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CFD analysis for membrane distillation optimization for wastewater treatment

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Objective

- Membrane distillation (MD) systems are temperature driven processes using for wastewater treatment; however, they are not commonly utilized in industrial scale due to their drawbacks such a temperature polarization.
- 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.
- Here, a CFD analysis of a MD system has been studied in order to predict the MD system's performance with different configurations.

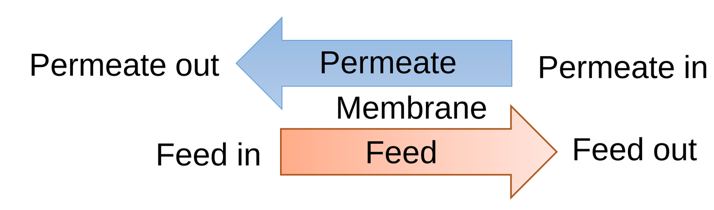

Fig.1. Direct contact membrane distillation configuration

Methodology

Geometry → Mesh → Simulation → Post processing

Geometry

- A 3D geometry of the MD system developed by Salome.
- 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.

Parameter	Value
Block length	0.2 m
Block width	0.01 m
Block height	0.0041 m
Membrane thickness	0.0001 m
Initial distance *	0.03 m
Filament radius	0.000499 m
Filament distance (attached)	0.01 m
Filament amount (attached)	11
Filament distance (detached)	0.01 m
Filament amount (detached)	11

Table 1. Parameters and dimensions of the geometry

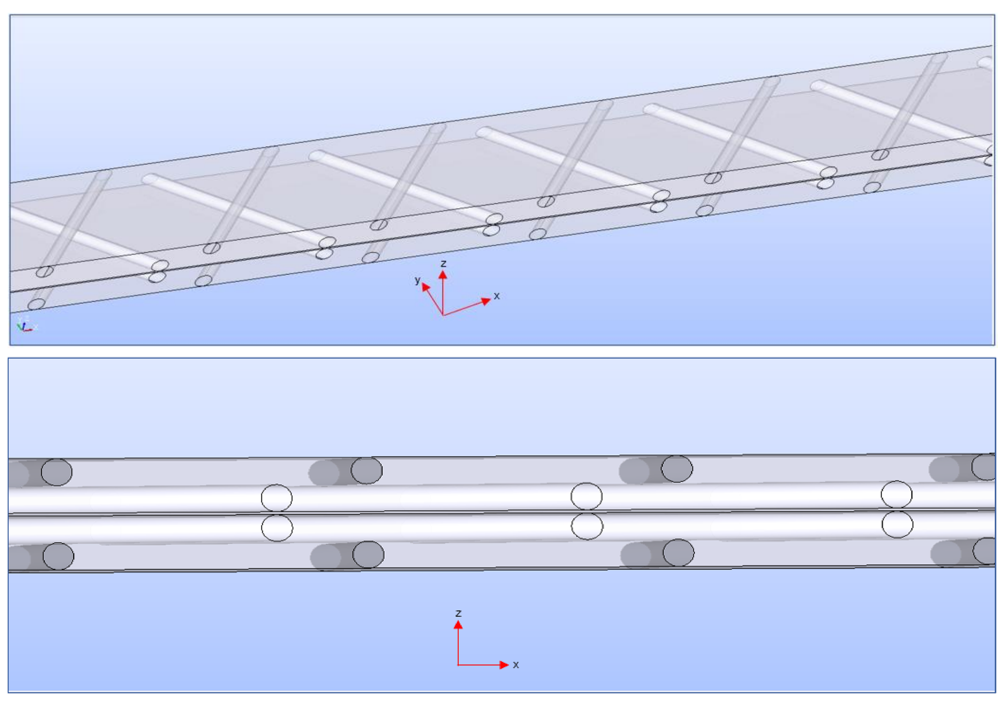

Fig.2. 3D geometry of the MD, top (top view of the module), bottom (side view of the module)

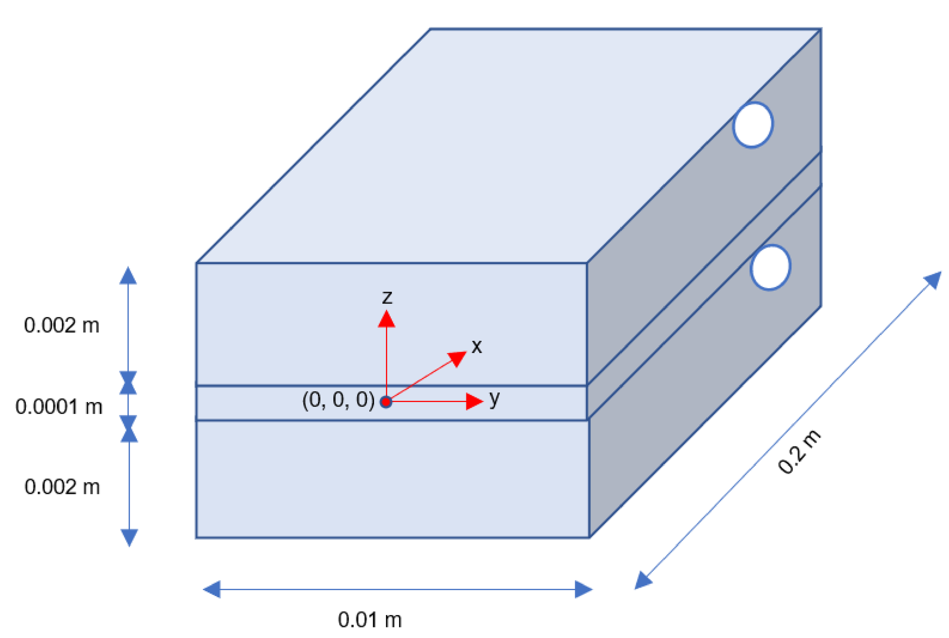

Fig.3. representation of the dimensions of the 3D geometry

Mesh

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

- hexahedra: 5,451,103
- polyhedra: 635,485

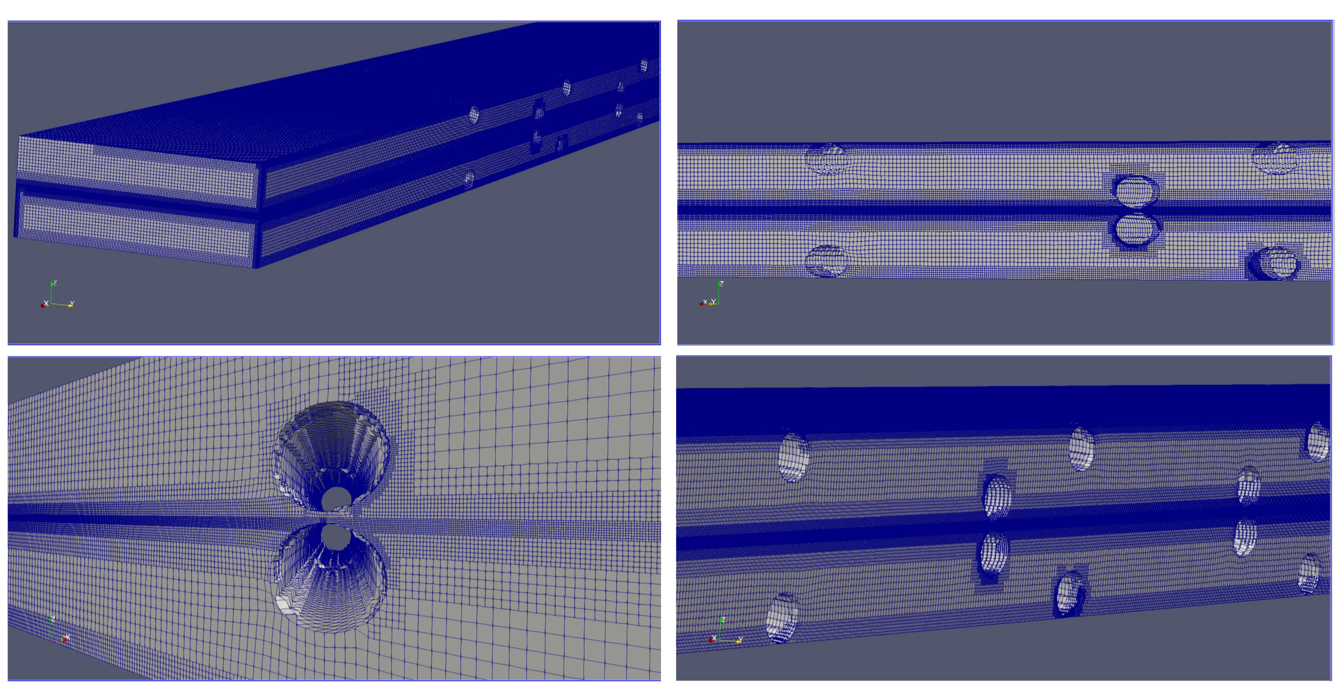

Fig.4. Mesh generated by snappyHexMesh

Simulation paramaters

- CFD Solver: chtMultiRegionFoam, steady-state
- Turbulence Modeling: RAS k-ε
- Simulation Time: 20 s
- Delta T: 0.001 s
- Number of CPUs: 40
- Initial Boundary Conditions:

Feed:		Permeate:	
T inlet: 333 ˚K	T outlet: Zero Gradient	T inlet: 293 ˚K	T outlet: Zero Gradient
U inlet: 0.05 m/s	U outlet: Zero Gradient	U inlet: 0.05 m/s	U outlet: Zero Gradient

Post Processing

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

Results

Preliminary CFD results are presented below with the focus on velocity and temperature distributions inside the feed and permeate channels. For each thermal and velocity distributions two sets of data have been reported in *x* and *z* direction, respectively.

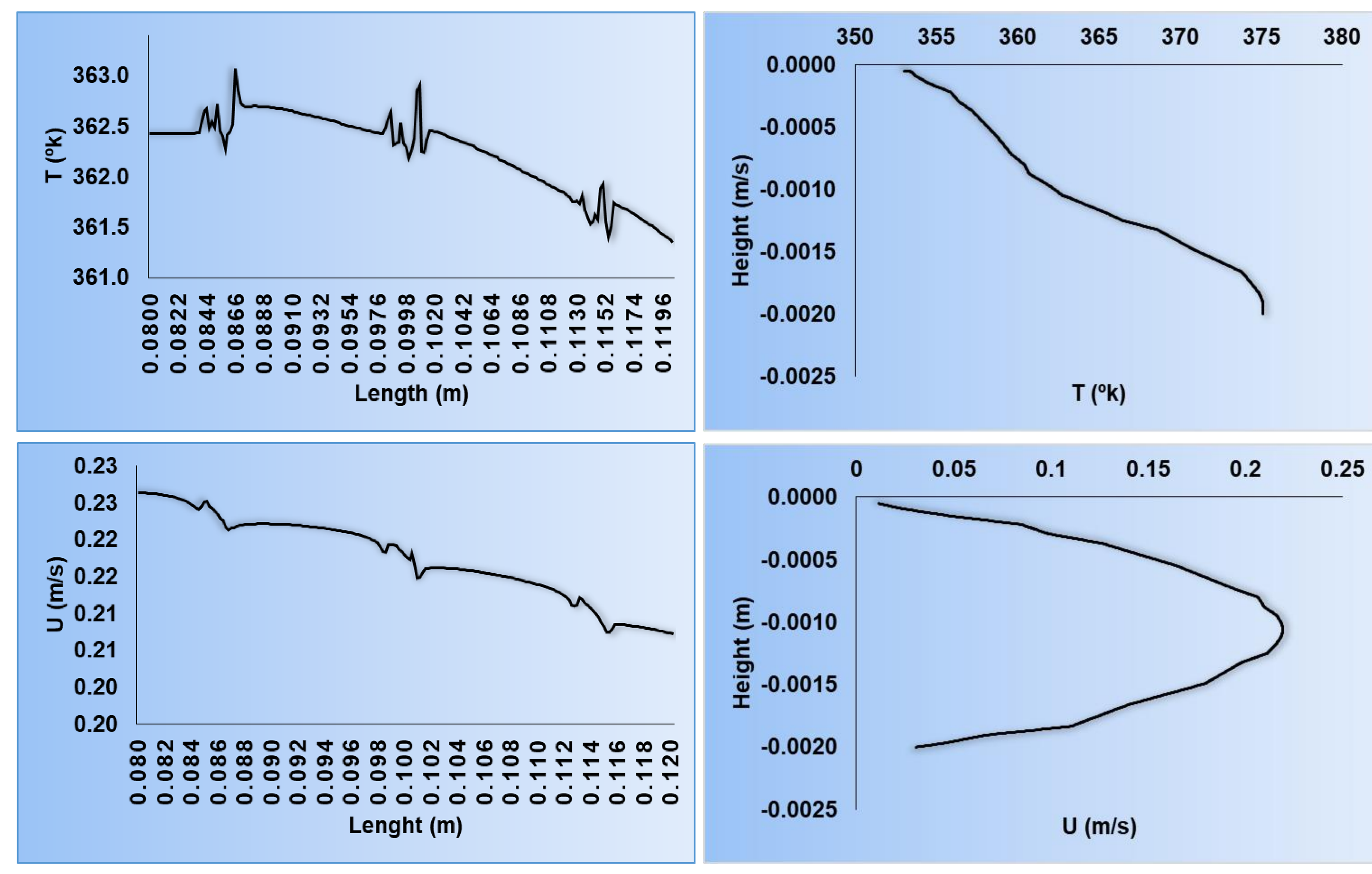

Fig.5. Thermal distribution in feed (top), left (along x direction), right (along z direction), Velocity distribution in feed (bottom), left (along x direction), right (along z direction)

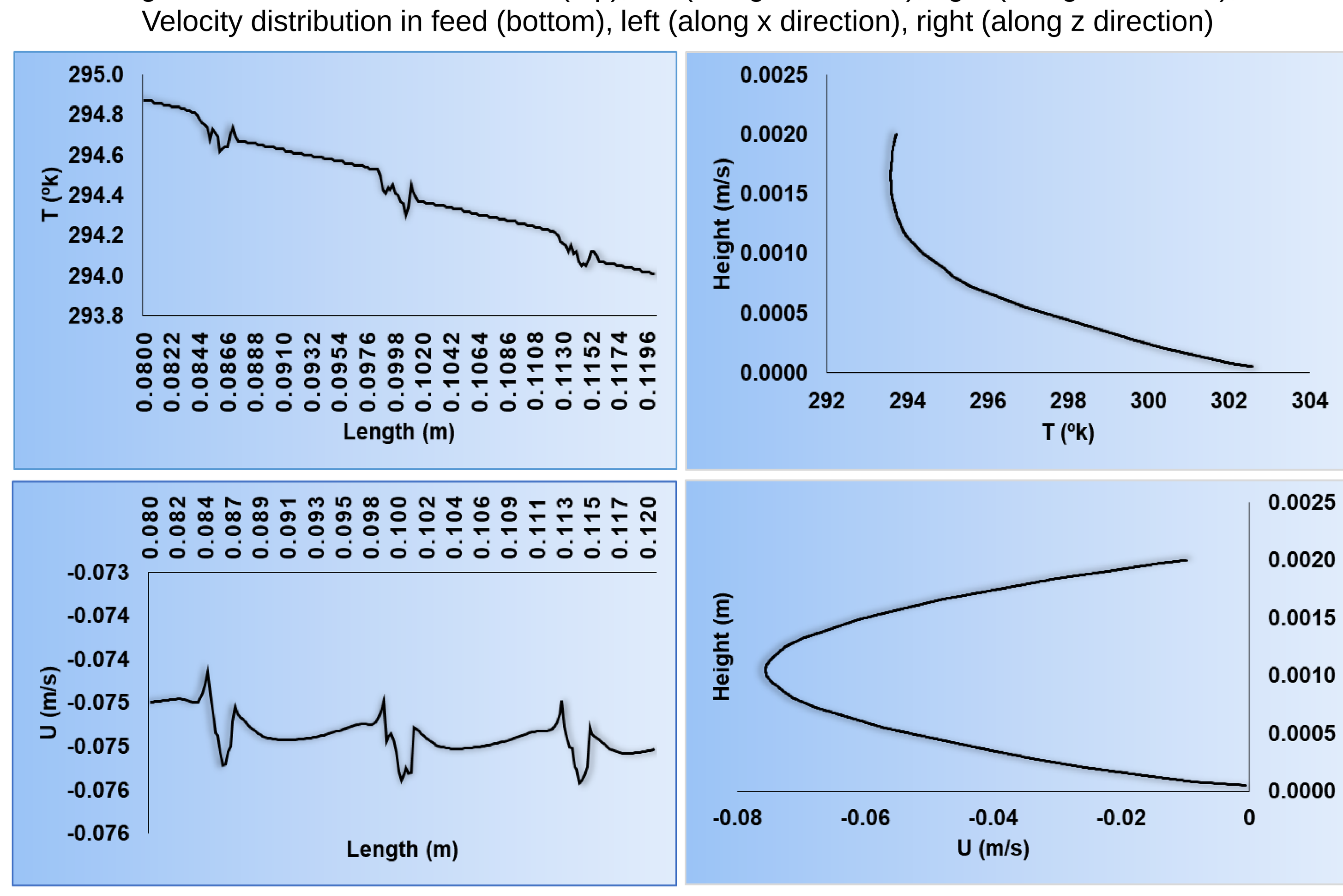

Fig.6. Thermal distribution in permeate (top), left (along x direction), right (along z direction), Velocity distribution in permeate (bottom), left (along x direction), right (along z direction

- As expected, the temperature along the *x* direction for feed channel is gradually decreasing, while increasing for permeate channel.
- In *z* direction the minimum temperature for feed flow is observed near the membrane. However, for permeate the highest temperature is encountered there.
- The velocity distribution along the *x* direction for both feed and permeate channels shows fluctuations due to the presence of filaments in the system.
- In *z* direction for both channels the lowest velocities are logically observed near the surfaces due to the zero gradient boundary condition.

Following Works

- Different configurations/dimensions of the spacers will be designed for CFD analysis, to find the best suited structure optimizing the thermal gradient.
- Preferred configuration of spacers will be 3D printed for laboratory-scale experimental tests.
- The results of the CFD simulation will be compared with the results obtained from the experimental work in order to assess the validity of the developed model.

References 1. Tijing LD, Woo YC, Choi JS, Lee S, Kim SH, Shon HK. *Fouling and its control in membrane distillation—A review*. J Memb Sci. 2015 Feb 1;475:215–44. 2. Shakaib M, Haque ME ul. *Numerical simulations for fluid dynamics and temperature patterns in membrane distillation channels*. Heat and Mass Transfer/Waerme- und Stoffuebertragung. 2019 Dec 1;55(12):3509–22. 3. Shakaib M, Hasani SMF, Ahmed I, Yunus RM. *A CFD study on the effect of spacer orientation on temperature polarization in membrane distillation modules*. Desalination. 2012 Jan 4;284:332–40. 4. ChtMultiRegionFoam - OpenFOAMWiki

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