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# Industrialized modules for MED Desalination with polymer surfaces

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**ABSTRACT**

This work presents a novel membrane distillation process developed and produced by memsys in Germany. memsys invented a Membrane Distillation device based on a multi effect desalination process under vacuum which leads to the technical name V-MEMD (vacuum-multi-effect-membrane-distillation). For the V-MEMD process a new type of plate and frame module has been designed, built and tested. An industrial production process for an integrated and highly automated module production has been developed. Serial production of the module is possible since early 2010. This results in the first modular thermal separation process which can be produced highly automated and therefore meets market requirements regarding quality and price.

*Keywords:* Desalination; Distillation; memsys; Thermal separation; Membrane distillation; Multiple effect; Energy recovery; Waste energy use; Polymer surface; Vacuum

## 1. Introduction

Membrane distillation is a unit operation that uses hydrophobic membranes as a barrier for contaminated water from which mass transport of vapor is driven by differences in vapor pressure.

For more than 20 y membrane distillation is matter of research and development containing a lot of hope for an alternative separation process. Several membrane distillation processes have been developed. The common processes of membrane distillation are:

1. Direct contact membrane distillation
2. Air gap membrane distillation
3. Sweeping gas membrane distillation
4. Osmotic membrane distillation
5. Vacuum membrane distillation

These membrane distillation processes are realised with different kind of membranes and different module designs.

Membranes can be flat sheet membranes or hollow fibres. With flat sheet membrane frames plate modules and spiral wound modules can be built. With hollow fibres mostly tube and bundle modules are built. Flat sheet module in a spiral wound module configuration can be a direct contact membrane distillation module or a module in an air gap membrane distillation configuration. The hollow fibre tube and bundle modules are mostly in a direct contact membrane distillation configuration.

Another classification can be done by type of heat recovery. Desalination processes with frame and plate

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modules, spiral wound direct contact membrane distillation-modules and hollow fibre modules can be built with external heat recovery systems [1]. Internal heat recovery can be achieved by spiral wound modules with airgap [2] and frame and plate modules [3]. Currently sweeping gas membrane distillation and vacuum membrane distillation processes [4] are built without heat recovery. The vapour produced is condensed outside the module at both processes.

Working pressure is a third classification for membrane distillation. In contrary to typical thermal desalination processes like multi-stage-flash (MSF) or multi-effect-distillation (MED) most membrane distillation processes work at ambient pressure like direct contact membrane distillation, sweeping gas membrane distillation and air gap membrane distillation. Only vacuum membrane distillation is working at negative pressure by definition.

## 2. Principles of membrane distillation

Membrane distillation can be most easily explained by the direct contact membrane distillation-process. A microporous, hydrophobic membrane separates the solution on one side of the membrane from the product on the other side of the membrane, that is seawater/distillate. The temperature of the solution is higher than the temperature of the distillate side. The temperature difference across the membrane generates a vapour pressure difference across the membrane. Water evaporates on the warm/hot side of the membrane, vapour molecules flow through the membrane pores and condense on the cool side.

### *2.1. Membrane and transport process*

Membrane distillation is a combined heat and mass transport process. Traditional membrane processes like direct contact membrane distillation and air gap membrane distillation work at ambient pressure. Under this conditions non condensable gases stay in the membrane pores and limit vapor flux. The transport of the water molecules through the pores is a diffusion process and can be described with the Knudsen flow model [5].

### *2.2. Membrane*

Typical membrane materials are polypropylene (PP), polyvinyliden fluoride (PVDF) and polytetrafluorethylene (PTFE). Average pore sizes are 0.2–2 µm. Increasing pore size reduces water entrance pressure.

### *2.3. Mass and heat flow*

Standard thermal desalination processes like MSF and MED operate with negative pressure. Non condensable gases are removed by degassing the vacuum system. High amounts of heat can be transported by evaporation and condensation if the systems operates without non condensable gases. If non condensable gases are not removed they accumulate in the system and the heat and mass transport is reduced dramatically. The pure vapour flow changes into a diffusion process.

Membrane distillation processes like the spiral wound module [2] or the plate and frame system [3] operate at ambient pressure so the transport process is a diffusion process. Thermodynamically these processes can be compared with traditional MSF working at ambient pressure. The latent heat of condensation is released and need to be discharged by high solution flow or feed flow. The high flows cause significant pressure loss.

Due to their configuration direct contact membrane distillation and air gap membrane distillation cause essential heat losses by heat conduction. In spiral wound air gap membrane distillation modules with internal heat recovery which has been built and operated on the canary islands by the author in the 1980s heat losses of 20%–40% occurred depending on the operation temperature [6].

## 3. Vacuum membrane distillation

Vacuum membrane distillation [4] is an approach to reduce heat losses and to come to higher vapour flow rates. The configuration used is a hollow fibre module. Conclusion of this work is that permeability, heat transfer coefficients and water fluxes for a NaCl solution are not influenced by hydrodynamic parameters.

### *3.1. Vacuum multi effect membrane distillation*

All processes have been carefully evaluated. memsys came to the conclusion that the V-MEMD has the highest commercial potential due to the following reasons:

1. Lowest specific heat transfer surface for a given production and heat consumption
2. High water flux
3. Low heat loss
4. Internal heat recovery
5. Minimum mechanical stress due to low differential pressure on membrane from feed flow and negative pressure
6. Modular construction

The last point is crucial to compensate the major advantage of RO systems especially for small scale plants.

In the following it will be described how the MED process, which contains superior heat transport, low feed flow and an internal heat recovery in the stages was adapted for the memsys process (V-ME-membrane distillation).

For the first time V-MEMD combines the advantages of membrane distillation and MED. Like MED V-MEMD has defined stages, works at the boiling point and has a low feed flow. The heat is also transported by evaporation and condensation.

Fig. 1 shows the basic principle of the memsys V-MEMD process. In stage 1 steam from evaporator condenses on a PP-foil on pressure level P1 and corresponding temperature T1. This foil and a microporous hydrophobic membrane build a channel for the solution. The solution is heated by condensation energy from stage 1 and evaporates under corresponding negative pressure P2. This process can be replicated in further stages at always reduced pressure and temperature. In the last stage the steam is finally condensed in a condenser which is the cold side of the system. The vacuum system is not shown in Fig. 1.

A memsys module contains multiple parallel surfaces for condensation and evaporation in one stage. In Fig. 2 the flows of liquids and vapor are illustrated schematically in a single stage.

Vapour at a pressure P1 and temperature T1 enters the stage and flows into several channels whose are

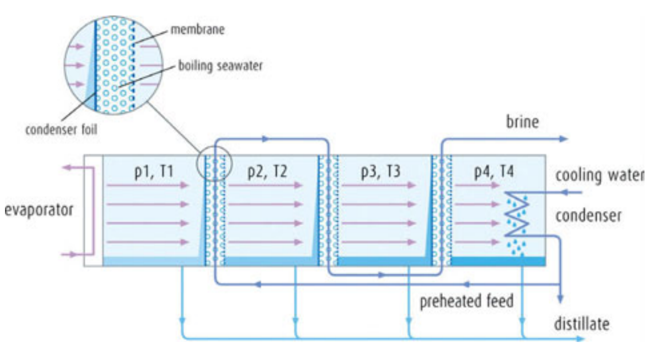


Fig. 1. Basic principles of memsys V-ME-membrane distillation.

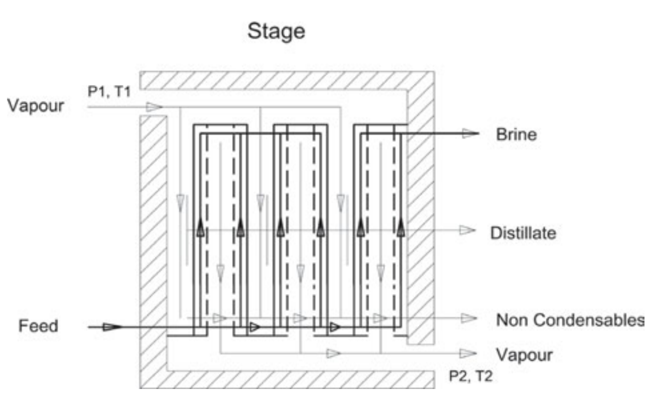


Fig. 2. Mass and vapour flows in separate stage.

arranged in parallel. These channels are limited on both sides with foils for condensation and are in a dead end configuration. The dead end contains a small channel for removing of non-condensable gases and to apply the vacuum. The vapour condenses and flows into a distillate channel.

The heat of condensation is transported through the foil and is immediately changed into evaporation energy which generates steam in the feed channel. The feed channel is limited by one condensing foil and a membrane. The feed channel is on pressure level P2 and at temperature level T2 which are lower than T1 and P1. The vapour leaves the membrane channels and is collected in a main vapour channel. The vapour leaves the stage via this channel and enters the next stage.

### *3.2. Memsys test rig*

Several test rigs have been installed in our laboratories to evaluate the perfomance of our modules for various operations and liquids. The modules contain impermeable membranes for condensation and permeable membranes for distillation. Following test rig has been built with standard memsys modules comprising a steam rising stage, two distillation stages and a condenser (Fig. 3).

All stages are produced on industrial scale from injection moulded PP-frames. The frame production is highly integrated and all membranes are welded on frames in one production step. Production capacity is currently at a level of 50 $m^3$ $day^{-1}$ modules equivalent and can be easily extended. The frames are welded together to build stages and modules. When welding the frames together necessary channels are formed and supported by PP-spacer.

Stages are separated by PP-plates which change direction of feed and vapour. Intermediate plates and cover plates are welded to frames by using one unique welding process resulting in a vacuum tight set up.

The distillate is transported via siphons from stage to stage transporting the pressure levels down to the condenser. On every rising side of a siphon distillate expands by boiling from the higher pressure to the lower pressure. This vapour also enters the foil channels and condenses.

A typical memsys module has the dimensions: 330 mm × 700 mm × 480 mm. The setup contains surfaces of membranes of 3.5 $m^2$ each for condensation and distillation. The distillation membrane is made of PTFE with a pore size of 0.2 µm, the condensation membrane is made of PP with a thickness of 40 µm. The dimension of all membranes are 335 mm × 475 mm. The feed channel has a thickness of 1–1.5 mm which can be adjusted during the welding process.

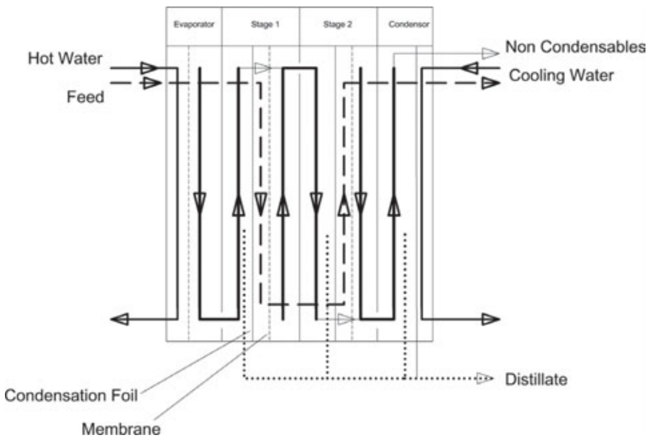


Fig. 3. Flow of liquids and vapour in a two-stage sample setup.

Results can be provided for this report under following conditions:

| | |
|---|---|
| Feed flow | 50–70 l $h^{-1}$ |
| Vapor pressure evaporator | 312–124 mbar |
| Corresponding head temperatures | 70°C–50°C |
| Condenser pressure | 40–80 mbar |
| Evaporator entrance temperatures | 80°C–55°C |
| Condenser entrance temperature | 19°C–26°C |
| Brine outlet temperature | 30°C–45°C |

Vapour produced in the evaporator enters stage 1 and condenses. New vapour is produced in the adjacent feed channel, leaves stage 1. Driven by pressure difference this vapour enters stage 2. Here the process of stage 1 is repeated and the vapour leaving stage 2 enters the final condenser. The distillate produced in each stage is accumulated and flows via siphons to the condensor where it is finally supplied to ambient pressure. This represents a heat recovery of a gained output ratio (GOR) of 2. The GOR describes how much thermal energy is used by a desalination system. Due to the modular design almost unlimited scalability and various thermodynamic setups can be produced.

## 4. Results

The sample set up confirms theoretical expectations. The distillate flow is measured in total from two stages. The distillate flow is 23.8 l $h^{-1}$ up to 33.5 l $h^{-1}$ this means an specific flow from 6.8 to 9.5 l $m^{-2}$ $h^{-1}$ at above mentioned temperature levels. Higher temperatures lead to higher fluxes.

Tests with high concentration of NaCl in the feed (60 g $l^{-1}$) showed no significant influence in mass and heat transfer.

## 5. Conclusions

The performance of the test rig confirmed the expected mass and heat transfer. Due to the industrial scale production of the memsys modules a very high and replicable quality can be assured. Production method and raw materials used for the memsys modules enable good competitiveness to existing technologies. At the time of writing further field demonstration units are under construction and envisaged for intensive tests under different working conditions and in connection with different heat sources as waste heat or solar heat.

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