ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Factsheet:

Membrane distillation

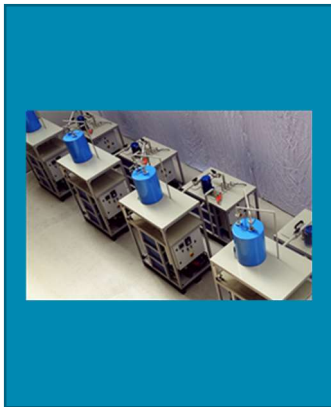**AUTHORS:** A. Naves, L. Sbardella

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VERSION: V1

Membrane distillation

Unique selling points:
- ✓ No need of hydraulic pressure to perform water desalination
- ✓ Modular and compact technology
- ✓ Possibility to treat high TDS brines
- ✓ Less fouling and scaling tendency
- ✓ Working range temperature between 40ºC and 80ºC
- ✓ Low-grade heat sources, such as waste heat or solar/thermal energy
- ✓ Capability to recover volatile compounds

Description of the technology

Membrane distillation (MD) is a novel desalination technology that produces fresh water in a pure vapor state from seawater using porous membranes with hydrophobic surfaces (**Ruiz-Aguirre et al., 2019**).

During the MD process, seawater comes in contact with one side of the membrane, but due to the high hydrophobicity of the membrane surface, the water does not penetrate the pores of the membrane, so only water vapor passes through the membrane. This process results in a highly pure distillate solution and a concentrated feed solution where the non-volatile solutes are retained (**Choi et al., 2016**).

MD process is driven by the temperature difference formed between the feed at high temperature and the distillate. This creates a vapor pressure difference between feed and distillate solutions, which causes evaporation at the feed side of the membrane and condensation at the distillate side.

The MD process can be applied in four different configurations (Fig. 1). These configurations differ from each other in terms of the medium in contact with the membrane at the permeate side (**Alkhudhiri et al., 2012**).

(i)   **Direct Contact MD (DCMD)**

In DMCD the membrane is in direct contact with both liquid phases (feed and permeate). This is the simplest configuration and is capable of producing reasonable high flux despite its high heat lost by conduction. It is best suited for applications such as desalination and the concentration of aqueous solutions.

(ii)   **Air Gap MD (AGMD)**

In AGMD an air gap is interposed between the membrane and the condensation surface. This configuration has the highest energy efficiency due to reduced heat lost by conduction. However, the flux obtained is generally low due to low-temperature differences across the membrane, and therefore, larger surface areas are required. The AGMD configuration can be

widely employed for most MD applications, particularly where energy availability is low or in those cases where volatile compounds need to be removed from aqueous solutions.

(iii)   Sweeping Gas MD (SGMD)

In SGMD a stripping inert gas is used at the permeate side to carry the vapor to condense outside the membrane module. Similarly, to AGMD, this configuration uses a gas barrier to reduce heat loss. However, in this case, the gas is not stationary, which enhances the mass transfer coefficient. In this technique, the vapor diffuses in the stripping gas as it is swept. This results in a need for a large condenser, which represents the main disadvantage of this configuration. Furthermore, an air blower or a compressor are needed to maintain the operation of this configuration, which causes an increase in both CAPEX and OPEX. SGMD configuration is suited for solutions containing volatile compounds.

(iv)   Vacuum MD (VMD)

In VMD the permeate side is vapor or air under vacuum conditions. This configuration makes the heat lost conduction negligible and allows for condensation outside the membrane module. VMD is used to separate volatiles from an aqueous solution.
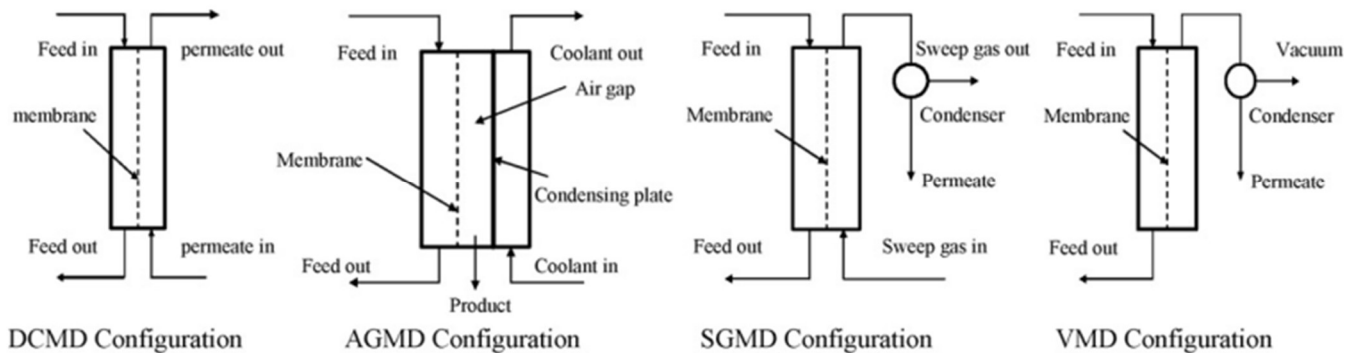

Fig. 1 MD configurations

Flow scheme of the technology

In the framework of the ULTIMATE project, in the Work Package 1, MD is applied to treat the concentrate of the reverse osmosis (RO) process (e.g. the brine), aiming at the achieving minimum liquid discharge (MLD), thus maximizing the water recovery throughout the entire process. In this context, the AGMD configuration has been selected, since it shows the best performance in terms of energy efficiency and capability for latent heat recovery. The flow scheme of the MD pilot plant installation which will be constructed in the Tarragona demonstration site can be represented in Fig. 2.
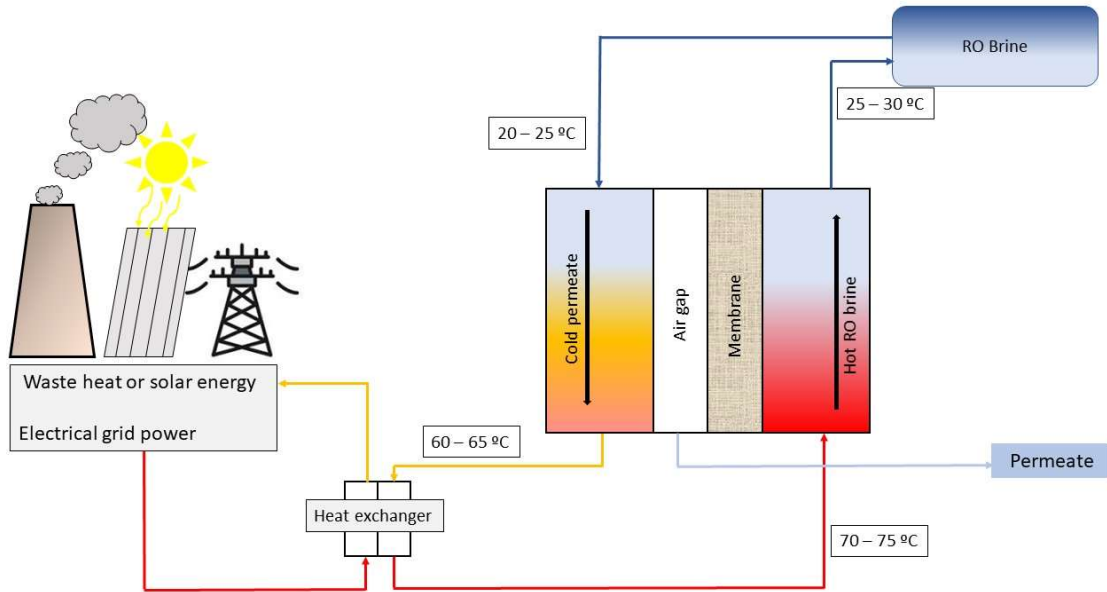
Fig. 2 MD process layout

Pictures of the technology and product

In the following Fig. 3 a CAD drawing of the MD pilot plant installation is shown on the left, while the picture on the right side, represents the lab-scale unit from SolarSpring.
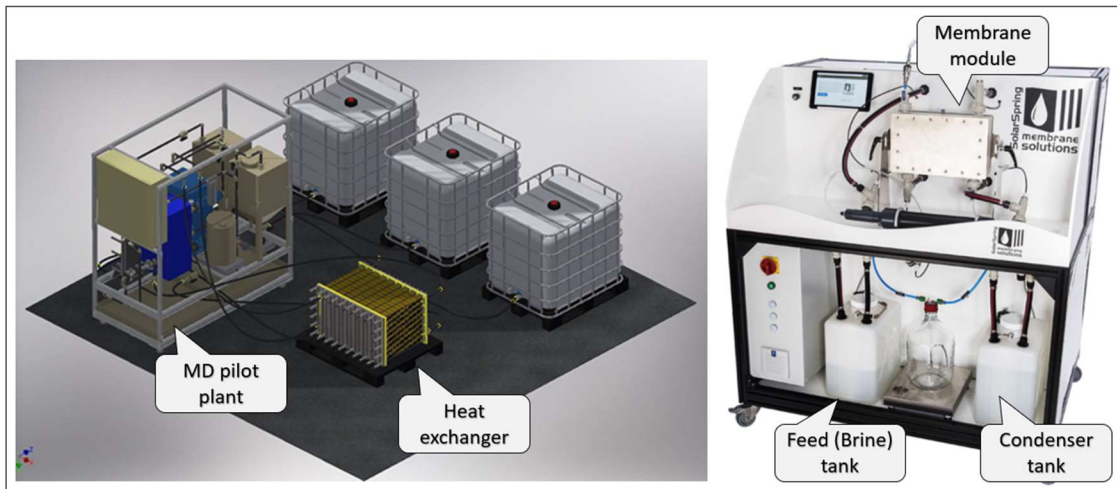

Fig. 3 CAD layout of the MD pilot plant, and picture of the lab-scale unit

Synergetic effects and motivation for the implementation of the technology

✓ *MD incorporates improving aspects compared to conventional thermal-based desalination technologies.*

Due to the possibility to use low-grade thermal energy, MD can use waste heat or renewable energies to operate the system, the risk of corrosion is almost negligible, can be applied in small and decentralized treatment plants, and therefore the operating and capital costs are lower. In addition to that, in the MD process there is no need to cool down the produced

water, since the latent heat of condensation is used to pre-heat the brine to be treated in the same process. Finally, conventional thermal-based technologies can achieve high quality permeate, but low-to-moderate water recovery indexes, while MD technology shows higher water recovery values without losing the high quality of the produced permeate (**Curto et al., 2021**).

✓ *MD incorporates improving aspects compared to conventional membrane-based technologies*

Comparing to other membrane separation processes, applying the MD allows to achieve 100% (theoretical) rejection of inorganic ions, macromolecules, and other non-volatile compounds, thus offering the possibility to produce high quality permeate (10 ppm of TDS). At the same time, MD requires lower operating pressure thank conventional pressure-driven membrane-based technologies. The latter aspect also results in less and more simple requirements on membrane mechanical properties. Due to the inner mechanisms governing the mass transfer during the MD process, it is also insensitive to feed concentration, being indeed able to treat brines up to 300,000 ppm of TDS (**Al-Obaidani et al., 2008**).

Requirements of the technology and operating conditions

The MD technology does not have significant requirements to ensure its correct operation. Since the driving force is the vapor pressure difference between the feed side (salty water or brine) and the permeate side (distillate), the temperature is the main constrain of such process. In the following Tab 1, the operating conditions are summarized.

Tab 1. Membrane distillation operation conditions.

Parameter	Min.	Max.	Reference
Temperature$_{in}$	40ºC	90ºC	**Alkhudhiri et al., 2012**
Temperature$_{out}$	10ºC	25ºC	**Alkhudhiri et al., 2012**
ΔT	30ºC	80ºC	**Alkhudhiri et al., 2012**
Pretreatment	To reduce wetting		**Al-Obaidani et al., 2008**
Flow	Depends on the application		**Al-Obaidani et al., 2008**

Key performance indicators

In the following Tab 2, the most important MD key performance indicators are listed.

Tab 2. MD Key performance indicators.

Indicator	Reference value	Unit	Reference
Flux	$4 - 6$	LMH	**Al-Obaidani et al., 2008**

Indicator	Reference value	Unit	Reference
Thermal efficiency	1 - 7	GOR*	**Zaragoza et al. 2018**
Electrical consumption	10.3 (With waste heat) 43 (Without waste heat)	kWh/m^3	**Curto et al. 2021**
Permeate quality	10	ppm	**Curto et al. 2021**
Water recovery	80	%	**Curto et al. 2021**

* GOR: Gained Output Ratio = kg of distilled water produced per kg of steam consumed.

Links to related topics and similar reference projects

Process/technologies	Reference

References

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Outlook
Case study specific information will be provided, when the results of the other work packages are available:

- **Lessons learned from the case study**

- **Outcome of the assessments**
- **Legal and regulatory information concerning the whole value chain concerning the technology**
- **Business opportunities**