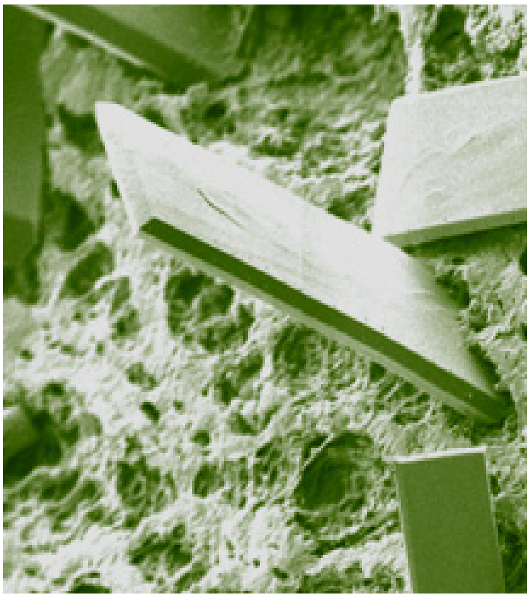

International Workshop on Membrane Distillation and Related Technologies

October 9 - 12, 2011

Auditorium Oscar Niemeyer
Ravello (SA) - Italy

Proceedings

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Dept. of Chemical Engineering and Materials
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Edited by E. Drioli, G. Di Profio, M.A. Liberti

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Membrane distillation: solar and waste heat driven demonstration plants for desalination

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Introduction

The world's arid and semi-arid zones are already faced with massive water scarcity, which is prospected to increase in the upcoming decades. Therefore the demand for desalination technologies is increasing rapidly. The development of medium size, autonomous and robust desalination units is needed to establish an independent water supply in remote areas. This is the motivation for research on alternative desalination processes. Membrane distillation (MD) seems to meet the specific requirements very well. The robust membrane allows it to follow alternating operation conditions given by e.g. solar energy. The Fraunhofer Institute for Solar Energy Systems (ISE) has been working on the development of energy self- sufficient desalination systems based on solar driven MD technology since 2001. The focus is on module and system development.

This work is focused on experimental studies on full scale demonstration systems, utilizing a parallel multi MD-module setup. The according MD technology background and module set up is presented in this conference in the paper “SPIRAL WOUND MODULES FOR MEMBRANE DISTILLATION: MODELLING, VALIDATION AND MODULE OPTIMIZATION” by D. Winter. From 2004-2008 different autonomous solar driven MD systems, covering a capacity range from 80 to 2000 liters/day, have been developed, installed and monitored. Simulation tools have been developed and validated with the data from pilot plant operation. As shown in figure 1 two different system configurations for different capacity ranges were developed.

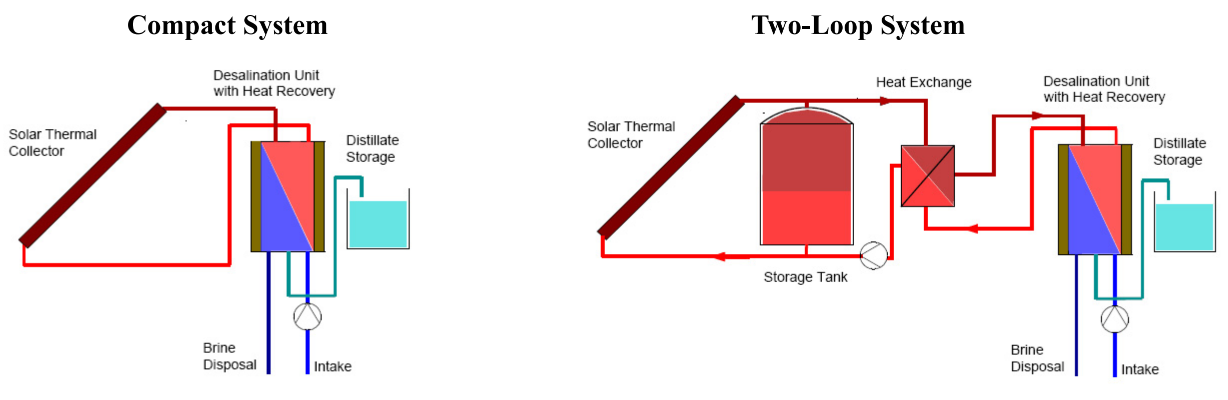

Figure 1: Two different system configurations, the “Compact System” for capacities of 150 up to 1000 l/day and the “Two Loop System” for capacities from 1m³/ day upwards.

The compact system is presented in the paper “MEMBRANE DISTILLATION – EXPERIENCE IN FIELD APPLICATIONS AND POTENTIALS” by M. Rolletschek.

This paper focuses on the two loop system design, which is designed for larger capacities. The main difference compared to the compact system is the use of a separated collector loop consisting of standard flat plate collectors and an integrated heat storage for 24-hour/day operation. The collector loop and the desalination loop are hydraulically separated by a titanium heat exchanger. The simulation tools were validated with the experimental data from the pilot plant operation. The tools were used to improve the MD-module technology and the overall system design. In the EU FP7 project MEDIRAS two two-loop systems were designed and installed in Pantelleria and Gran Canary between 2010 and 2011. Another two-loop system was installed in the frame of the BMBF funded project CuveWaters in the north of Namibia in 2010. Table 1 provides an overview on the technical specifications of the two loop systems installed between 2010 and 2011.

Location	Date of commis-sioning	System design capacity	Design capacity desalination unit 24h operation	Raw water source / recovery ratio	Heat supply	Comments
Amarika Namibia Etosha basin (remote inland location)	07/2010	4 m³/day at alternating temperatures 65 -80°C, 12 MD modules 168m² membrane	5m³/day at evaporator inlet temperature of 80°C, feed flow rate of 4800 l/h,	Ground water, drilling well 28Tppm R= 10 - 30%	Solar thermal flat plate collectors single glazed 232m²	-$T_{Evaporator\text{-}in}$ was reduced to 70°C to reduce scaling. - Significant problems with collectors
Pantelleria, island of Italy, Power station equipped with Diesel engines	10/2010	5 m³/day at constant temperature of 80°C, 12MD modules, 120m² membrane	5m³/day evaporator inlet temperature of 80°C, feed flow rate of 4800 l/h,	Sea water Mediterranean sea, open intake 35Tppm R= 0 -65%	Waste heat from diesel engine + solar thermal flat plate collectors 30m²	Top brine temperature was lower than designed (70 – 75°C only)
Gran Canaria Spain Test site of ITC	03/2011	3 m³/day at alternating temperatures65 - 80°C, 12MD modules, 120m² membrane	5m³/day at evaporator inlet temperature of 80°C, feed flow rate of 4800 l/h,	Sea water Atlantic ocean, beach well intake 35Tppm R= 0 -50%	Solar thermal flat plate collectors 180m² (90m² single glassed, 90² double glazed)	Problems with collector performance due to very high wind speeds

Table 1: Specifications of Two Loop Systems installed in 2010 and 2011

Namibia System

The two loop system in Namibia was designed for the fresh water production up to 5m³ in 24 hour operation from raw water of 20 - 28mS/cm conductivity. The location is remote in the land and without any infrastructure or technically trained staff. In order to make transportation and installation more convenient the complete system including desalination unit, controls and heat storage (12m³) were, installed inside a 20’ standard container. The set up can be seen in figure 2. The collector field consists of 100 flat plate collectors with a total aperture area of 232 m². All collectors are connected in parallel in order to minimize the pressure drop. The electrical energy is supplied by a PV system including batteries and DC-AC converter. The membrane distillation unit consists of 12 MD-modules, each of 14m² membrane area. All modules are connected in parallel to reduce the pressure drop of the desalination system. The desalination system is operating fully automated never the less the controller and data acquisition systems are connected to a satellite communication system for remote control and daily data transfer. Since raw water is very limited about 75% of brine is recirculated in order to increase the overall recovery ratio of the plant. The recirculated brine is cooled down in a cooling tower by 6 to 8K in order to reach the condenser inlet temperature after mixing with make-up water. Due to the brine recirculation the salinity of feed water is about 35g/kg. The maximum evaporator inlet temperature was reduced from 80°C to 70°C in May 2011 after scaling occurred in the heat exchanger and the hot section of the MD-modules. Accordingly the distillate productivity decreased from 170 l/hour to 150 l/h. Today scaling is controlled by periodic (6 to 12 weeks) flushing with sulphoric acid. The specific thermal energy

demand of the MD system was determined with 150 to 180kWh/m³. The reliability of the system was tested under extreme conditions due to the intensive solar radiation, very high ambient temperatures of more than 45°C, temperatures of more than 65°C inside the container respectively. Low temperatures of less than -5°C and very high temperature gradients between day and night (>30K) occur. Comprehensive experiences were made particularly on the reliability of key components (e.g. pumps, frequency converters, controllers,...). The performance of the collector loop was significantly reduced due to degradation of the solar thermal collectors.
The graphs in figure 3 show typical operation parameters as feed flow rate (Vp feed), raw water flow rate (Vp raw), global radiation (I global), evaporator inlet temperature (Tevap in) and the distillate flow rate (Vp dist) for system performance of 15th of October 2010.

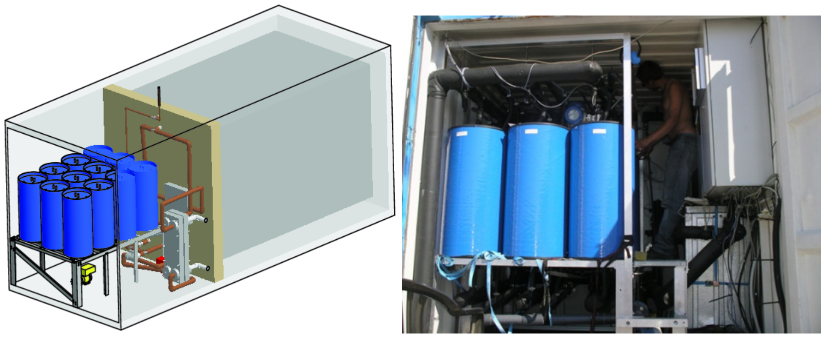

Figure 2: Design of the Namibia system and view into the ready installed container

In general the experience in Namibia show that the predicted performance was not achieved due to different technical problems. On the other hand the ambitious aim to make a stand alone MD system running under extreme remote conditions was achieved and very relevant experiences regarding plant design and component selection were made. The performance is currently improved by different measures.

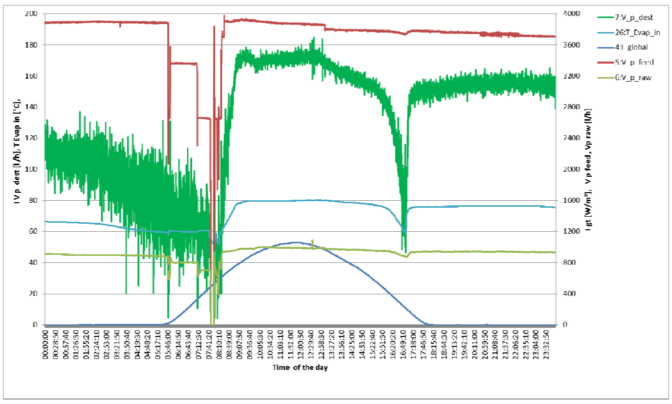

Figure 3: Operation parameters of the MD system in Namibia on October 15th, 2010

Pantelleria System

The Pantelleria system was mainly designed for steady state operation utilizing waste heat from a diesel engine of a power station. Additionally a solar thermal collector field of 30m² was installed in order to investigate the control of a hybrid heat supply. The design capacity of the MD-unit is 5m³/day in a 24h operation mode. The raw water source is the sea water intake of the power plant where sea water is used for cooling. The salinity of the raw water is about 35g/kg. For experimental investigations a brine recirculation is possible. For the cooling a particular brine evaporative cooler (BCC) was developed by the University of Palermo and University of Bremen. The pictures in

figure 4 show the CAD drawing and the ready installed MD system on site. It consists of 12 MD-modules each of 10m² membrane area connected in parallel.
The evaporator inlet temperature is typically between 65 and 75°C depending on the mechanical load of the Diesel engine. The design temperature of 80°C was not achieved with the design feed volume flow rate of 4800 l/h. The graphs in figure 5 show experimental results from plant operation at different evaporator inlet temperatures between 55and 75°C and different feed salinities of 45, 57 and 100g/kg. The mean condenser inlet temperature was 25°C. The trend lines show, that the average value of the distillate flow rate increases almost linear with an increase of the evaporator inlet temperature. Higher feed salinities lead to a significant decrease in total distillate flow. An increase of feed salinity from 45 to 100g/kg at an evaporator inlet temperature of 75°C induces an reduction of distillate flow rate from about 180 down to 125kg/h.

Figure 5: Construction drawing and ready installed pilot MD system in Pantelleria

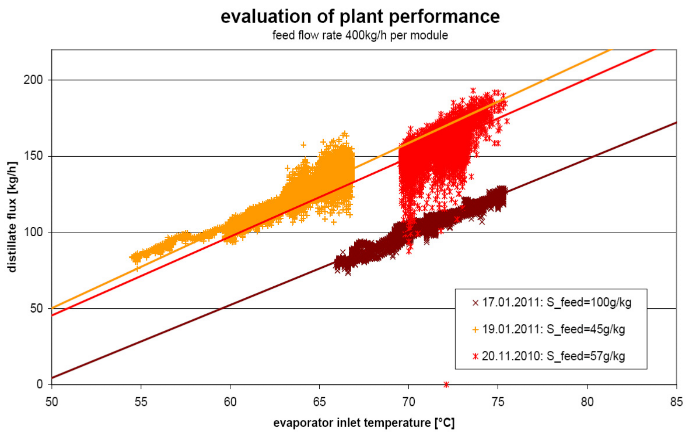

Figure 6: Experimental investigations of the Pantelleria plant demonstrating the effect of feed water salinity and evaporator inlet temperature on the distillate flow rate

Figure 6 shows that the Pantelleria plant could produce about 220 l/h (5280 l/day) distillate if the plant could be operated according the primary design parameters (Tevap in=80°C, S feed=50g/kg).