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Membrane Distillation (MD) is an established technology which has been proven to produce an extremely high quality product. Until recently it was limited to laboratories and small scale systems. Over 10 years ago a consortium of European governmental agencies, universities and corporations set out to further develop this technology as a low cost replacement to RO in treating seawater. Full-scale test were performed in Asia and Europe at numerous locations. After the initial goals of the system were achieved, additional development was undertaken to determine the full capabilities of the technology. It was found that the High Performance MD systems required only a fraction of the pretreatment required by RO, were very easily maintained, could easily operate at TDS levels in excess of 140,000, and could achieve a higher level of separation as compared to RO. One of the markets for this product is for its use in conjunction with existing RO systems to further recover product water. It was also found that it was not limited to salt water and could work with a large variety of liquids. HDMD systems utilize heat instead of pressure to bring about the separation process. If waste or solar heat is available, its operating cost is significantly lower than any other technology.

HDMD technology in conjunction with several thermal process steps can achieve Zero Liquid Discharge that is simpler and more cost effective as compared to other technologies.

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HIGH PERFORMANCE MEMBRANE DISTILLATION (HPMD) MOVES FROM THE PILOT TO PRODUCTION

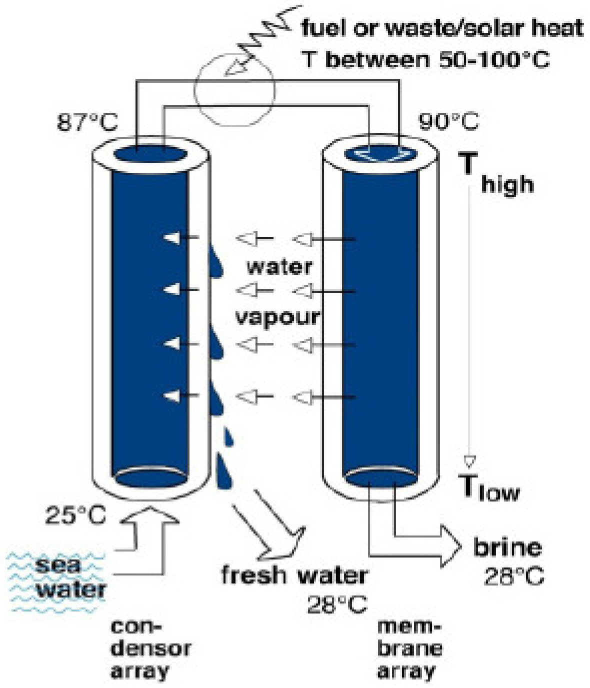
There are many different technologies which are promoted as a result of laboratory or pilot testing. A large percentage of these technologies never make it into commercial production due to the difficulties in scaling up the laboratory test into an economically commercial product. Membrane Distillation (MD) is a technology that has been known and used for many years in laboratories and very small systems but has never been commercially produced for large applications. After over 10 years of research and development WWSE, incorporating High Performance Membrane Distillation, is starting full production runs.

Membrane Distillation is a separation method which uses a porous, non-wetting (hydrophobic) membrane with a circulating heated liquid feed on one side and circulating cooler permeate liquid on the other side. MD simultaneously utilizes both membrane separation and evaporation. The relative operating pressure for the process is only that pressure which is required to overcome the head pressure and frictional losses. Typically this is less than 5 psig. Note that this is not the pressure which drives the separation. The driving force is the vapor pressure across the pores in the membrane caused by the temperature difference between the feed liquid and the distilled permeate. The temperature difference is approximately 5- 20° C and can be modified for different fluids. MD has the theoretical capability of achieving 100% salt rejection in a desalination application. The chart below shows the distillation capabilities which were achieved at one of the pilot sites.

		Feed	Distillate
• Na	(mg/l)	7500	0.19
• Cl	(mg/l)	13400	0.32
• SO4	(mg/l)	1890	< 0.02
• Ca	(mg/l)	300	0.48
• Mg	(mg/l)	910	0.15
• HCO3	(mg/l)	150	7.5

MD has been mentioned for many years as the technology which has the potential of replacing technologies such as Reverse Osmosis (RO) and Multistage-Flash (MSF) for desalination. The limiting factors to the acceptance of MD has been the low water flux, unknown long term performance of the membrane materials, higher heat energy requirements, and difficulties in commercially assembling large quantities of hydrophobic materials.

The Dutch Consortium was established over 10 years ago with the purpose of refining and improving the existing MD technology to the point where it could became a commercially viable product. The Dutch Consortium consisted of 9 European governmental, commercial and educational parties whose goal was to develop a lower cost alternative to RO and the other available technologies. They initially targeted desalination of seawater. Their initial goals were to increase membrane flux, reduce the heat requirement, make the system scalable for ease of expansion, minimize pretreatment and cleaning, and finally make the operating cost competitive with other technologies. As noted previously the initial systems targeted seawater desalination. The specific seawater applications chosen focused on only partial recovery of fresh water so that the concentration level of the reject was not much higher than the source seawater. They also cooled the reject water to minimize any environmental impact in its direct return to the sea. The Dutch system originally utilized the air-gap method of membrane distillation. Dutch changed from air-gap to direct contact membrane distillation in 2002.



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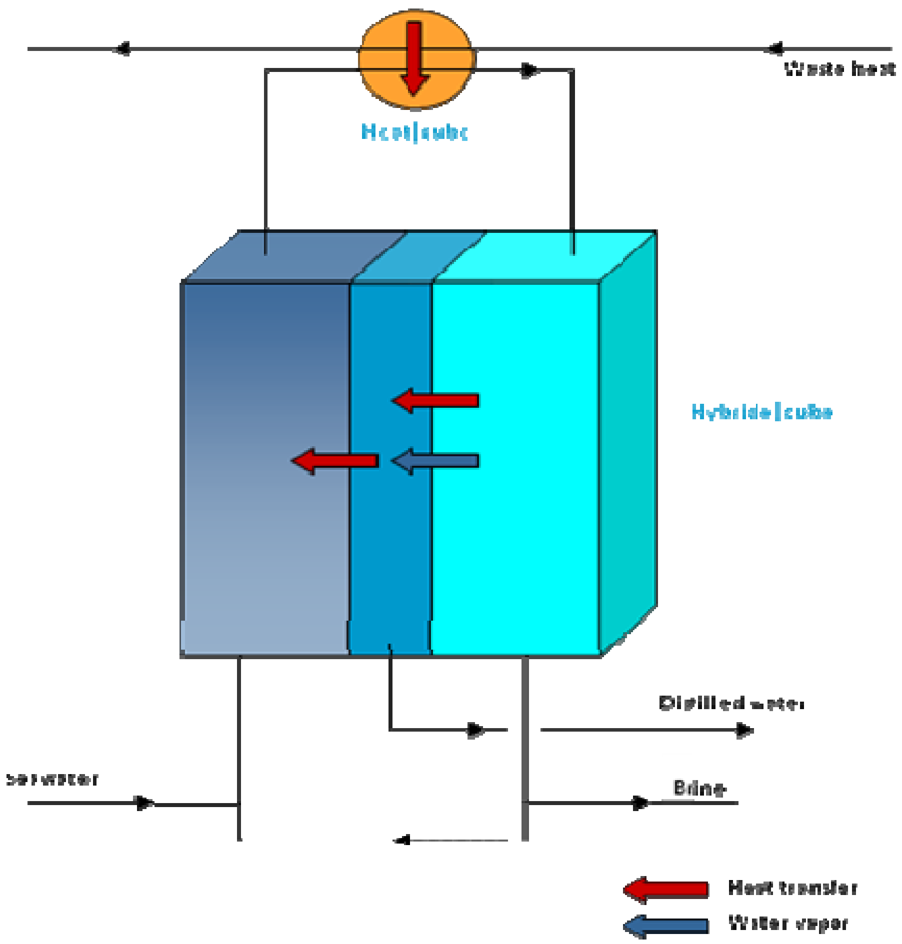
The next goal of the consortium was to establish several pilot plants to prove the capabilities of the Dutch process. Multiple pilot sites in Singapore and Europe were constructed and the operational goals were achieved. Patents for this new technology are held by the Dutch governmental agency TNO.

One of the university test performed studied the ability of the Dutch process to handle higher concentrations. This test showed that large concentration increases, although slightly reducing the flux rate, could easily be handled. It was noted that concentration levels of approximately 130,000 TDS could be achieved on the feed water side while the distilled product water quality was maintained. It was also found that the flux rate, although decreased, was still acceptable for commercial application. It is felt that even high levels of concentration are possible.

Dutch changed from air-gap to direct contact membrane distillation



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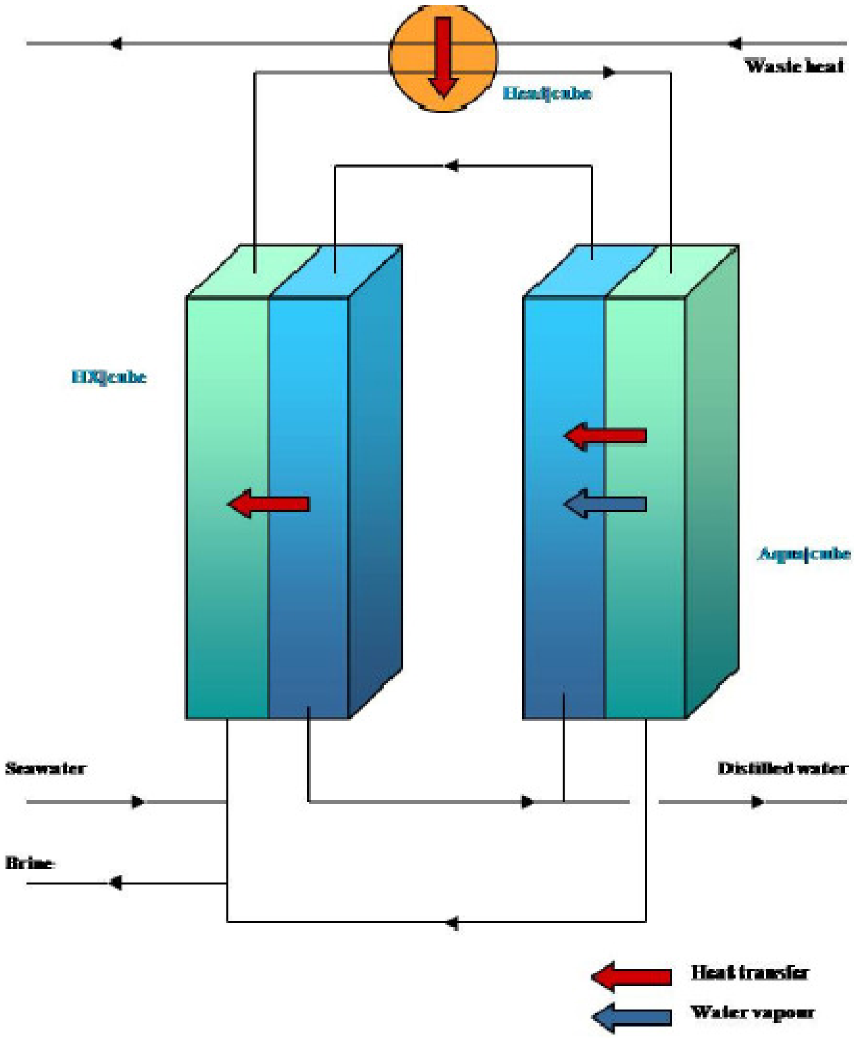
HIGH PERFORMANCE MEMBRANE DISTILLATION (HPMD)

As a member of the Dutch Consortium, Hamers Engineering a sister company of Water Technologies Holland both owned by the AKA-invest holding, received the license to manufacture the Dutch technology. Hamers Engineering. Noted previously, the goal of the group was to develop a product which could inexpensively produce drinking water from seawater and return the reject to the sea. WWSE felt that this approach did not fully tap the full potential of MD. New goals were established by WWSE to expand the technology. Higher concentrations, higher temperatures, higher flux, and lower operating energy define High Performance Membrane Distillation (HPMD). In order to achieve these goals it was necessary to make several fundamental changes in the process design. Below is a flow diagram which shows WWSE as a multi-cube system with a continuous flow path. Two flow paths are established. The feed water flows in the outer loop and is heated to the required temperature through direct and indirect methods. A key element to WWSE is the ability to recover a much higher percentage of the initial heat and keep it within the process. Once the operating temperature is achieved after startup, the total amount of energy needed to keep the system in operation can be greatly reduced. The unique heat transfer cubes were designed specifically by WWSE for this process. Another principal difference between MD and HPMD is the elimination of flow path dead zones inside of the membrane cubes. The WWSE cubes utilize a proprietary design which increases the total flow capability of each cube and also provides for more efficient cleaning.



WWSE- High Performance Membrane Distillation (HPMD)
AquaCube = Provides for Direct Contact Membrane Distillation
HX/Cube = High Efficiency Heat Exchanger to recapture internal system heat.
Heat/Cube = High Efficiency Heat Exchanger for external heat source.

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Minimized Pretreatment

The cost of the pretreatment equipment associated with Reverse Osmosis (RO) along with the high maintenance required for this equipment, can in some systems exceed the cost of the RO system. The HPMD WWSE system was designed to utilize minimum pretreatment. HPMD has several major advantages in this area. First, in HPMD the unobstructed circulation inside the AquaCube, HX/Cube and the Heat/Cube is created by very low pressure pumps. This only creates flow across the face off the membrane and is not the force which moves fresh water through the membrane. The second is that all internal materials are hydrophobic and highly corrosion resistant. The feed liquid and the vast majority of the suspended and dissolved components are highly resistant to any attachment to the membrane surface. Testing has shown that the pretreatment system for the WWSE HPMD system was only a fraction of that required for RO systems. Below is a picture of a membrane which was contaminated and still operational.


Higher Concentration Capability Minimizes Total Reject Flow

The original goal of Dutch was to separate freshwater from seawater. As noted previously, the initial systems sought to recover only a small amount of the freshwater which would minimize the level of concentration in the reject stream. Although this was suitable for locations adjacent to seawater where they could return the reject water, there exist many locations where reject disposal is difficult. The HPMD design sought to move from minimum concentration to maximum concentration. Testing showed that the WWSE system was capable of continuous operation at concentration levels approaching 130,000 TDS. There is a reduction in flux as the concentration levels increase but this reduction is small. The test goals were not to determine the maximum limit of concentration but to test at various concentration levels. Future test are planned to determine the actual upper concentration limit for commercial operation. Initial production of WWSE systems for nominal seawater applications (approx 35,000 TDS) are expected to recover 75-80% freshwater. This compares very favorably to the best RO systems which are capable of capturing only about 40-50% at this concentration level. One of the target markets of WWSE is to further concentrate the reject stream from existing RO systems.

Variability of the Feed Concentration

One of the very distinct limitations of RO is its reduced ability in handling variances in concentration of the feed water stream. Different membranes and pressure requirements are required for different levels of feed concentration. There are limits of acceptable concentration variation with each of the selected membranes. Typically these variations are in the range of 5-10% from a selected value. The WWSE does not have this limitation. The same membrane is used for all concentration levels. There will be a slight decrease in flux for the higher concentrations. During operation of the system, changes in feed concentration can be easily handled by the control system. The primary reason for this difference between RO and WWSE is the mode of operation. RO systems rely on high pressure to force water molecules through the membrane pores. As concentration levels increase, the pressure to operate the RO system increases. WWSE only relies on the temperature difference between the feed and the permeate flows and is not forcing water molecules under pressure.

Flux- Flow through the Membrane

All membrane systems are affected by temperature and the concentration level of the feed source. WWSE is designed to operate at a temperature of approximately 90° C for the feed source and 70° C for the cooled distillate. WWSE is capable of operating at higher and lower temperatures with a resulting change in the flux.

Maintenance and Operation

One of the initial goals for the Dutch product was to provide low cost drinking water from seawater for small communities. This goal also required the process to be easy to operate and maintain. Being a very low pressure system made this achievable. The system is designed to operate continuously without the need for chemicals. After a period of time, typically 2 to 3 months, if there is a noticeable decrease in flow through the membrane, it may be necessary to perform in-place cleaning. The internal surfaces of the AquaCube are hydrophobic and chemical resistant. If any fouling occurs it is typically biological. In-place cleaning can be accomplished through a temporary slight increase in the temperature of the feed water loop (added heat to the Heat/Module) to a level which kills any biology. A second method is to add a mild chlorine solution while the system remains in operation. Since the WWSE system has its own internal circulation loop and can use the existing pumps, no additional equipment is needed. In cases of sand or other debris entering the cubes, the system can be back-flushed using clean water while the cubes remain in place. Test have shown that after the membranes were intentionally 100% fouled with salt crystals, they were returned to full service by a simple back-flush with clean water in less than 30 minutes. The flow path of the feed stream is reversible and self contained. The Cubes can be all flushed at the same time or individually. Complete cleaning operation typically can be accomplished in a few hours.

Capital Cost

The simplicity of design and operation of the WWSE HPMD system also results in lower capital cost. Minimal pretreatment, low pressure components, the ability to use plastic piping, minimal controls, and modular design, all contribute to reduce capital cost as compare to RO and other desalination technologies. Cost comparisons of identical systems between RO and WWSE show a 20-40% advantage to WWSE. As production of the modules increase there will be further cost reductions.

Heat Energy Requirement

One of the initial negative features of membrane distillation was its need for energy to heat the feed water. Although pumping cost are very low since this a low pressure system, the cost of heating could be considerable. A

great deal of emphasis was placed on the use of waste heat and solar heating. Any method of low cost heating will greatly improve the operational cost for membrane distillation. WWSE has taken the recovery and reuse of heat to a higher level. The HX Cube and the Heat Cube were specifically designed to operate with WWSE. Special heat transfer materials and an innovative flow structure maximize the recovery of heat within the process. With the WWSE HPMD system, once the operating temperature is achieved, the primary heat requirement is greatly reduced.

Modular Design

The WWSE HPMD system is a modular design. Three cubes (AquaCube, HX/Cube, Heat Cube) make up one Cube set. If the incoming water is already at the needed temperature, the Heat Cube can be downsized or eliminated. Cube sets are connected in parallel. The number of sets and their arrangements are specific to the flow requirement and the amount of redundancy required. The space requirements are equal to or smaller than an RO system.

Zero Liquid Discharge (ZLD)

One of the disadvantages of being able to recover very high amounts of fresh water is the issue of disposal of the high concentrate reject water. The AquaTration process by AquaTec Inc. is a three step process which includes the WWSE HPMD. WWSE first separates about 75-80% of the fresh water leaving a reject with a concentrate of over 100,000 mg/l. The AquaTrate Process further separates fresh water and concentrates to over 300,000 mg/l. The WaterVap process makes the final separation leaving only dry salt. Optimized for use with WWSE, this process has significantly lower cost and energy usage as compared to other technologies.

Summary

Membrane distillation has been an established technology for over 30 years. The Dutch Consortium was tasked with taking the technology and making it commercially viable and lower cost as compared to RO and other existing technologies. WWSE, as part of the Consortium, used the lessons learned and moved the technology to the next level, High Performance Membrane Distillation (HPMD). The primary difference between MD and HPMD is the ability to handle much higher concentrations, higher levels of product water separation, operates at higher temperatures, and reduces the operating energy requirements.

Parameter	Reverse Osmosis (RO)	Membrane Distillation (MD)	High Performance Membrane Distillation (HPMD)
Operating Temperature (C)	15-40	40-90	30-100
Operating Pressure (MPa)	2-8	Atmospheric	Atmospheric
Pretreatment Required	Extensive	Low	Low
Feed Water Salinity Range	Low to 50,000 mg/l	Low to 50,000 mg/l	Low to over 100,000 mg/l
Product Water Quality (ppm)	100-500	1-40	1-40
Ability to handle variances in feed water Concentration	Limited	Excellent	Excellent
Product Water Recovery Ratio (%)	25-50	3-10	Up to 80+
Scaling/Fouling and Corrosion Potential	Low –Moderate	Low	Low
Spare Parts Replacement Rate	High (high pressure pumps, membrane, instruments and controls	Low Membranes	Low Membranes
High Technology Components	High pressure pumps, piping, controls	Membranes	Membranes
Maintenance Requirement	High	Low	Low
Operator Skill Requirements	Medium	Low	Low

Foto installatie:

Advantages summary:

- *Low consumption of heat and electricity*
- *Simple, fast modular construction*
- *Small footprint*
- *Minimal site work*
- *Low investment and total costs*
- *Very high product water quality*
- *Limited corrosion and fouling*
- *No additives*
- *Ecologically justified brine disposal*