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Application of Geothermal Energy for Brackish Water Desalination in the South of Tunisia

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ABSTRACT

In arid areas of Tunisia potable water is very scarce and the establishment of a human habitat in these areas strongly depends on how such water can be made available. On the other hand, these regions have important resources of underground brackish (salinity more than 3g/l) and often geothermal (temperature between 40°C and 90°C) water. Hence, these resources and can not be used directly.

Brackish water desalination is one of the ways to provide water in these regions for drinking and irrigation purposes. On the other hand, the conventional desalination technologies are not adapted for this situation. In fact, the investment and operating costs are so high that the recourse to this solution is justified only for large scale utilization. Moreover, the conventional energy supply of remote areas presents technical and economical problems. In this case, production of fresh water using desalinations technologies driven by renewable energy sources (solar, wind, geothermal, etc.) can be promising.

Since the brackish water is often geothermal in the south of Tunisia, and the water demand is low, the use of geothermal energy for water desalination can be promising.

In this paper we present a state of the art on using renewable energy sources, notably geothermal, for brackish and seawater desalination in the world and in Tunisia. An example of coupling an innovant desalination unit including horizontal-tubes falling-film evaporator and condenser, made of polypropylene with a geothermal spring is presented. The advantage of this plant is that it is made from cheap materials (polypropylene) allowing the use of low temperature energy (60°C to 90°C), which corresponds to the geothermal water temperature in the south of Tunisia. Moreover, the plant can be used for geothermal water cooling before utilization for irrigation or drinking.

1. INTRODUCTION

Most of the Mediterranean **C**ountries have to struggle with serious water problems : **W**ith a rising water competition between the agriculture sector (irrigation), households and in the industry but limited and/or salt-affected water resources; with irregular rainfall in time and space, increased by the local and global climate change; with an escalating dehydration of the landscape, causing high nutrient and mineral losses with extreme negative impacts for the agriculture industry; and with inefficient wastewater treatment systems, polluting surface and groundwater.

High temperatures in combination with missing water retention structures in the landscape cause high water losses because more water evaporates and vanishes through big scale air streams than can be hold in short water cycles in the region. This is the case in almost all regions of the Mediterranean countries. Scarcity of water and the inability to grow food limit the conditions for sustainable development, for increased quality of live and peace. In all the North African countries and most of the Southern Mediterranean countries the volume of water available per inhabitant per year is under 1000m^3/ inhab/year. This rate is commonly considered as the critical threshold before the move to scarcity. It is probable that the water resources per inhabitant will halve in several MPCs until 2025 (see Fig. 1).

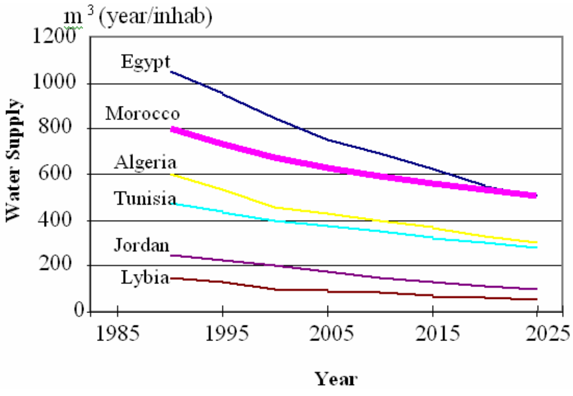

Fig 1 : Evolution of supply of available waters per inhabitant and per year in comparison with some countries of the Mediterranean.

According to Fig 1, it can be seen that Tunisia is one of the Mediterranean countries most concerned by water deficiency. In fact, the country is characterized by an arid to a semi-arid climate due to the low received quantities of rain. For this raison, the available water resources in the country are rather modest in terms of both quantity and quality. The global potential of water resources in the country amounts to only 4545 Mm^3/y (1845 Mm^3 are ground water resources and 2700 Mm^3 originate from surface waters, see Table 1). Potential water resources (i.e., surface water and ground water) are unevenly distributed within the country, Houcine et al. (1999). Table 1 and Fig 2 show the available quantities of water and their respective sources within each region.

The northern part, covering an area of only 17% of the country, has 60% of the total water resources. On the other hand, the largest southern part (61% of the total area) has only 23% of the country’s water resources. In these regions, especially in the south-west, agriculture is often the first economical resource (date palm and fruit farming). For the development of this kind of agriculture more water resources are required.

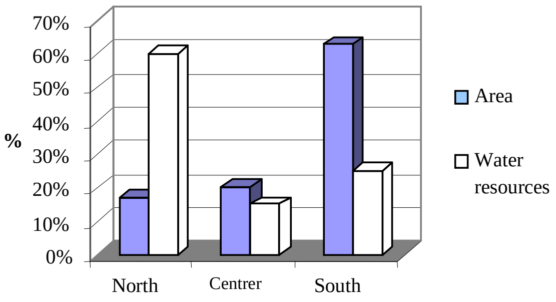

Fig 2: Regional distribution of potential water resources in Tunisia

Table 1: Water resources availability in Tunisia by region

	Region (Area%)			
	Northern (17)	Central (22)	Southern (61)	Total (100)
Surface Water Mm^3/y	2185	290	225	2700
Ground Water Mm^3/y	550	465	830	1845
Total Water resources Mm^3/y	2735	755	1055	4545
Total over all regions, %	60	17	23	100

Moreover, in many parts of the country and particularly in the south, ground water resources are often brackish, thus unsuitable for drinking or irrigation. However, the southern oases are directly irrigated by underground water, provoking a deterioration of soil and inducing to deforestation and desertification. Fig 3 shows a detailed classification of water resources in Tunisia according to their salinity, Ben Jemaa et al. (1999). According to this figure we remark that only 8,4% of the total shallow groundwater has salinity levels less than 1,5 g/l.

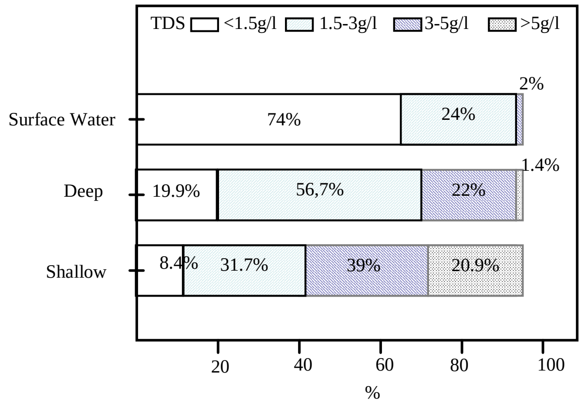

Fig 3 : Water resources classification according to salinity levels

Given its modest water resources potential, the mediocre quality of most of its groundwater resources and the necessity of agriculture development, Tunisia has to find new water resources.

To cover for any future deficit in water and to improve the quality of distributed water, desalination seems to be an adequate solution, which has already been undertaken in a number of locations. Currently, desalination is practiced in Tunisia on a small scale mainly in the southern region of Gabes and in the islands ok Kerkenah and Djerba. However, given the statistics on water resources availability and water demand figures, desalination is expected to carry out on a wide large scale in the near future. In fact, the actual total production of desalinated water in Tunisia exceeds 70,000 m^3/d.

All desalination stations currently under operation in the country are powered by conventional energy resources. On the other hand, examining the energy situation in the country, the demand is soon expected to exceed the available fossil energy sources. In fact, by the year 2010, the energy consumption is expected to reach 8.5 Mtep per year (see Table 2) whereas the fossil energy available will only be 2.9 Mtep/y, Houcine et al (1999).

All the desalination plants installed in Tunisia function with conventional energy sources. Tunisia suffer also from an environmental point of view. It is obvious, that the use of fossil energy sources, especially hydrocarbons, has a negative effect on the environment and contributes to a progressive pollution and deterioration in the quality of soil, water and air.

Table 2 : Energy demand projections in Tunisia (in Mtep)

	Year		
	1998	2001	2010
Oil products	3,48	3,90	5,60
Natural gas	0,51	0,62	1,30
Electricity	0,60	0,80	1,40
Coke	0,06	0,08	0,10
Solar	---	---	0,10
Total	4,65	5,40	8,50

Faced with a depletion of is fossil energy sources and progressive degradation of its environment due to the pollution and gas emissions, Tunisia looks for the answer to the water scarcity problem in the use of its abundant and readily available renewable energy sources (solar, geothermal and wind) as a cleaner and safer way for providing fresh water.

Renewable Energy Source (RES) driven desalination technologies mainly fall into two categories. The first category includes distillation desalination technologies driven by heat produced by RES, while the second includes membrane and distillation desalination technologies driven by electricity or mechanical energy produced by RES, Ten and Morris (2003). Table 3, based on the studies of Rodriguez-Groins et al. (1996) and Hunter (1996), summarize the different possible combinations RES-Desalination technologies.

The most popular is the combination of Photovoltaics with Reverse Osmosis (Fig 4) which is particularly interesting for small applications in sunny areas. For largest plants wind energy can be more interesting.

The selection of the appropriates RES desalination technology depends on a number of factors. This includes plant size, feed water salinity, remoteness, availability of grid electricity, technical infrastructure and the type and potential of the local renewable energy source. In Tunisia, RES vary in their importance and distribution from one region to the other. A survey of these sources showed that at any territorial region of the country at least one or more sources of renewable energy are readily available, especially geothermal energy, which is present over the entire country. The coupling of this kind of energy and an innovant desalination plant is discussed in the present paper.

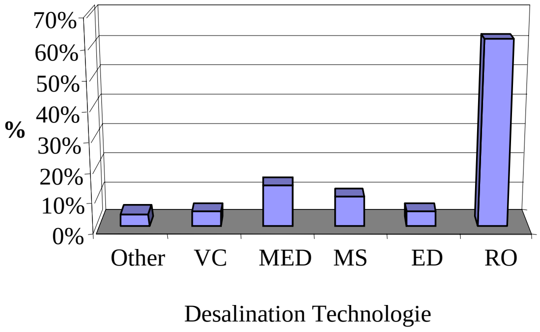

Fig 4: Desalination processes used in conjunction with renewable energy

2. GEOTHERMAL ENERGY – DESALINATION UNIT COUPLING

There are different geothermal energy sources. They may be classified in terms of the measured temperatures as low, medium and high. The corresponding thresholds are lower than 100°C, between 100°C and 150°C, and up to 150°C, respectively.

Most geothermal sources in Tunisia have low enthalpy with maximum temperatures of 70-90°C. Nevertheless, the northwestern part of the country is characterized with a geothermal zone of high energy. These sources can be found not only in the northern part of the country where desalination is least needed, but also along coastal regions and in the south where the fresh water problem is most acute.

South Tunisia can be divided into the following major geothermal aquifers (Fig 5), Ben Mohamed (2003):

- The Continental Intercalaire, CI., extended on an area of 600.000 km^2 in the whole region of Algeria, Libya and Tunisia. The small part localized in Tunisia is distinguished by an aquifer (more than 1000 m of depth) with high pressure (10 bars), temperature reaching 70°C and with TDS range from 2.5 to 5g/l.
- The Complex Terminal CT., with geothermal aquifers in Nefzaoua and El Djerid. The reservoir has an extension of about 350.000 km^2 in which a small area is located in Tunisia. Its temperature range from 30-50°C (100-600 m of depth). The total dissolved solids (TDS) range from 1.5 to 8g/l.

These geothermal aquifers are mainly localized in south east of Tunisia, particularly in the regions of Tozeur, Kebili and Gabes. Details of the amount and the available potential are present in Table 4.

Table 4: Potential and exploitation of geothermal water aquifers in south Tunisian in Mm3/year

Aquifers	**Total resources**	**Withdrawal**	**Aquifers exploitation (%)**
CT	352.300	460.870	131%
CI	82.360	72.010	87%
Djeffara	115.110	102.88	89%
Total	549.770	635.760	116 %

Major direct utilization projects exploiting geothermal energy exist in about 60 countries, and the estimates total installed thermal power involved is 16,2 MW$_t$, Ben Mohamed (2003). The great part of this energy is used in space heating (37%), and swimming and bathing (22%) (Lund, 2002). In Iceland, 99% of the buildings in its capital are heated by geothermal energy, Vera (1991).

Table 3 : Plausible coulping combinations between renewable energy sources and desalting technologies

Renewable energy sources		Desalting technologies					
		RO	ED	ME	TVC	MVC	MSF
Solar	Solar thermal			✓	✓	✓	✓
	Solar photovoltaic	✓	✓			✓	
Wind	Wind shaft	✓				✓	✓
	Wind electric	✓	✓			✓	
Geothermal	Geothermal heat			✓	✓	✓	✓
	Geothermal electric	✓	✓			✓	

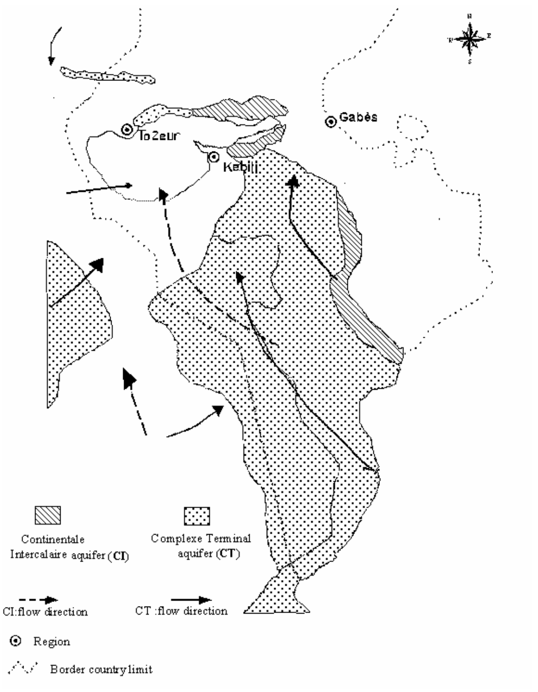

Fig 5 : Geothermal water resources in the south of Tunisia

In the south of Tunisia, 95% of the geothermal resources are used in agriculture, 77% for oases and 19% for greenhouses. The remainder (4%) is used for bathing (Hammams), tourism (hotels and pools), washing, and animal husbandry, Ben Mohamed (2003). Fig 6 shows the different direct geothermal uses in the area.

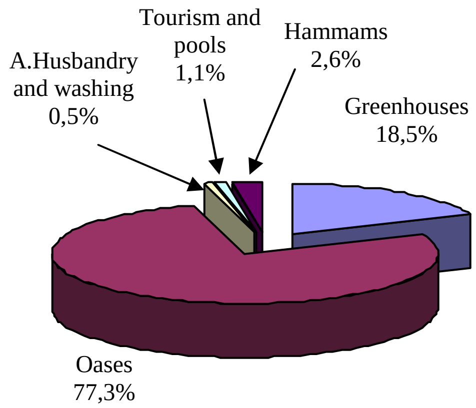

Fig 6: Geothermal uses in the south of Tunisia

The main advantages of geothermal energy are first that the thermal storage is unnecessary in such systems. Secondly, the energy output of these resources is generally invariant with less intermittence problems (compared to solar energy and wind). This makes them ideal for thermal desalination processes. The oldest paper found about desalination plants assisted by geothermal energy was published in 1976. Awerbuch et al. (1976) reported that the United States Department of the Interior, Bureau of Reclamation, performed an interesting research about a geothermal-powered desalination pilot plant near Holtville, California, USA since 1972. Boegli et al. (1977), from the same department, report experimental results of geothermal fluids desalination at East Mesa Test Site. MSF distillation and high-temperature ED were analyzed; different evaporation tubes and membranes were tested.

Even though most of the geothermal sources in Tunisia are of low enthalpy class, they cannot be disqualified from potential coupling with desalination plants. Even in the case of limited geothermal energy, thermal desalination processes such as MED, thermal vapor compression (TVC), single-stage flash distillation (SF) and MSF can benefit greatly when coupled to geothermal sources by economizing considerable amounts of energy needed for preheating.

Rodriguez et al. (1996) stated that waters in the upper 100 m may be a reasonable alternative to desalination. Karystsas (1996) developed a technical and economical analysis for the use of geothermal sources between 60°C and 90°C on MED. The unit was installed in the Kimolos island (Greece) in 2000 with a capacity of 80m^3/d. The input geothermal water temperature is about 61°C. Bouchekima (2003) analyses the performance of solar still in which the feed water is brackish underground geothermal water.

To use the geothermal water for agriculture and potable water uses, Tunisia resorted to cooling towers to lowdown temperature and hardness. Cooled brackish water irrigates greenhouses, oases, and feeds desalination plants. The cooling operation of brackish water rejects an important quantity of thermal energy in the atmosphere. This geothermal waste energy could be used in the desalination process to increase its productivity. In fact, the productivity of RO membranes (water flux through it) increases with increasing the temperature of the feed water, unless the temperature tolerance of the membrane is respected. For example, Kamal (1992) had shown that enhancement of feed water temperature for seawater Reverse Osmosis plants located in southern California induced a substantial reduction in the cost of potable water. The membrane productivity increases by about 2-3% per one °C increase of the feeding temperature, Parekh 1988. Most of the membranes commercialized for RO desalination processes can tolerate temperature up to 40°C. However, few membrane suppliers offer new membranes for high-temperature applications (Backpulseable), Houcine et al (1999).

TM membranes (polypropylene tubular membranes) will increase its productivity of about 20-30%. Moreover, the use of higher temperature tolerance membranes will considerably increase this productivity to about 60-90%. However, due to the increase of the feeding temperature, considerations have to be taken into account, such as possible higher salt permeation and compaction of membranes, and if necessary, higher-grade materials of construction have to be used. Since geothermal water cannot be economically transported for long distances, it is preferable to use the geothermal groundwater in an RO desalination process at their production site or to convert this geothermal energy to more portable forms (not efficient due to the low enthalpy geothermal energy).

An other promising process to be combined to geothermal energy is developed: the membrane distillation, El Amali et al. (2000).

Bouguecha and Dhahbi (2002) carried an experimental investigation on a fluidized bed crystallizer and air gap membrane distillation for geothermal water desalination in Tunisia. Membrane distillation (MD) is an emerged desalination technology, which can be driven by a thermal energy at low enthalpy (less than 90°C) as geothermal energy, and a fluidized bed crystallizer can ensure reduction of an important portion of hardness without significant loss of temperature;

3. CASE STUDY

If the energy requirements of thermal desalination plants are too excessive to be supplied by a geothermal resources, some other processes based on evaporation and condensation can be used. Air humidification and dehumidification can be a very interesting process to be combined with geothermal source. Bourouni et al (1999) investigated an innovant desalination plant, functioning by Aero-Evapo-Condensation Process (AEC), able to operate at low temperature (75-90°C), allowing the use of renewable energy (geothermal and solar). The main important features for such system are the low cost, low maintenance requirements, simple operation, as well as the high reliability.

The prototype is presented in Fig 7. It includes an evaporator (1) and a condenser (2). Each heat exchanger consists of circular plastic tubes and an insulated envelope. Heat recovery in a low-temperature process requires a large exchange surface. The two exchangers are 2 m long with a rectangular section (1.2 m in length and 0.8 m in width), and they includes 865 m of tubes. Two tanks (3), under the evaporator and (4) under the condenser, contain salt and distilled water. The two exchangers are linked by two pipes (5) and (6) of a diameter of 0.2 m, allowing the circulation of humid air from the evaporator to the condenser. The air flow is maintained by a blower (7). Two pumps (8) and (9) permit the circulation of salt and distilled water.

In order to avoid an excess of salt water concentration, the tank (3) level is held constant by a continuous supply of salt water. The salt concentration is controlled by a purge sluice. Furthermore, the level in tank (4) is held constant by a distilled water levy. The cooled hot brackish water moves down the tubes. Its temperature at the entrance can vary from 60°C to 70°C. The cooling air moves up in the space between the tubes. The cold salt water in the tank (3), at ambient temperature, is sucked up by the pump (8) to the condenser (2). In this exchanger the water moves up inside the tubes. At the condenser outlet, salt water is preheated to 50°C.

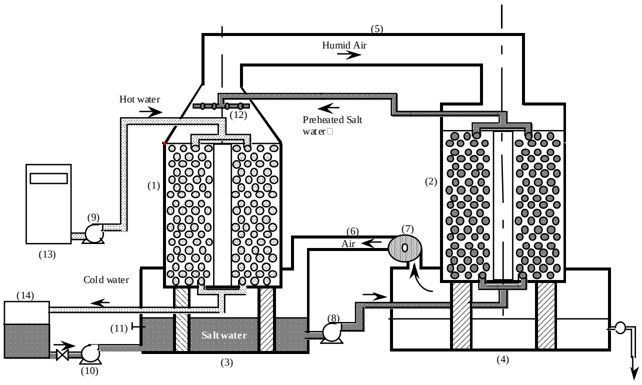

Figure 7: Presentation of the desalination prototype functioning by the Aero-Evapo-Condensation Process (A.E.C.P)
(1) evaporator; (2) Condensor; (3) Salt Water Tank; (4) distilled water tank; (5) and (6) pipes; (7) blower; (8) (9) and (10) pumps; (11) purge sluice; (12) liquid distribution system; (13) brackish water
▩ Salt water to evaporate ⬚ Coolant fluid

The liquid is introduced through the water distribution system (12) into the top of the evaporator and falls from tube to tube. The feed water distribution system is a slot placed at the top of a 25 mm diameter tube. The liquid film flows and evaporates on the outside surfaces of the tubes. The vapour is carried by the air flow to the condenser. At the top of the condenser, the air is hot and humid. In the condenser (2), the humid air moves down through the space between the tubes. On contact with the cold tube walls, there is film condensation coupled with latent heat restitution to the salt water circulating inside the tubes. Finally, the distilled water is recovered in the tank (3'). The characteristics of the film flowing around the horizontal tubes are visualized during the tests through two Plexiglas windows, placed on each exchanger. The humid air velocity is adjusted using a frequency controller linked to the ventilator. Two flow adjusting valves, placed upstream from the evaporator and the distributor, allow the control of the hot water and liquid film flow rates.

A prototype has been built and tested in the south of Tunisia. A geothermal brackish water source, with an input water temperature of 65°C, has been used to feed the unit. The capacity of this unit was about $3m^3$/day, which is sufficient to cover the potable water needs in remote villages due to the dispersed population that characterize the south Mediterranean and Gulf areas.

Energy cost is one of the most important elements in determining water costs where the water is produced from desalination plants. In some cases it can represents more than 80% of the total desalted water cost. Since the use of direct geothermal energy in the AEC process is almost free, an interesting cost is obtained, as low as 1,2 USD per cubic meter of fresh water. A second study (Bourouni et al 2003), has shown that when solar collectors are coupled to the AEC pilot, the water cost can reach 1,58 USD per cubic meter of fresh water produced. Ophir (1982) reports an economic analysis of geothermal desalination: sources of 110°C-130°C were considered. He concludes that geothermal desalination represents as low price as multi-effect dual purpose plants. Tzen and Morris (2003) showed that for the desalination units driven by renewable energy installed worldwide, the lower cost obtained is about 3,5 USD/m^3 for the project Almeria, Spain CIEMAT, DLR. The desalination unit has a capacity of $3m^3$/h with an RES installed power of 6,5 MWh_t collectors.

4. CONCLUSION

The world's water needs are increasing dramatically. New alternatives for water production are developed such as desalination and wastewater treatment. The classical desalination techniques have proved their efficiency since 20 years (MSF, MED, VC, etc.). RO is the emerging technique thanks to the improvement of the membrane reliability. However, in cases of remote areas where the population is dispersed and conventional energy is not available these techniques are not adequate. Hence, there is a need to accelerate the development of novel water production systems from renewable. New wind, solar, geothermal and other technologies that can be used for desalination are rapidly emerging with the promise of economic and environmental viability on large scale.

In this frame, we developed an innovant desalination unit functioning by Aero-Evapo-Condensation process and can be combined to geothermal and solar source. The water cost obtained is as low as 1,2 USD/m^3. However, the unit capacity is only about $3m^3$/d. The future work will consist in increasing the capacity of the unit by improving the efficiency of the process.

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