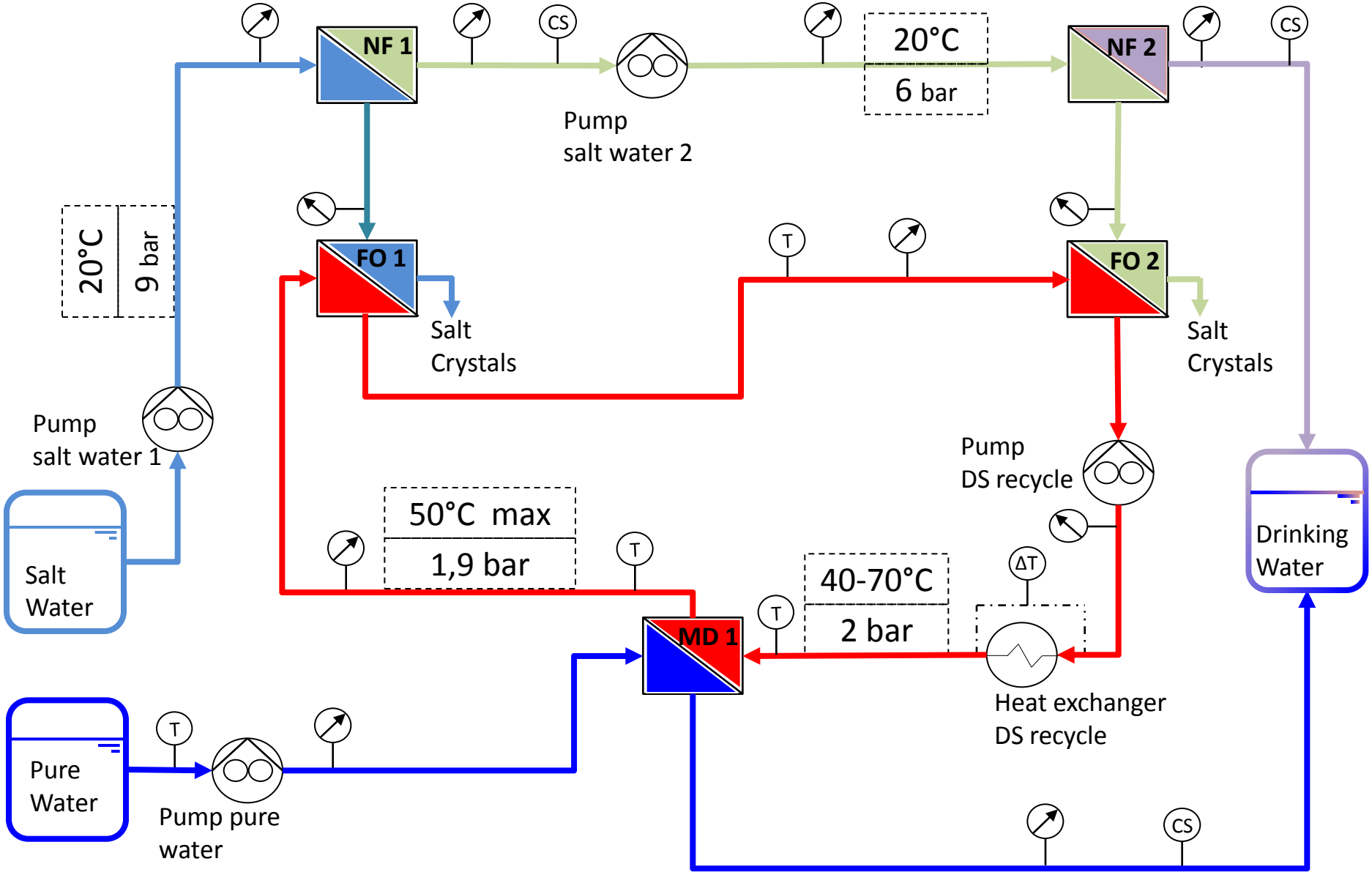


CNT-PEI-TMC hollow fiber FO membrane

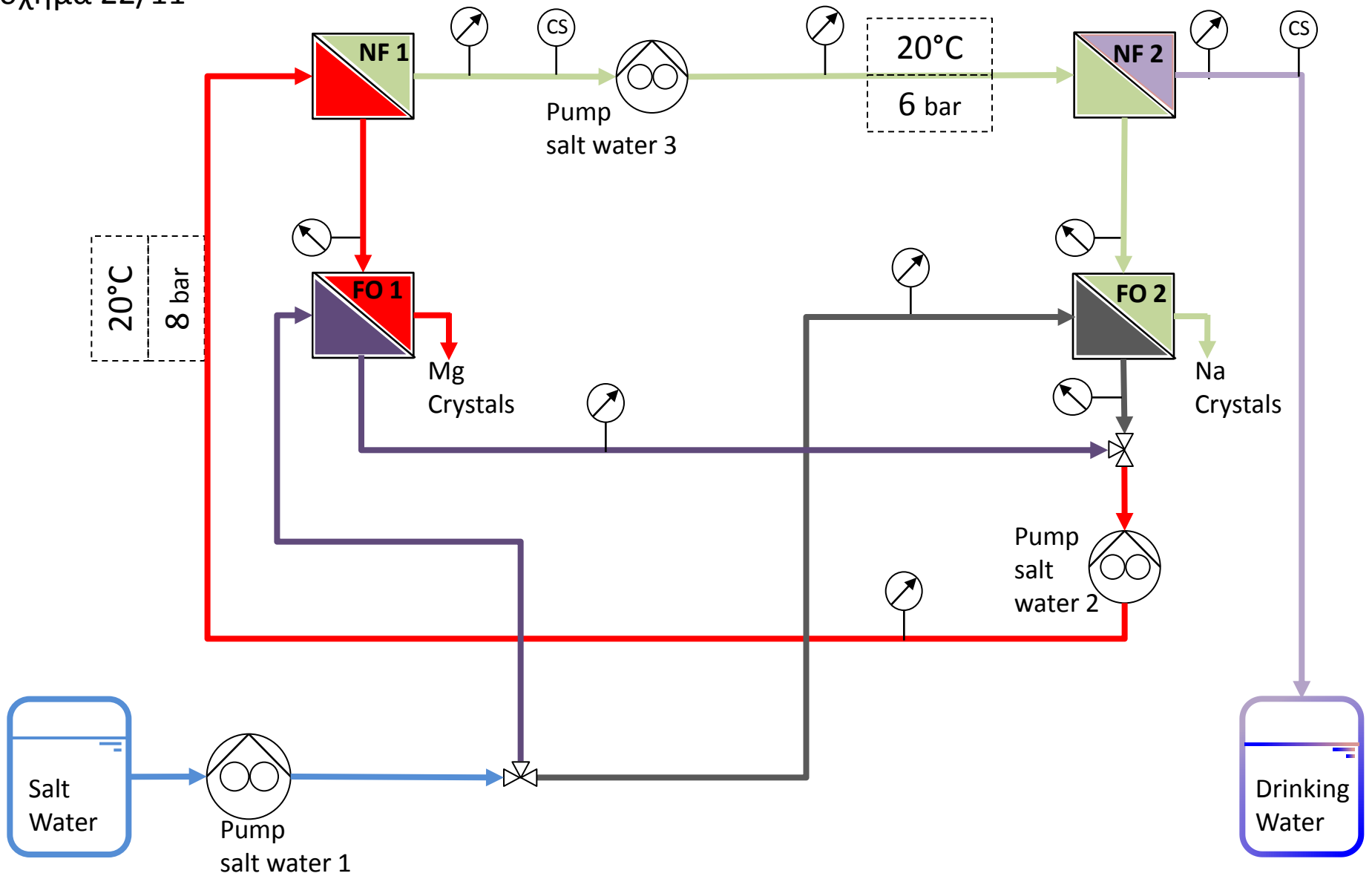


CNT-PEI-TMC hollow fiber FO membrane

Pilot Unit Schematic



σχήμα 22/11


NF 1
CS
Pump
salt water 3
20°C
6 bar
NF 2
CS
20°C
8 bar
FO 1
Mg
Crystals
FO 2
Na
Crystals
Pump
salt
water 2
Salt
Water
Pump
salt water 1
Drinking
Water

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