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# A NEW CONCEPT FOR SOLAR THERMAL DESALINATION

Results of In-Situ Measurements

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**ABSTRACT**. The need of water is a major problem in many developing countries. A new concept of a solar thermal desalination plant with integration of a heat storage tank was developed and successfully installed in Tunisia. The performance of the unit working since 20 months will be described.

## 1. INTRODUCTION

Due to polluted surface water and salty ground water the basic water supply in the threshold country Tunisia is not guaranteed for 35 - 50 % of the inhabitants. This is especially true in areas with poor infrastructure, where the water for daily use has to be transported partly over very large distances.

In the following we will present a measure by which an agricultural cooperative association in the outskirts of Sfax/Tunisia - Sfax is a partner city of Marburg since 1975 - is provided with water for agriculture. The centre enables the education and training of mentally and physically handicapped young people and secures their living by selling the agricultural products. The co-operative association could not use their own well, because the concentration of salts in the water is too high. Therefore the management was forced to transport the water by means of a tractor from a well 5 km away.

To minimize the organizing and financial expenditure and to guarantee the future of this institution, a new concept of a solar driven thermal desalination plant was developed and installed. Special emphasis was laid on the implementation of a technology which is long lasting and requires little maintenance. Another important condition was the use of well tested components and materials, that withstand the extreme conditions of sun, heat and wind prevailing in southern countries. A corresponding unit was constructed in April 1997 with financial support of the German Ministry of Economic Cooperation and Development (BMZ). In addition a unit for drip-irrigation was implemented to reduce the water consumption.

## 2. DESALINATION PROCESS

The desalination plant consists of a solar unit, which provides the thermal energy, and a desalination module that uses multi-effect-distillation to treat the water.

The brackish water evaporates under ambient pressure and the saturated air is transported by free convection to the condensor area, where it condenses on the surface of the plastic heat exchanger (Fig.1). The air circulates in the opposite direction of the water, which is thereby preheated in the condensor plates by the heat of condensation. Thus a great amount of the thermal energy provided by the solar collectors is recovered [1]. The efficiency of the heat recovery is described by the ratio of the energy needed to evaporate the respective amount of distillate, and the energy, which is actually needed to gain this amount. This quotient is named 'Gained Output Ratio' (GOR).

The evaporator consists of vertically suspended tissues made of polypropylene, where the hot brackish water is uniformly distributed. The condensor is made of polypropylene bridged double plates, through which the cool brackish water flows upwards.

Based on that concept, a pilot plant with direct flow through the collectors has been working nearly without maintenance and repair for more than seven years on the island of Fuerteventura.

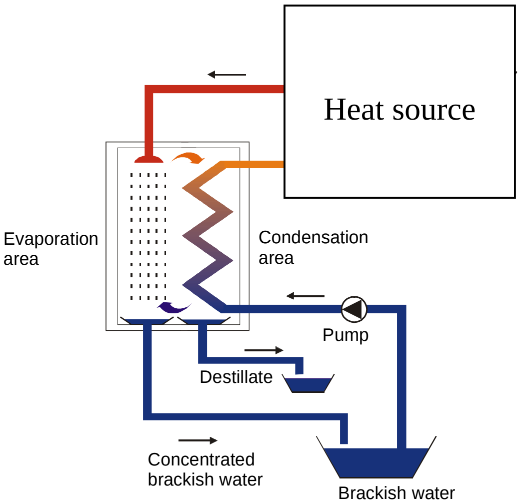

Figure 1: Illustration of the multi-effect-distillation without storage implementation


Figure 2: The plant installed in Sfax, consisting of collector, storage and desalination unit

## 3. COMPONENTS AND OPERATION CONDITIONS FOR A 24-HOUR-OPERATION OF THE PLANT

A new concept was developed and installed in Sfax with the implementation of a conventional heat storage tank, a temperature controlled mixing valve and a heat exchanger between collector circuit (desalted water) and distillation circuit.

In spite of higher investment costs the specific water costs of a plant with thermal storage can be decreased significantly. The distillation module being the most expensive unit of the plant can be operated under optimum conditions by minimization of thermal losses during idle periods and low efficiency periods following the restart of the system. Under laboratory conditions the distillation unit can reach a GOR of 8.6 to 9.8 (e.g. 70 - 80 kWh/$m^3$ water). Under field conditions the specific energy consumption of a unit without storage is much higher (150 - 180 kWh/$m^3$), due to the varying solar energy supply during the day [2].

Figure 2 shows a picture of the plant implemented in Sfax [3]. The corresponding system scheme (Fig. 3) is an illustration of the installed components along with the description of the different modes (daytime and nighttime / storage mode), which enable distillate production up to 24 hours.

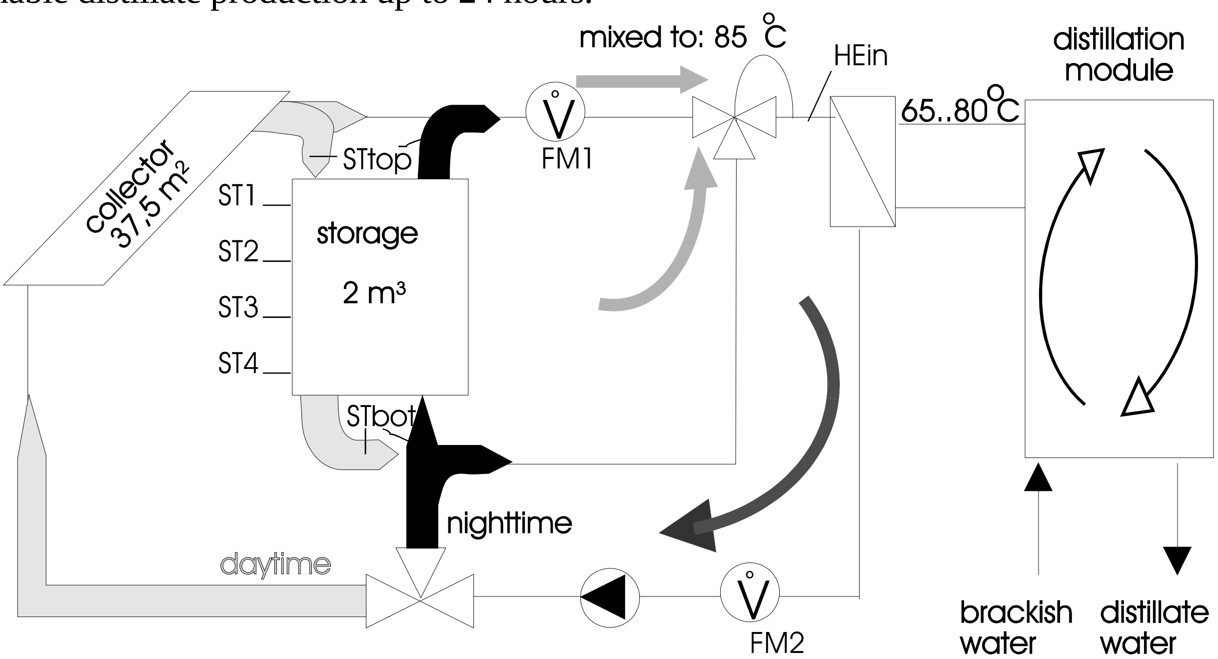


Figure 3: System scheme of the desalination plant installed in Sfax

The unit consists of the following components:

A. distillation module with titanium heat exchanger (HE) and controlling device

B. solar unit

- flat plate collector field (37,5 m², TiNOX absorbers)
- control unit, circulation pump, and an electrically driven three-way-valve
- insulated pressure tank, capacity 2 $m^3$
- temperature controlled mixing valve

With the installation of the three-way-valve, quasi steady-state conditions for the evaporation are guaranteed even during the daytime mode: if the temperature of the collector outlet exceeds the temperature adjusted for the mixing-valve, cold water from the bottom of the storage tank is added. At the same time the storage tank is automatically filled from the top with the surplus of hot water.

The conditions stipulated by the manufacturer of the desalination module to guarantee a distillate production between 25 and 30 l/h are a thermal power supply of 3 kW at a temperature level for the evaporation between 65 and 85°C and a flow rate in the secondary circuit of 600 l/h. As polypropylene is used for the condensor plates, the temperatures must not exceed 85°C for longer periods. The heat exchanger was constructed to set the temperature difference between primary and secondary circuit to 5 K assuming similar flow rates. Optimum operating conditions for the module are therefore temperatures of the heat exchanger inlet between 70 and 85°C in the primary circuit.

With the weather data of Tunis, the size of the collector field for a 24-hour-operation during summer was calculated as 40 $m^2$. The calculation was based on the condition of heating a storage tank of 2 $m^3$ from the minimum temperature after the end of evaporation (early morning), e.g. 65°C, to the maximum temperature allowed for the completely loaded pressure tank, which is 95°C. It took into account a simultaneous power consumption of 3 kW for the evaporation.

The temperature at the inlet of the heat exchanger in the primary circuit is set to 85°C by the mixing-valve, resulting in a constant evaporation temperature of 80°C. This is an experimentally justified compromise when considering collector efficiency on one hand and maximum heat and mass transfer for the distillation on the other hand [2].

The control device of the solar unit regulates the whole desalination system. When one of the following conditions is fulfilled, the three-way-valve switches the system into the storage (night-time) mode automatically, discharging the tank from above: a) the temperature level of the collector outlet is lower than the minimum temperature for the evaporation, b) the security criterion of the storage tank, e.g. the maximum temperature at the bottom of the tank, is reached. The pump of the solar unit works in the storage mode until the minimum temperature for evaporation is reached. With a fully loaded storage tank, a 24-hour-operation of the desalination plant can be realized with this concept.

## 4. RESULTS OF THE IN-SITU-MEASUREMENTS

In Figure 3 the positions of the temperature sensors (Pt-100) and flow meters for the measurements of all relevant data of the solar unit are indicated. The global irradiance was registered by a pyranometer. The insolation and the distillate production rate from July 21 and 22, 1997 (fig.4) reveal a daily distillate production up to 21 hours.

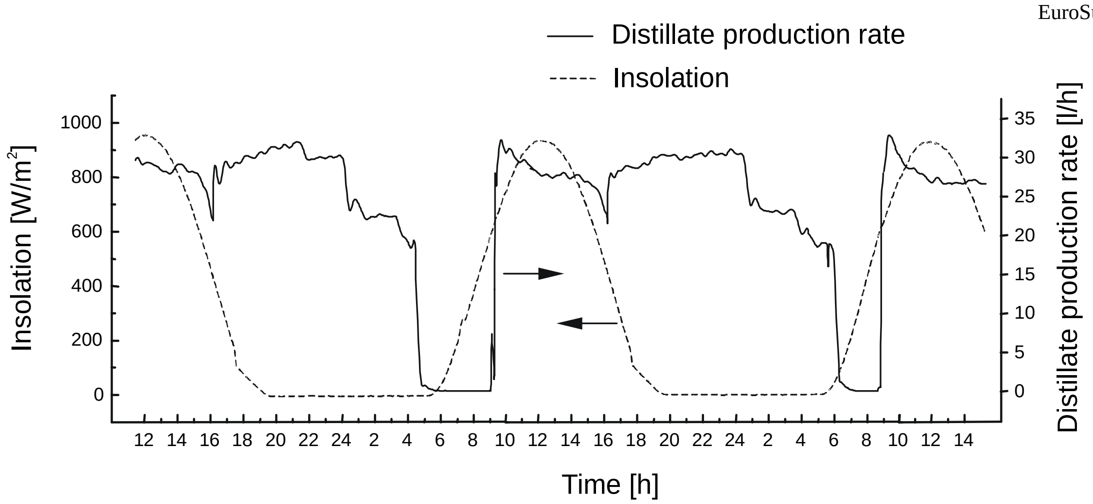


Fig. 4: Distillate production rate and insolation of July 21 and 22,1997

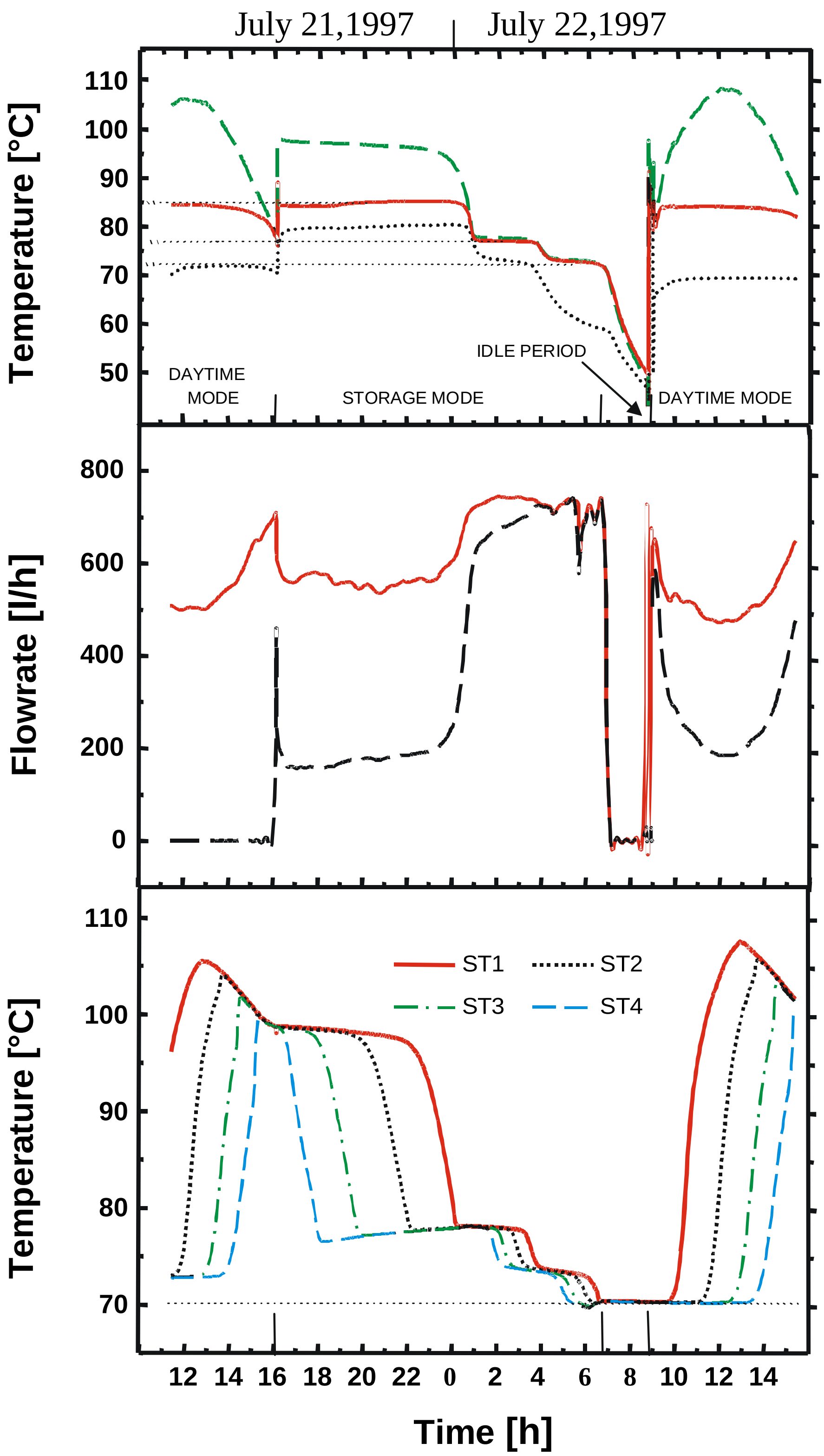


Fig. 5: Some results of the measurements at the desalination system in Sfax. (a) the temperature profile monitored at the inlet of the heat exchanger ($HE_{in}$, solid line), the temperature at the outlet ($ST_{bot}$, dotted) and the inlet ($ST_{top}$, dashed) of the tank, respectively, (b) the flow rates measured at the outlet of the heat exchanger (FM 2, solid) and at the top of the storage tank (FM 1, dashed) and (c) the temperatures at the different temperature sensors in the storage tank

The temperature profiles (Fig. 5 a) measured at the inlet of the heat exchanger show three different temperature levels, e.g. three circuits for the evaporation in the storage mode were achieved. The first level at 85°C is given by the mixing valve. The second one at 77°C is given by the heat exchanger reflux temperature of the first circuit, the third at 72°C is given by the reflux of the second circuit. In the storage mode the reflux temperature is equivalent to the temperature measured at the bottom of the tank. The temperature difference between the reflux of the first circuit and the heat exchanger inlet of the second circuit indicates the presence of big thermal losses in the storage. The constant temperature profile of the heat exchanger inlet confirms, considering the respective flow rate in Fig. 5 (b) as well, the steady-state conditions for the evaporation over periods of several hours. Nevertheless, the drop of the flow rate from 700 l/h to 500 l/h (at FM 2) during the daytime mode, due to the flow rate dependent pressure drops at the mixing valve, should be avoided in a future plant. This could either be done by modification of the mixing valve or by an adjustable circulation pump.

The temperature profiles of the storage tank 5 (c) show the charging (daytime mode) and discharging (storage mode) of the storage tank. At 16.00 h the system switched into the storage mode, the temperatures at all sensors being 97°C, revealing a completely loaded tank. The three circuits discharging the tank can be observed in this figure as well. During the first one occurring at 97°C, cooler water from the heat exchanger reflux is mixed to the hot water at the mixing valve, leading to a duration of that circuit of almost 6.5 hours. The second and third circuit only last about three hours, respectively, because at these low temperatures no heat exchanger reflux is mixed with. The similar shape of the curves, monitored at different heights inside the storage tank, indicates the preservation of stratification, justifying the concept of high temperature storage in a relatively small storage tank. Another concept, using the same desalination module but lower storage temperatures (just above the evaporation temperature) and a bigger storage tank (approximately 12m$^3$) is discussed [2], but was not yet experimentally verified.

In the table the results of the measurements are summarized.

| | 7/20/97 | 7/21/97 | 7/22/97 |
|---|---|---|---|
| Distillate production [l/d] | 488 | 536 | 516 |
| specific energy consumption [kWh/m$^3$] | 114 | 106 | 107 |
| GOR | 6,0 | 6,4 | 6,4 |

The specific energy consumption for the production of 1 m$^3$ of distillate was even under field-conditions reduced to 106 kWh/m$^3$, resulting in a GOR of 6.4.

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