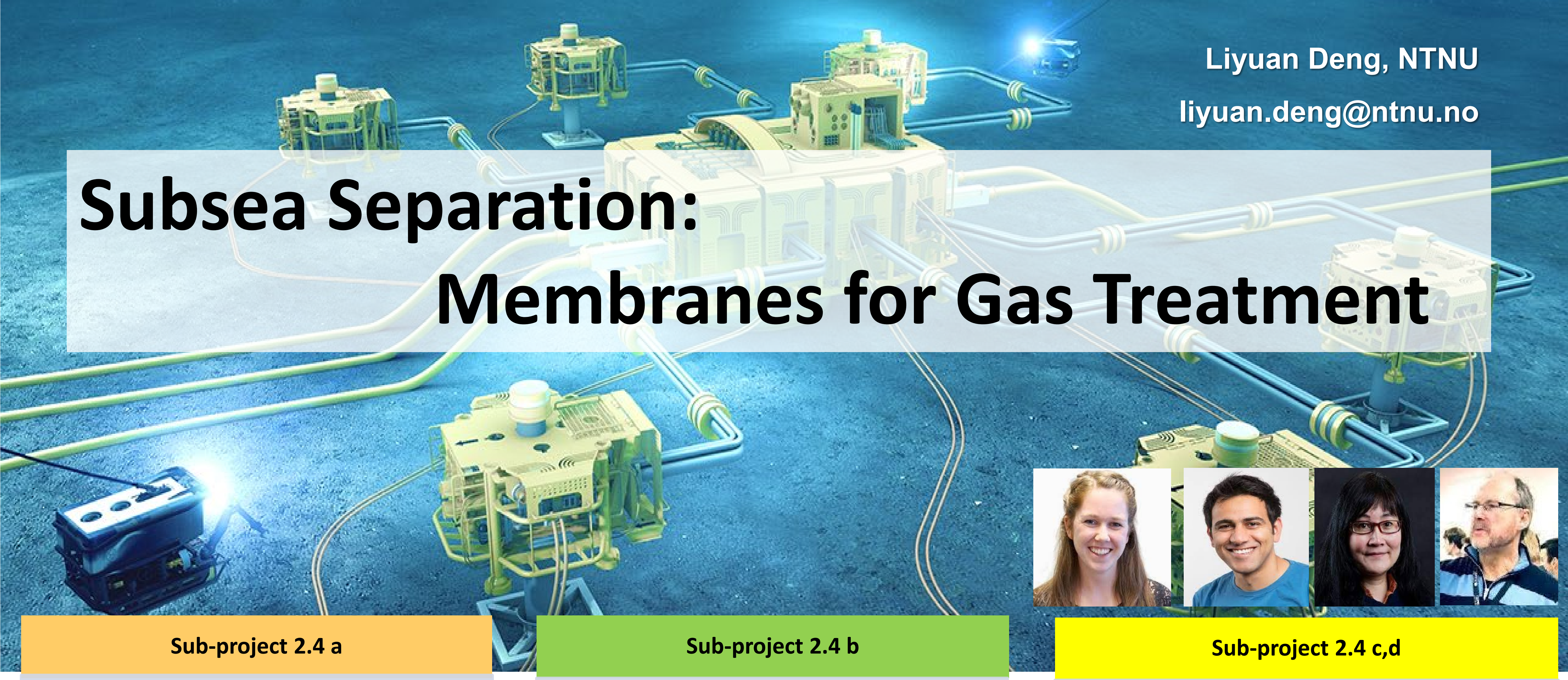

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Subsea Separation: Membranes for Gas Treatment

Sub-project 2.4 a

- Conceptual design of a membrane process for subsea natural gas dehydration by modelling and process simulations.
- Evaluate the feasibility of the process

Sub-project 2.4 b

- Experimental study of the dehydration performance in both MC and TPV steps
- Optimize the modules and testing methods
- Update and validate the models

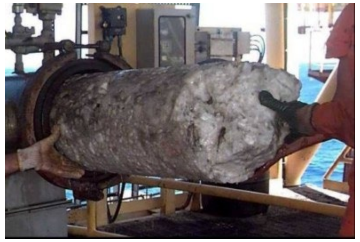
Sub-project 2.4 c,d

- Extend the models for configurations suitable for large scale operation
- Experimental study on durability and stability of the membranes, and concerned issues.

Background

Why subsea dehydration:

- Avoid continuous injection of chemical to prevent hydrate formation subsea
- Enabling tie-in of new fields to existing platforms with limited gas processing capacity



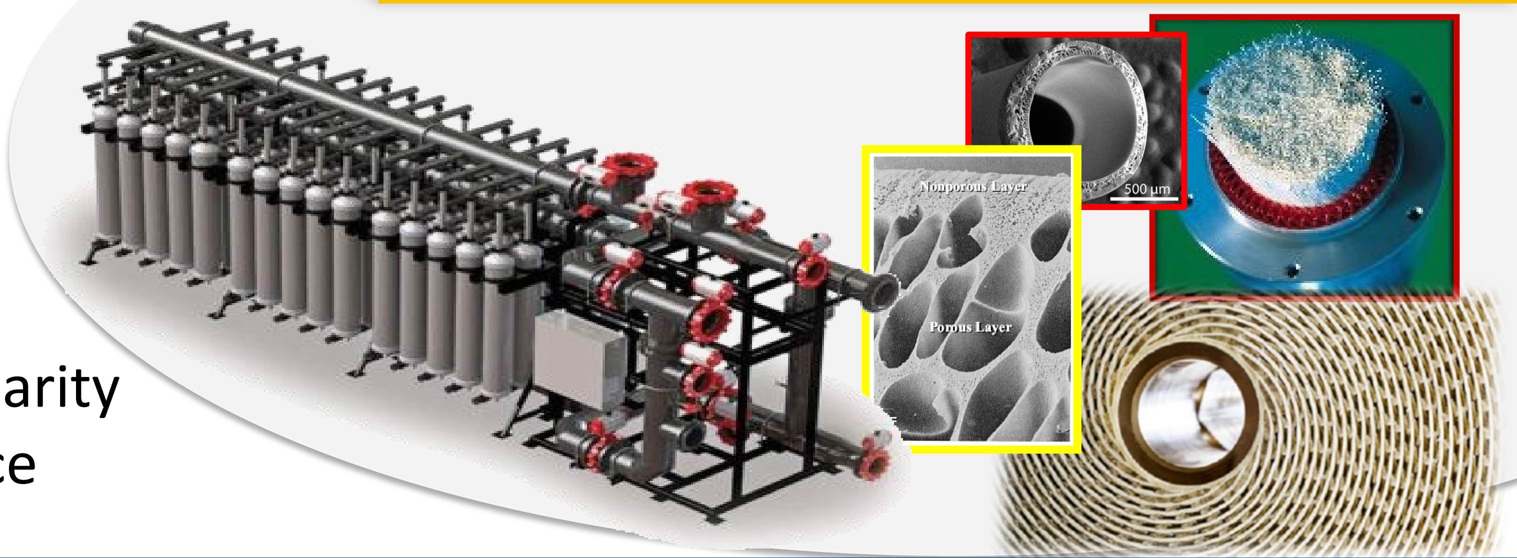
Hydrate formation

Corrosion

Erosion

Challenges

- Membrane life time?
- Material limitations in performances? Mainteance?
- Membrane durability and stability?

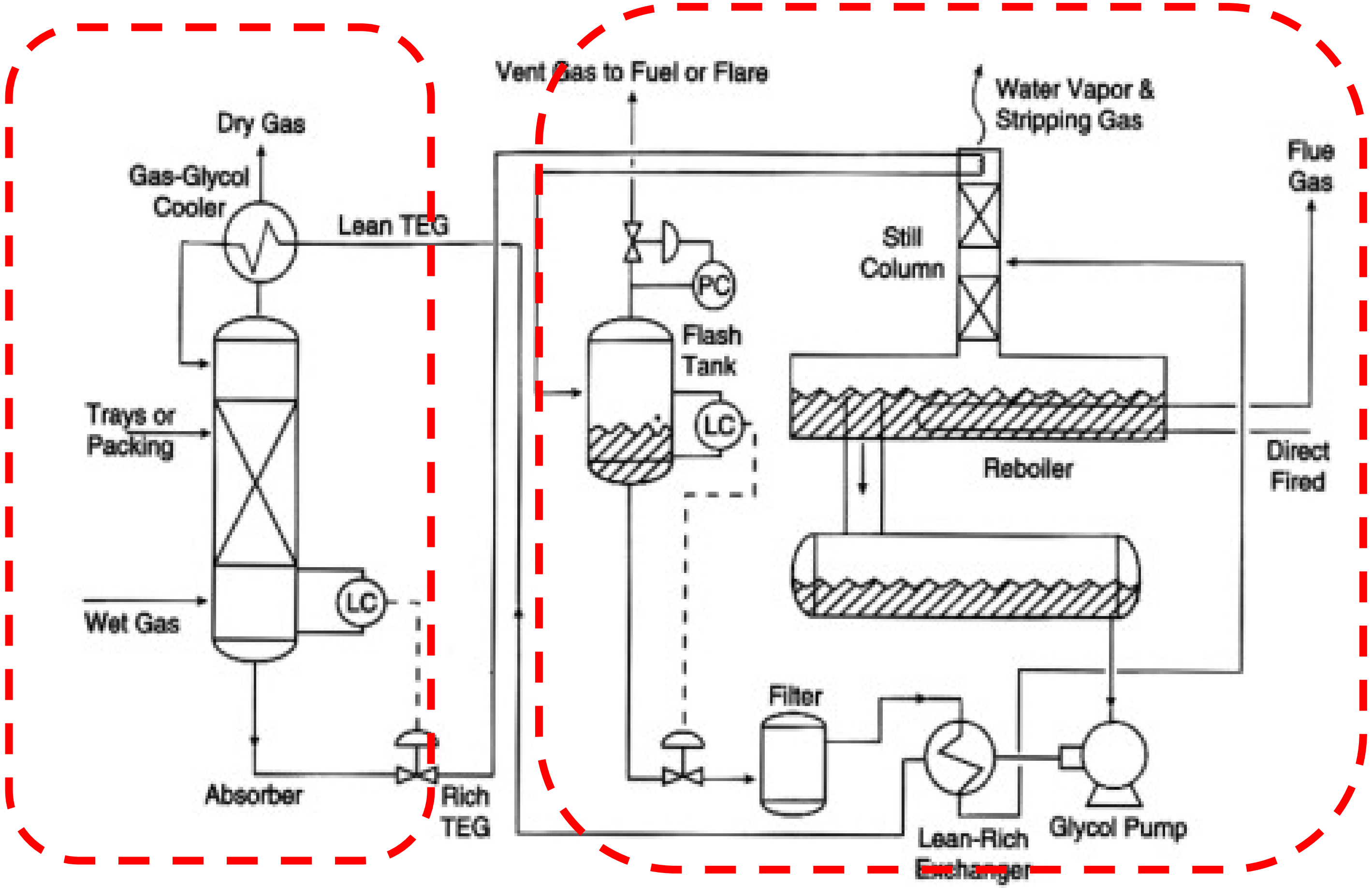


Why using membrane process:

- Small footprint/No moving parts
- Closed loop/Flexible operation
- Module compactness and modularity
- Easy up-scaling/easy maintenance

Conventional natural gas dehydration

vs membrane processes



Membrane Contactor (MC)

Thermopervaporation (TPV)

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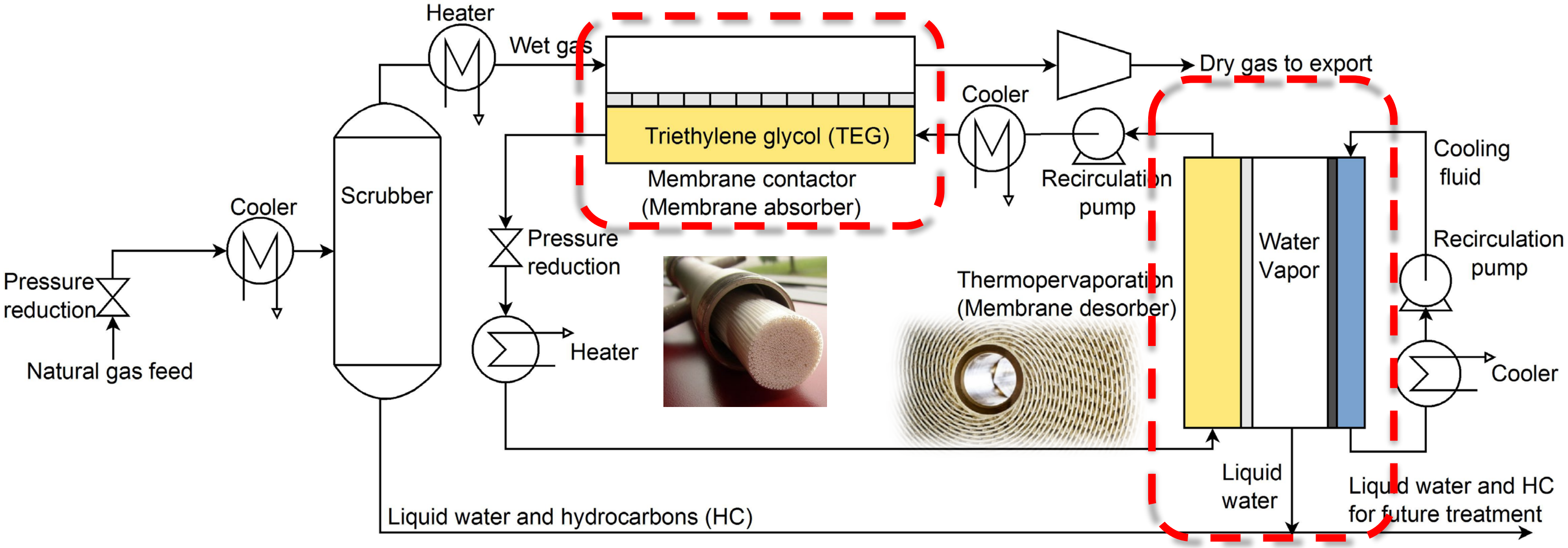
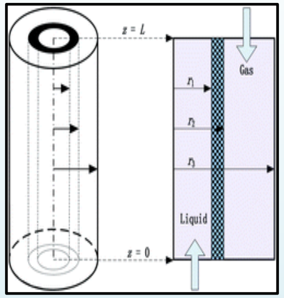
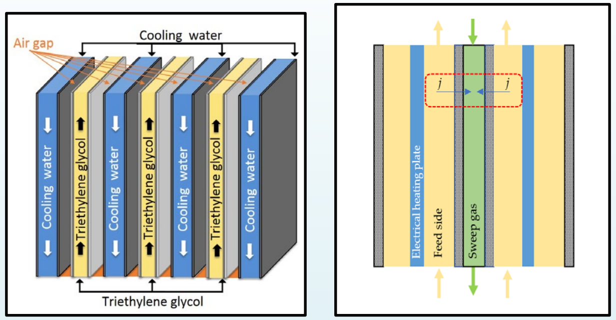
Closed-loop subsea natural gas dehydration system

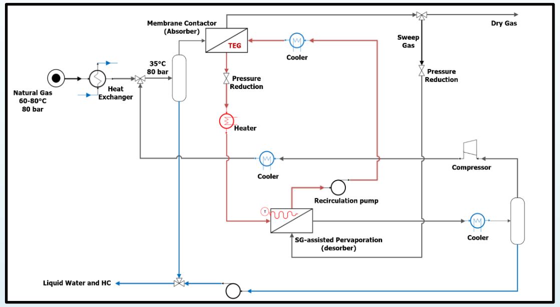




Membrane Contactor

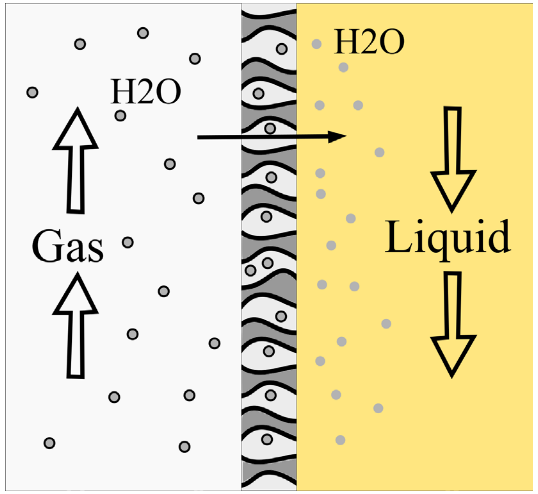


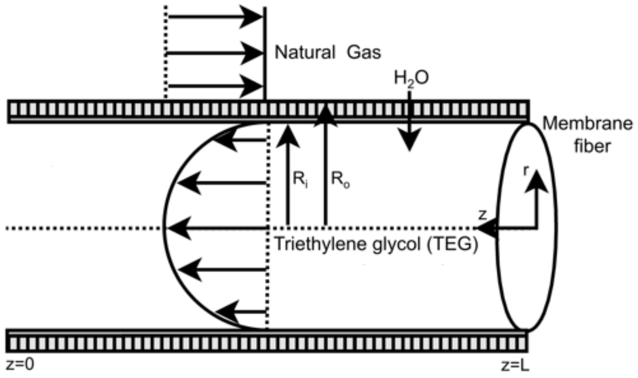
Membrane (Thermo)Pervaporation



Process Design and Optimization

Membrane contactor: modeling





Gas phase (Shell side)

$$\frac{dn^{s}_{g,H_2O}}{dz} = -J_{H_2O}a$$

$$\frac{dT_g}{dz} = -\frac{U_{tot}a}{\sum(c_{p,i}\, n^{s}_{g,i})}\left(T_g - T_{l,mem}\right)$$

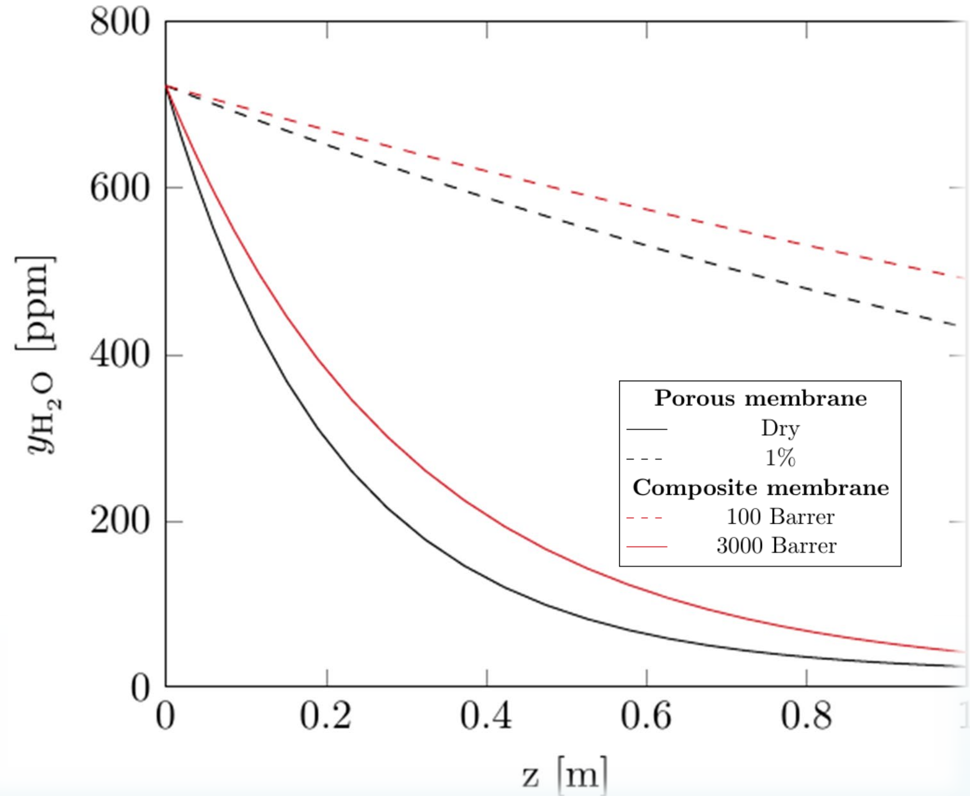
$$\frac{dP_g}{dz} = -f_{D,g}\frac{1}{2}\rho_g v_g^2 \frac{1}{d_h}\frac{1}{1000}$$

Liquid phase (Fiber side)

$$\frac{\partial C_{l,H_2O}}{\partial z} = \frac{-D_{l,H_2O}}{v_z}\left(\frac{1}{r}\frac{\partial C_{l,H_2O}}{\partial r} + \frac{\partial^2 C_{l,H_2O}}{\partial r^2}\right)$$

$$\frac{\partial T_l}{\partial z} = \frac{1}{\rho_l C_{p,l} v_z}\left[\lambda_l\left(\frac{1}{r}\frac{\partial T_l}{\partial r} + \frac{\partial^2 T_l}{\partial r^2}\right) - 1000(-\Delta H_{i,abs})J_{H_2O}a_L\right]$$

$$\frac{dP_l}{dz} = f_{D,l}\frac{1}{2}\rho_l v_{z,av}^2 \frac{1}{d_i}\frac{1}{1000}$$

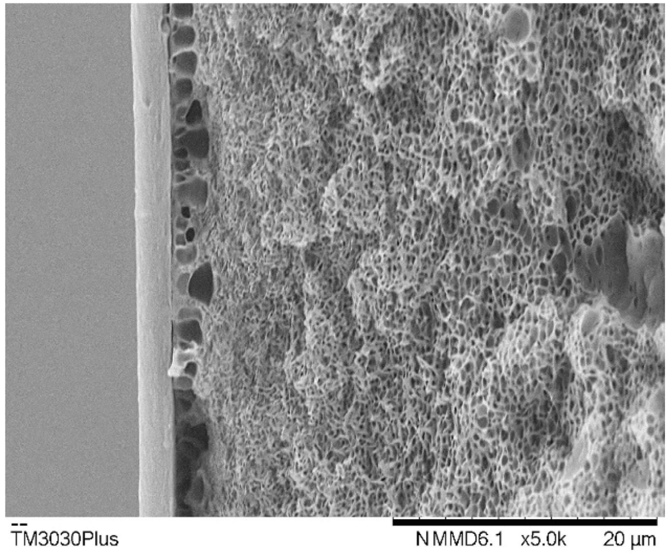


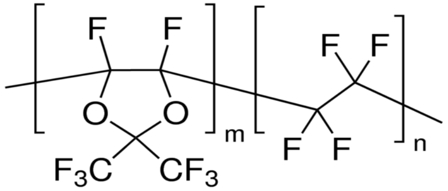
*K. Dalane, et al, J. Nat. Gas Sci. Eng. 39 (2017) 101–117.
*K. Dalane, et al., J. Memb. Sci. 556 (2018) 263–276.

Sub-project 2.4 b

Membrane contactor : experimental

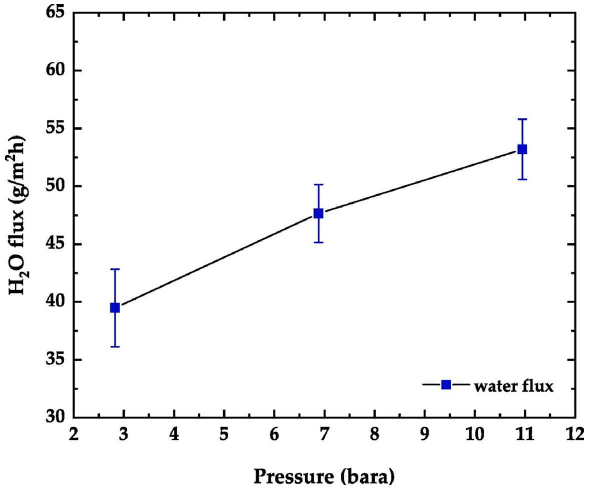
SFI SUBPRO

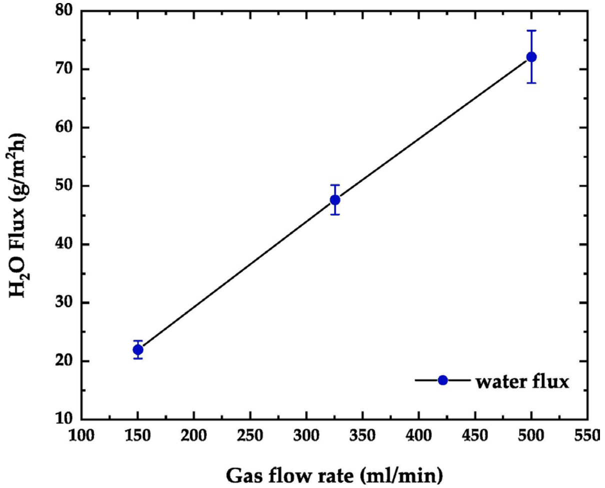


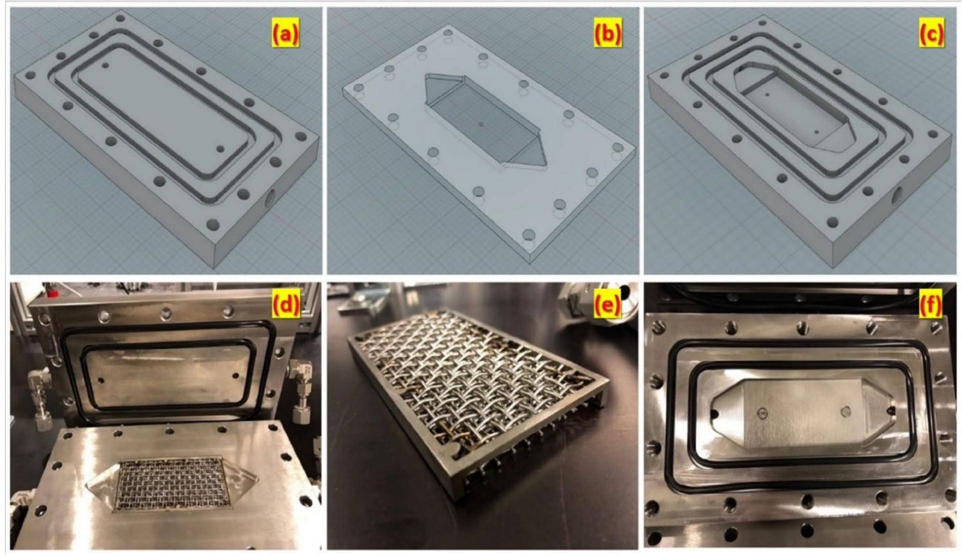


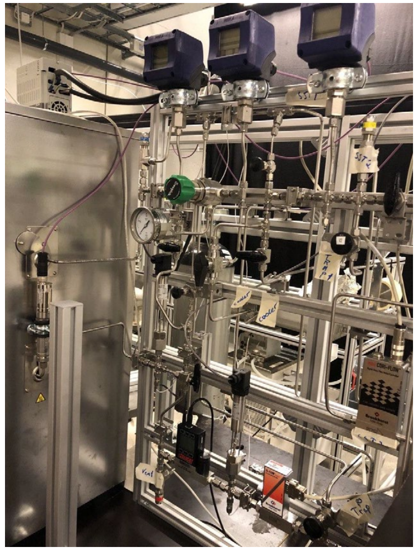
Teflon® AF2400

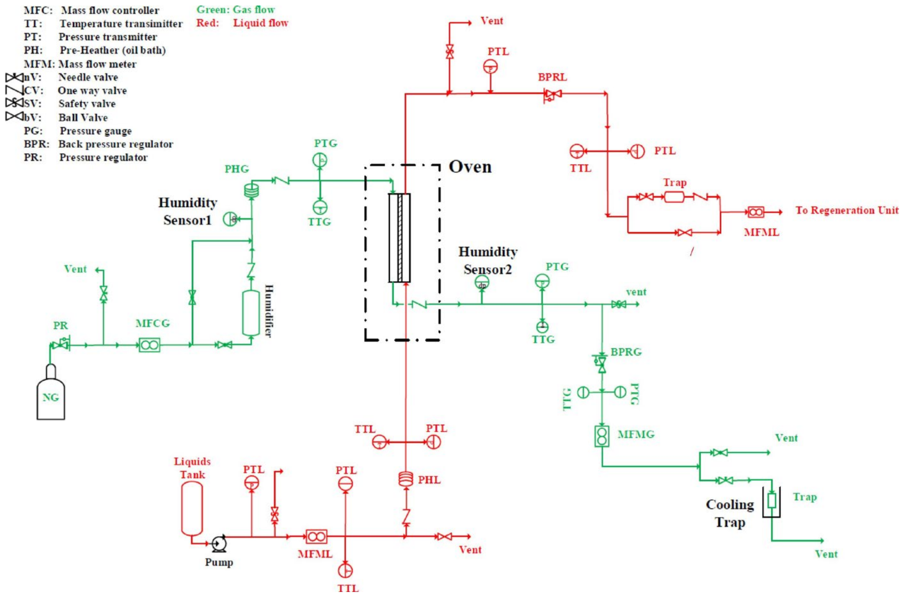
- Hydrophobic
- Glassy Polymer
- High Free Volume
- High thermal/chemical stability











 M. Ahmadi, et al. Chemical Engineering Journal, 404, 126535.

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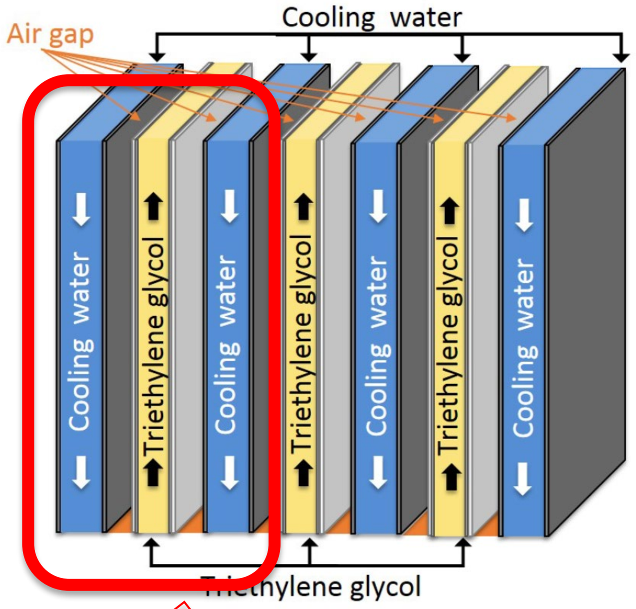
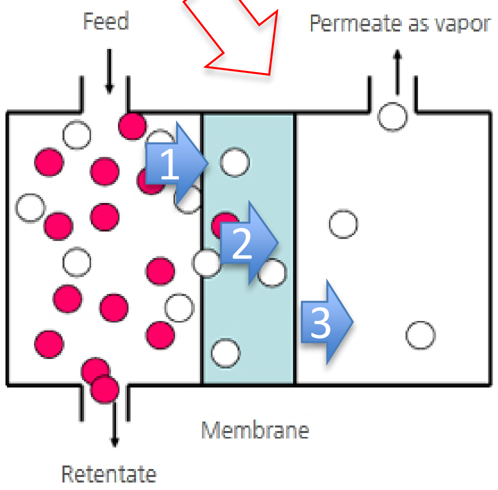
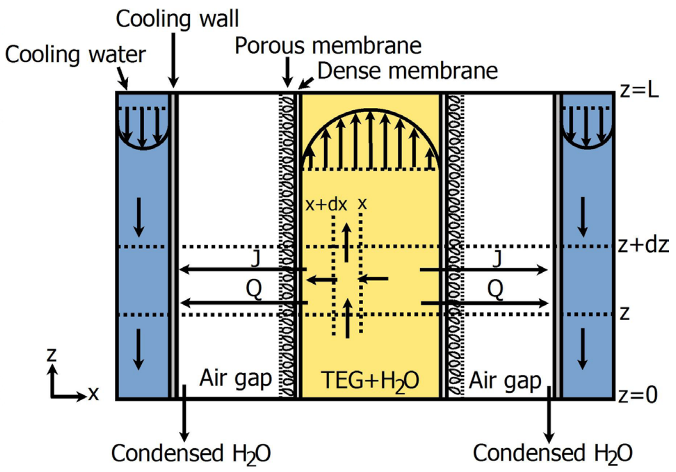
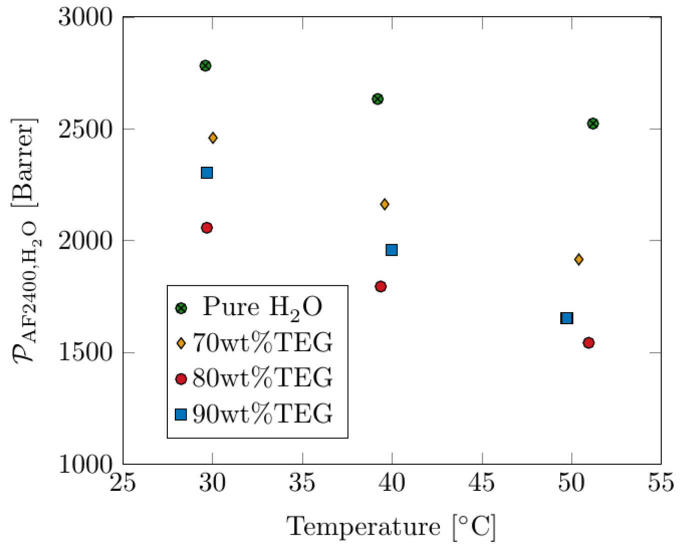
Sub-project 2.4 a

Thermopervaporation Modell

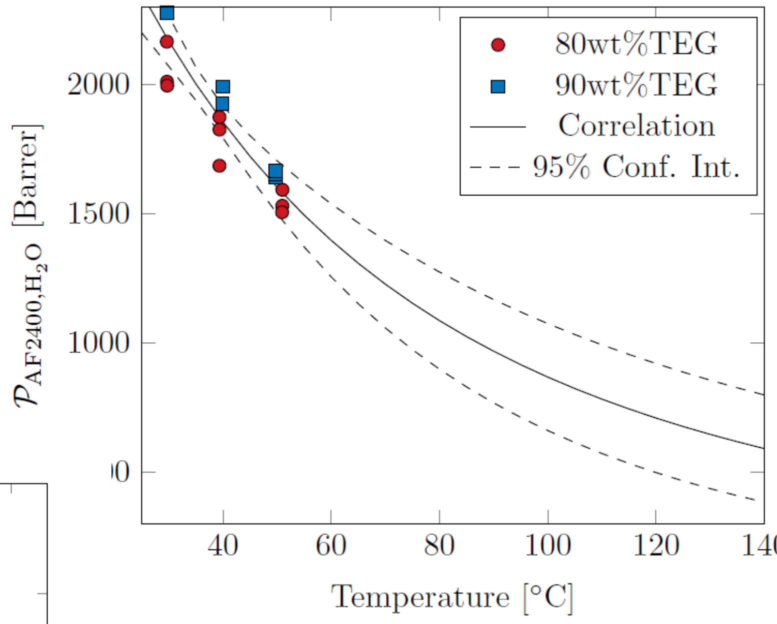


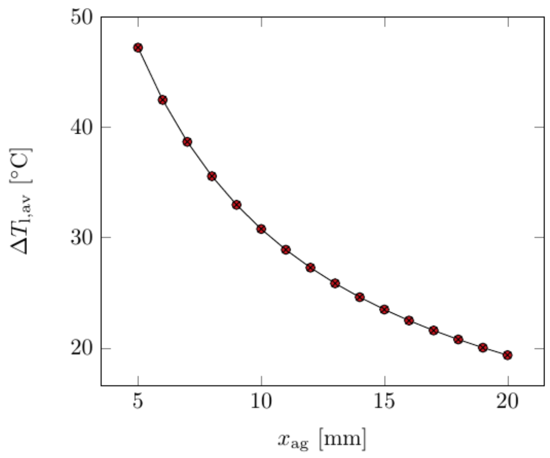






Permeability correlation of Teflon®AF2400





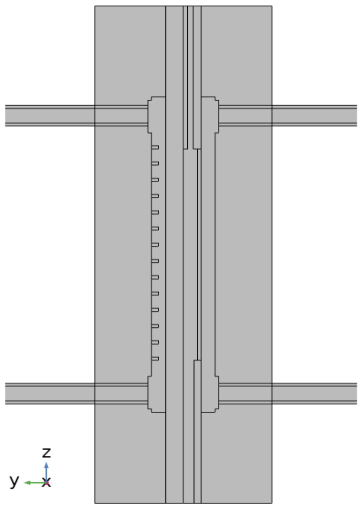
→Airgap

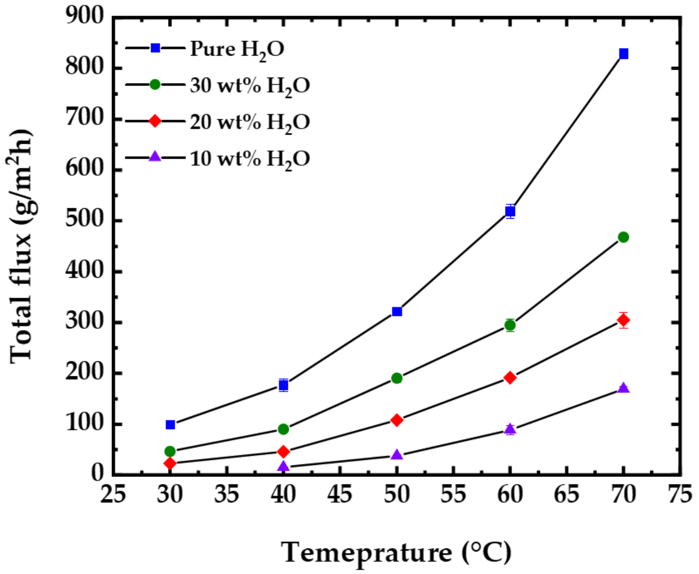
*K. Dalane, et al., J. Memb. Sci. 588 (2019) 117205.

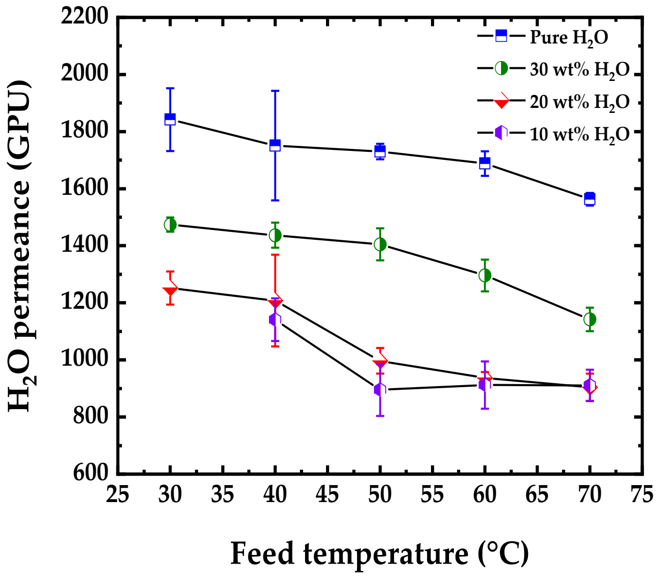
Sub-project 2.4 b

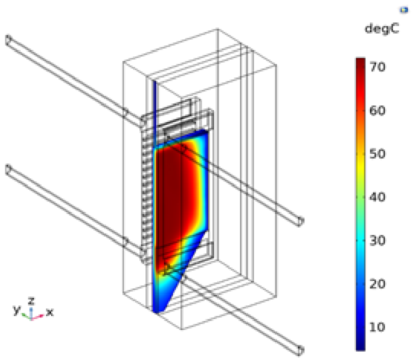
Thermopervaporation: Experimental

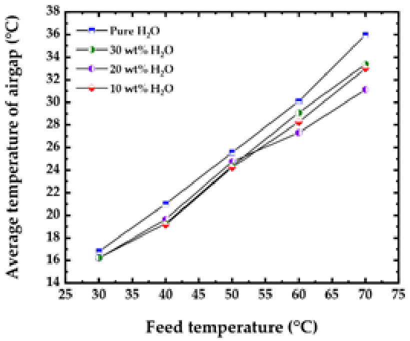
SUBPRO

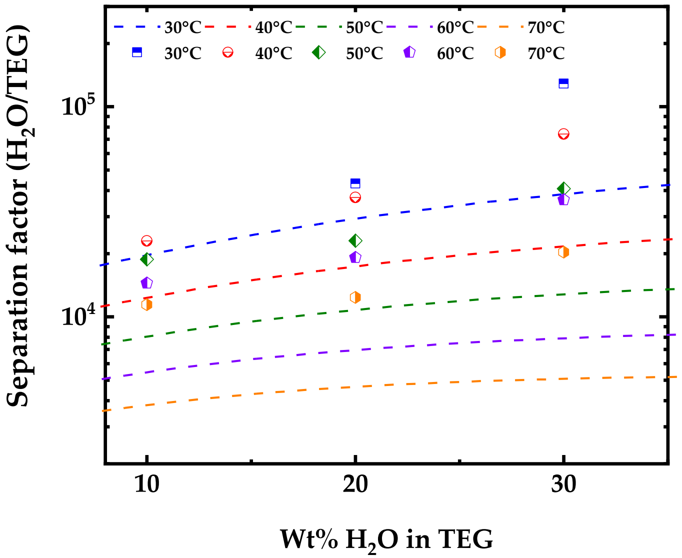












 * M. Ahmadi, et al., Industrial & Engineering Chemistry Research 60 (17), 6262-6276

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Sub-project 2.4 a

System Optimization and Feasibility Evaluation

SUBPRO

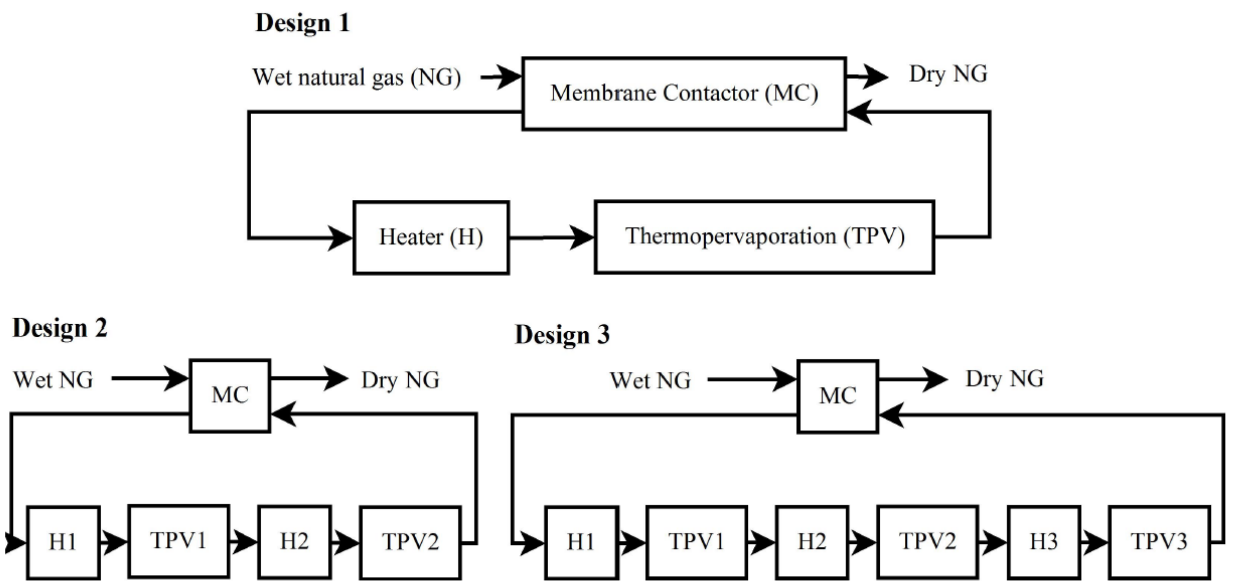
- Membrane contactor feed

Parameter	Values
Temperature [C]	30
Pressure [bar]	80
Flow [Sm^3/d]	24.9
Molar flow [kmol/h]	$4.4x10^4$
H2O content [ppm]	600

- Objective function for minimization

$$f = C_I \cdot ACCR + Q_{el} \cdot C_{el}$$

Optimization variables
TEG flow rate
fibers in membrane contactor
channels in thermopervaporation unit



✓ Membrane contactor and thermopervaporation show a potential for subsea operation.
  - Thermopervaporation is the limiting step

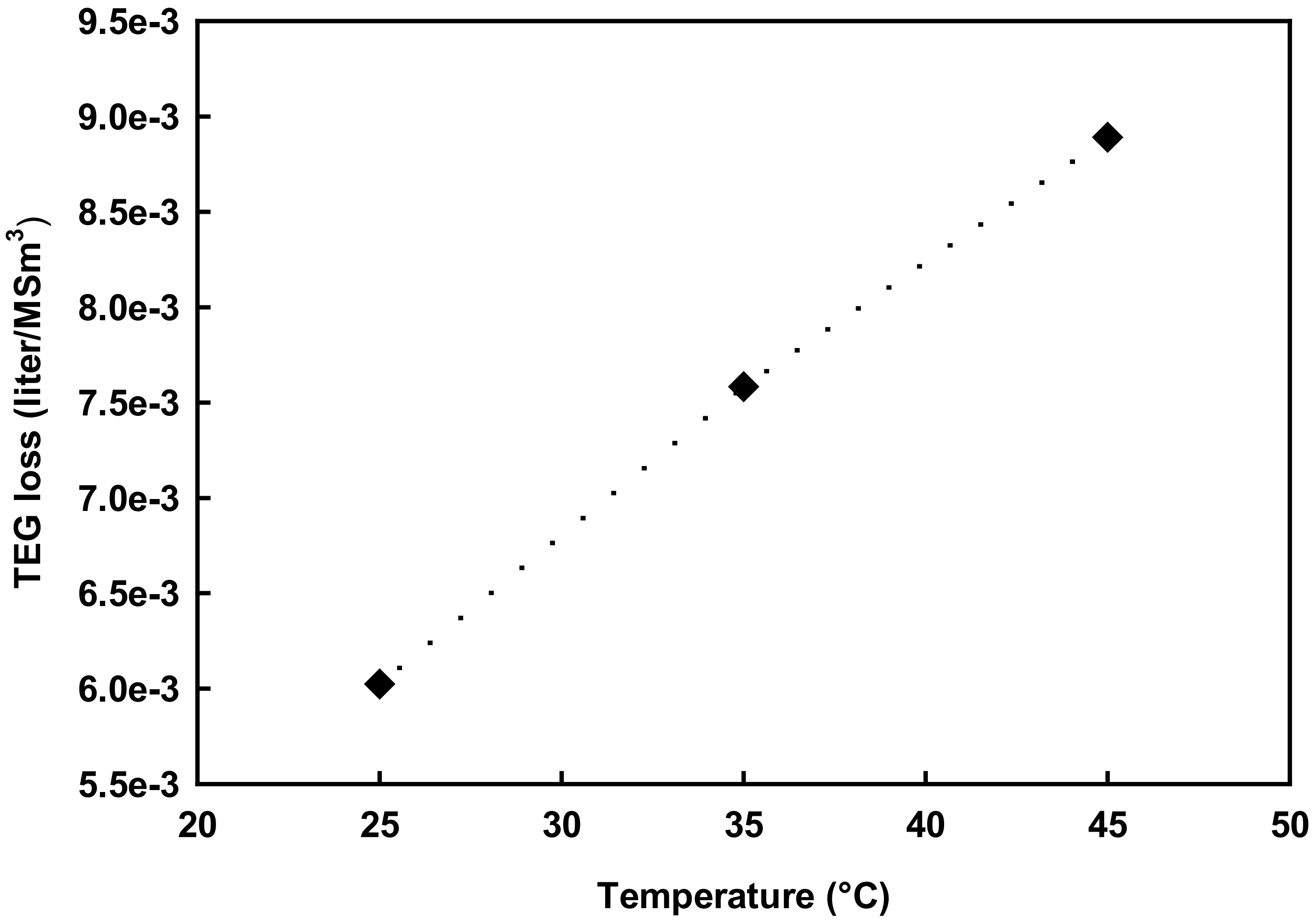
✓ Staging of the regeneration with heating between the thermopervaporation units are preferred.

*K. Dalane, et al., Chem. Eng. Res. Des. 142 (2019) 257–267.

Sub-project 2.4 c

SFI SUBPRO

TEG loss prevention



- Daily average TEG loss in pipeline specifications:

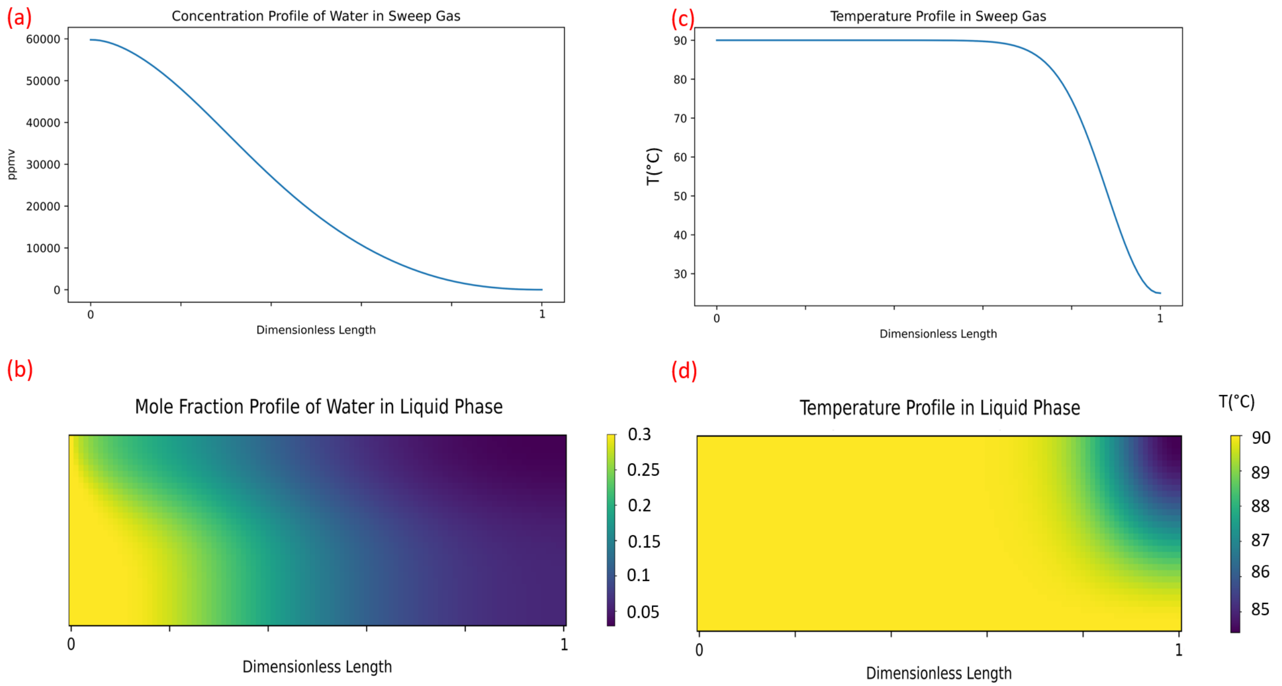
  < 8 liter/MSm^3

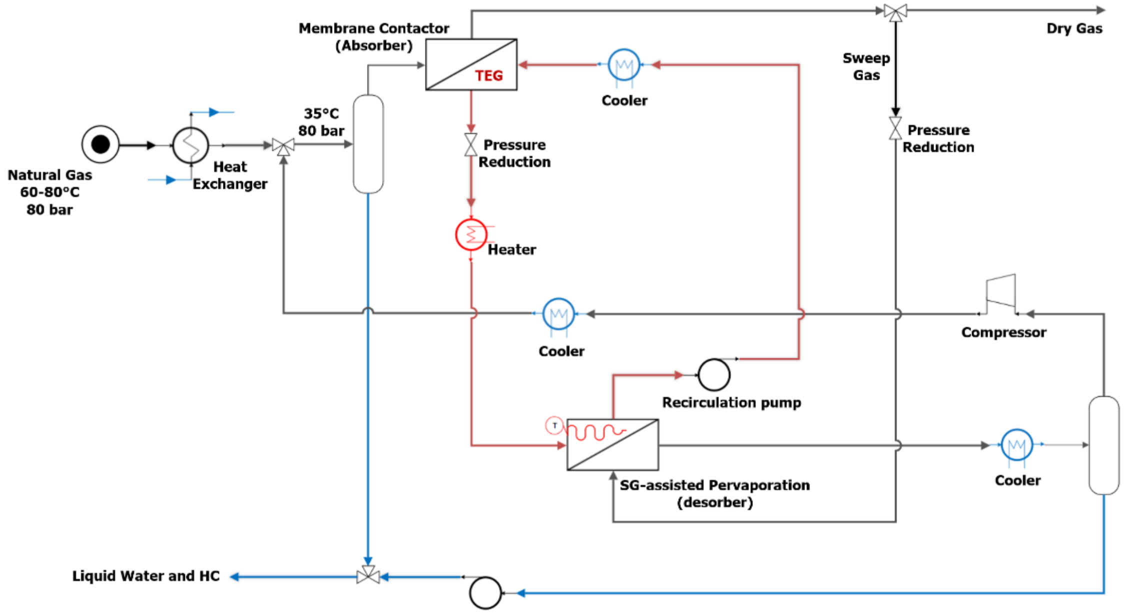
→ Membrane contactor achieved three order of magnitude reduction than the maximum TEG loss allowed according to pipeline specifications

Sub-project 2.4 c

Novel Process Design with Sweep Gas

SUBPRO





New pervaporation unit was designed and modeled, assisted with sweep gas which is supplied either from dry natural gas or exhaust gas from offshore. An electrical heating plate was implemented in the feed side to avoid heat loss. It shows very efficient method to regenerate TEG.

New process was designed and optimized. The process was implemented in Aspen HYSYS and new interface was developed (.NET) to interact with Python to solve the models (contactor and pervaporation units) in Python.

Thank you!