SimHydro 2025

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8th International Conference
2 – 4 June
Nice, FRANCE

A CFD study on the impact of the 3D printed feed spacers on fouling and wetting in direct contact membrane distillation

Atefeh Tizchang [1,2], Morgan Abily [3], Olivier Delestre [4,5], Hussam Jouhara [6,7], Luca Montorsi [8,9], Wolfgang Gernjak [1,10]

[1] Catalan Institute for Water Research (ICRA), 17003 Girona, Spain [2] University of Girona, 17003 Girona, Spain [3] Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, IRD, Géoazur, France [4] Université Côte d'Azur, CNRS, LJAD, Nice, France [5] Laboratoire d'Hydraulique Saint-Venant, Ecole des Ponts ParisTech - EDF R&D, Chatou France [6] Bioeconomy Research Institute, Vytautas Magnus University, LT-44248 Kaunas, Lithuania [7] Heat Piep and Thermal Management Research Group, College of Engineering, Design and Physical Sciences, Brunel University of London, Uxbridge UB8 3PH, UK [8] Department of Science and Methods for Engineering, University of Modena and Reggio Emilia, 42122 Reggio Emilia, Italy [9] InterMech—MO.RE., University of Modena and Reggio Emilia, 41121 Modena, Italy [10] Catalan Institution for Research and Advanced Studies (ICREA), 08010 Barcelona, Spain

OBJECTIVE

- Membrane distillation (MD) systems are temperature driven processes used for wastewater treatment; however, they are not commonly utilized in industrial scale due to their drawbacks such a temperature polarization [1].
- Filament spacers, used both for structural maintenance and for flow mixing promotion purposes within the MD units, can enhance the mass and heat transfer, which finally will result in reduction of concentration and temperature polarization [2].
- Here, 3D printed spacers have been used in a MD system to study their impact on MD performance through experimental analyses, and on temperature polarization through CFD analysis.

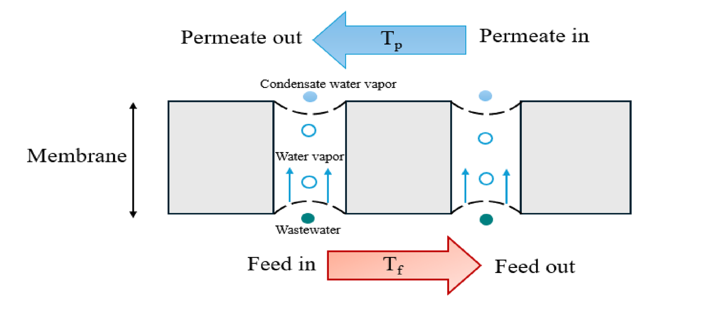

Fig.1. Schematic of direct contact membrane distillation (DCMD).

METHODOLOGY

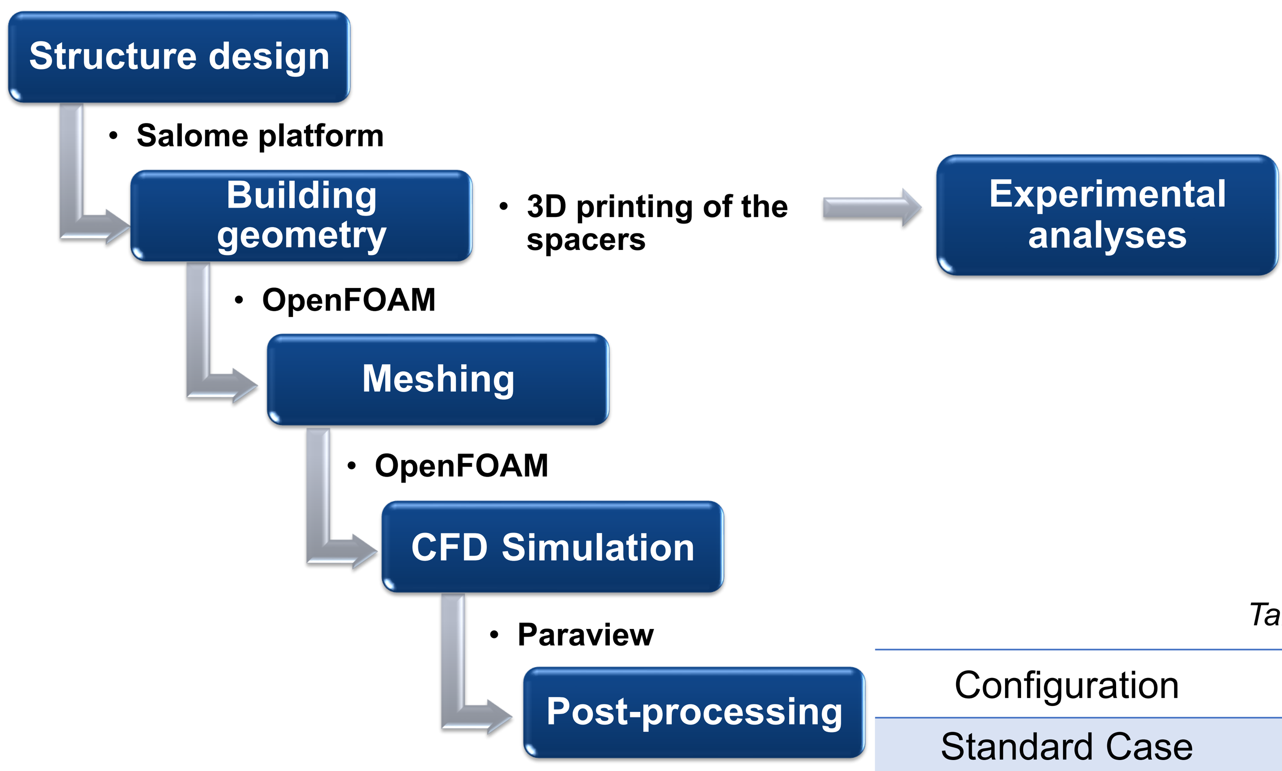

Table. 1: Dimensions of the membrane module.

Parameter	Value (mm)
Block length	300
Block width	150
Block height	10.15
Hot channel height	5
Cold channel height	5
Membrane thickness	0.15

Table. 2: Characteristics of 3D printed spacers.

Configuration	Angle	Diameter (mm)	Spacing (mm)
Standard Case	45º, -45º	2.5, 2.5	15

Geometry

- The 3D geometry of the MD system was developed using GEOM/Shaper module of by Salome GUI.
- The geometry consists of feed and permeate channels with a double layer filament spacers.
- The filaments have an angle of 45º degree to the incoming flow inside the channels.
- The CAD files of the spacers, were 3D printed using Fused Deposition Modeling (FDM) method.

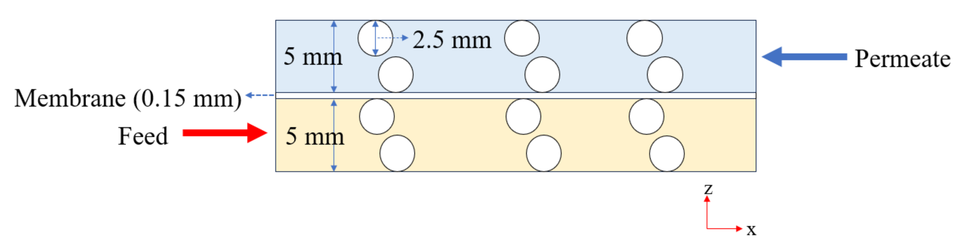

Fig. 2. Schematic of membrane distillation modules with spacers (side view).

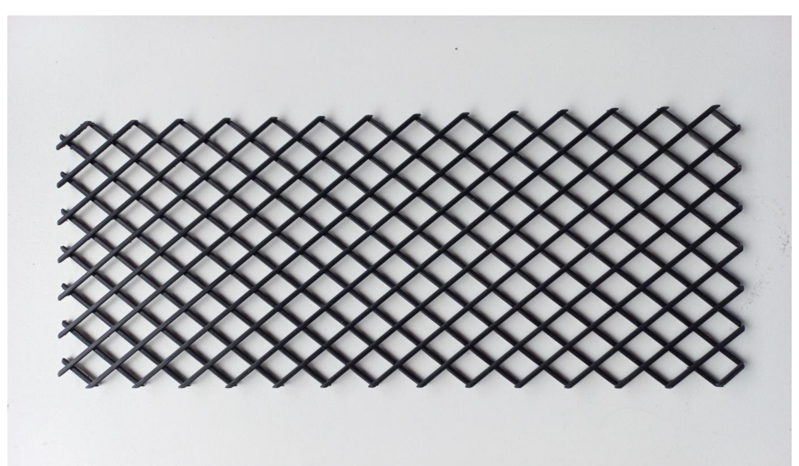

Fig. 3. Picture of the 3D printed spacer.

Mesh

- A hex-dominant meshing tool called snappyHexMesh was used to generate a 3D mesh.
- Overall number of hexahedra cells: 4,000,000

Simulation paramaters

- CFD software: OpenFOAM
- CFD Solver: chtMultiRegionFoam, steady-state
- Turbulence Modeling: RAS k-ε
- Simulation Time: 10 s
- Delta T: 0.001 s
- Number of CPUs: 40
- Initial Boundary Conditions:

Feed:
T inlet: 333 K   T outlet: Zero Gradient
U inlet: 0.11 m/s   U outlet: Zero Gradient

Permeate:
T inlet: 303 K   T outlet: Zero Gradient
U inlet: 0.11 m/s   U outlet: Zero Gradient

Post Processing

- The results of the CFD in OpenFOAM is visualized using paraview tool implemented in OpenFOAM.

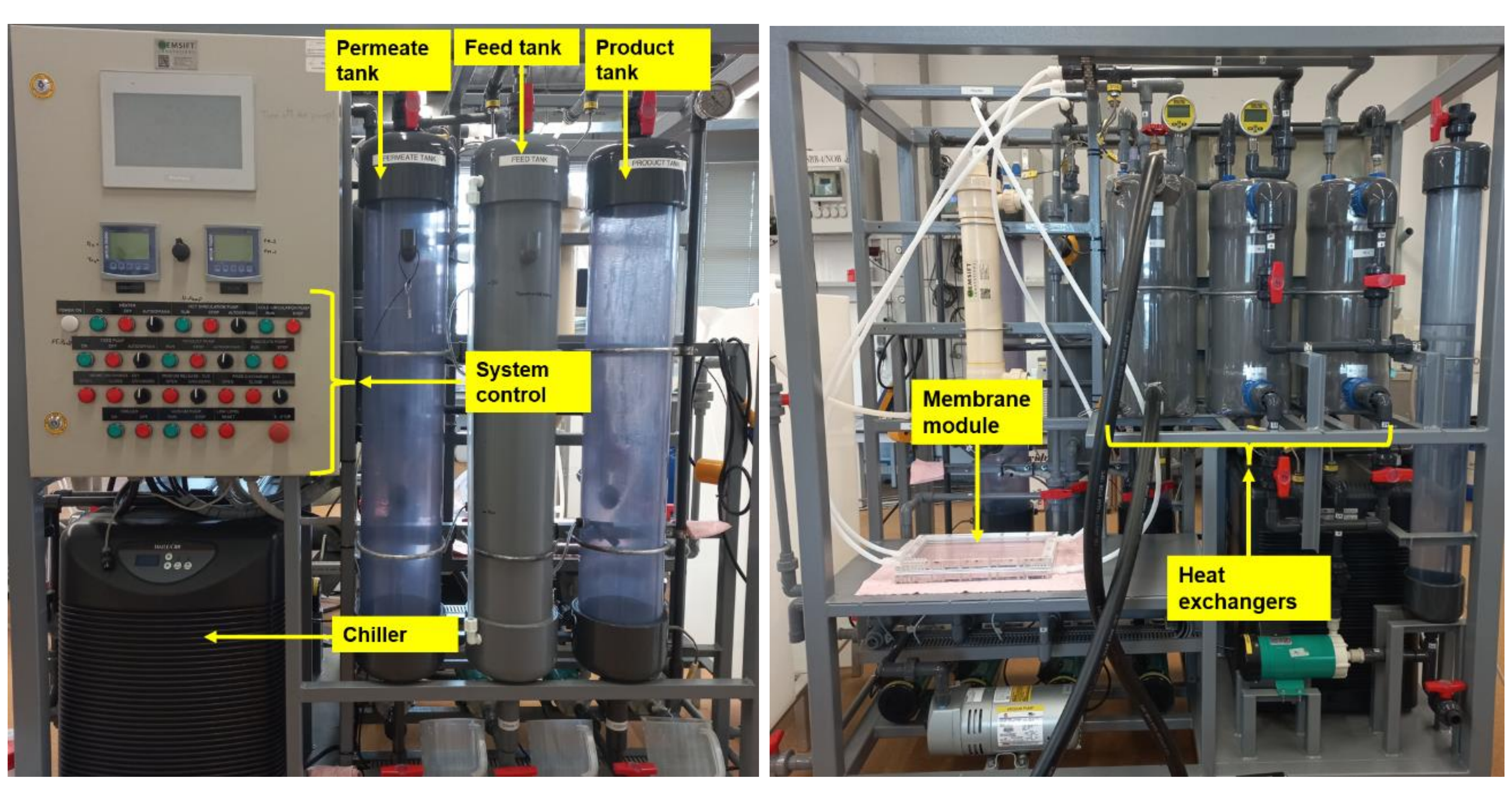

Fig. 4. Front side of the MD unit (left), and back side of the MD unit (right).

Experimental conditions:

- polytetrafluoroethylene (PTFE) membranes were used for both experiments.
- 3% NaCl solution was prepared to be used as feed solution.
- Initial feed and permeate temperature were 60 ºC and 30 ºC, respectively.
- Both experiments were performed for 10 hours.

RESULTS

The permeate flux of the membranes with and without spacers are investigated and the results are shown in Fig. 5.

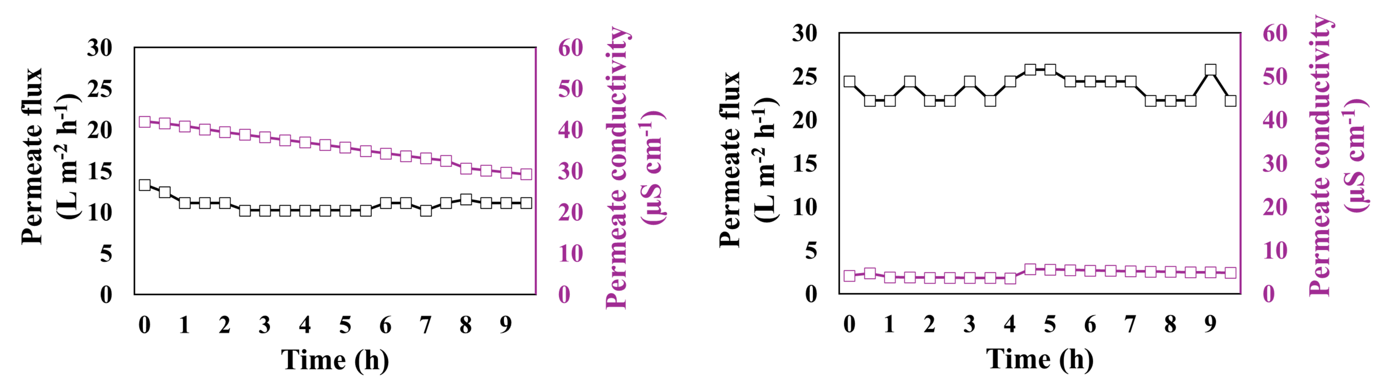

Fig. 5. The effect of adding spacers on the membrane flux without spacer (left), with spacer (right).

- Permeate flux increased by 53% for 10-hour experiment by adding the spacers, while the rejection remained above 99%.

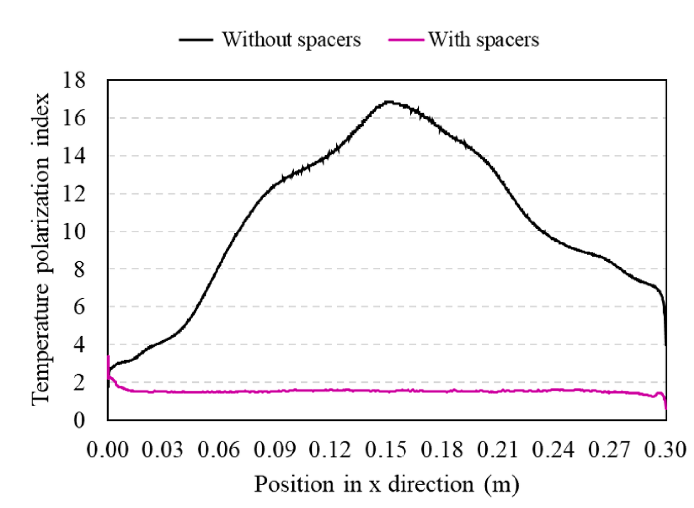

Fig. 6. Temperature polarization index with and without spacers.

- Temperature polarization (TP) refers to a phenomenon where the temperature of the bulk feed solution is different from that at the membrane surface. Lower TP is a good indicator of the better performance of the membrane, and based on the results adding spacers has improved TP of the membrane.

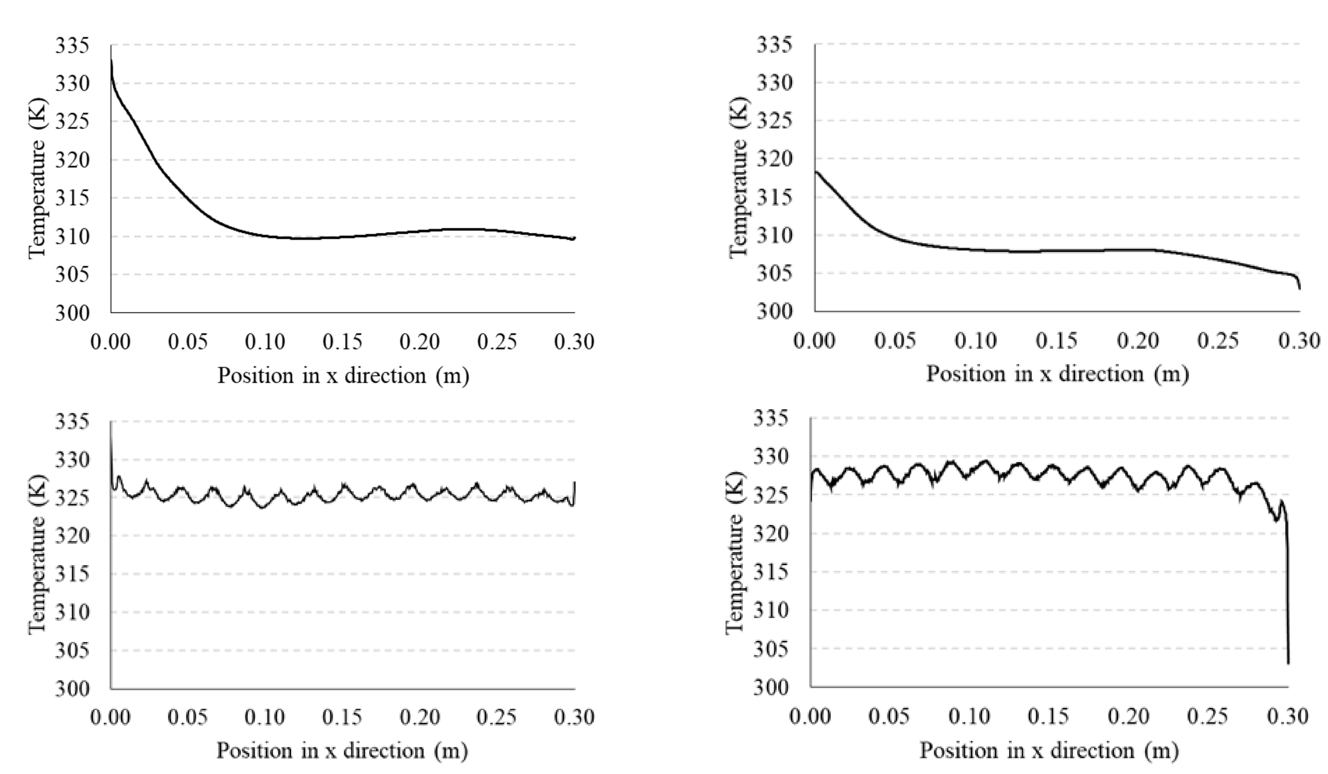

Fig. 7. Thermal distribution along x direction, in feed channel without spacers (left top), in the permeate channel without spacers (right top), in feed channel with spacers (left bottom), in the permeate channel with spacers (right bottom).

- The thermal distribution in the presence of spacers is more stable along the membrane module for both permeate and feed flows which can be attributed to the turbulence created by the spacers and lower temperature polarization index. The fluctuations in the thermal distribution along the membrane module are due to the contact between two layers of spacers in those regions.

FOLLOWING WORKS

- Investigation on the impact of 3D printed spacers in the membrane distillation system for a **real industrial wastewater.**
- Developing an ongoing CFD model using OpenFOAM to study the hydrodynamic impact of addition of **different configurations of spacers** in the MD system.

References *1. M.M.A. Shirazi, M. Mahdi, A. Shirazi, A. Kargari, A Review on Applications of Membrane Distillation (MD) Process for Wastewater Treatment, Journal of Membrane Science and Research 1 (2015) 101–112. https://doi.org/10.22079/JMSR.2015.14472. 2. M. Shakaib, S.M.F. Hasani, I. Ahmed, R.M. Yunus, A CFD study on the effect of spacer orientation on temperature polarization in membrane distillation modules, Desalination 284 (2012) 332–340. https://doi.org/10.1016/J.DESAL.2011.09.020.*

Acknowledgement Funding obtained from the European Union's Horizon 2020 research and innovation program for the iWAYS project (grant no 958274), and Departament de Recerca i Universitats de la Generalitat de Catalunya (Codi ajut: 2021 SGR 01283) is gratefully acknowledged.