GEOTHERMAL UTILIZATION IN AGRICULTURE IN KEBILI REGION, SOUTHERN TUNISIA

Mouldi Ben Mohamed, Engineer, M.Sc.
CRDA Kebili, 4200 - TUNISIA

INTRODUCTION

The use of geothermal energy is limited to direct utilization in Tunisia, because of the low enthalpy resources. The resources are localized mainly in the southern part of the country in the regions of Gabes, Kebili and Tozeur and utilized mostly for agricultural purposes (irrigation of oases, greenhouses). The government's policy in the beginning of the 1980's was oriented to the development of the oasis' sector and the main aim was to supply oases with geothermal water for irrigation. Therefore, in the Kebili area, about 35 boreholes are operating mostly for irrigation of 15,500 ha of oases after cooling the water in atmospheric towers. Fifteen years ago (1986) the State started using geothermal energy for greenhouse farming, by planting an area of one ha. The results of this experiment were very encouraging and thus, the areas today have increased to 40 ha.

Figure 1. A well used for oases irrigation.

GEOTHERMAL RESOURCES IN TUNISIA

The geothermal resources in Tunisia have been described by Ben Dhia and Bouri (1995). They divide the country into five geothermal areas. This division is based on the geological, structural and hydro-geological features of the different regions. A very coarse classification of the geothermal resources would be to distinguish only between two areas, the northwest part and the remaining part of the country.

The northwest region is characterized by a complex geological setting where volcanic rocks are more common than in other regions. The density of thermal manifestations is higher here than in other parts of the country. This region is greatly affected by the over thrust of the alpine napes, dated as upper Miocene, and thick deposits of sandy layers ''Numidian formations." In southern Tunisia, the flow rate from the hot springs is usually higher (Stefánsson, 1986). Outside the northwest region, the geothermal aquifers have been found in well-defined geological formations (sedimentary rocks), which in some cases are mapped over large areas (basins). These reservoir rocks have very high permeability and many of the wells drilled in the south have artesian flow rates of the order of 100 L/s (Figure 1). The geothermal gradient is in the range of 21EC/km to 46EC/km. These values are in the same range as the world average values for thermal gradient. In general it is, therefore, expected that the geothermal resources in Tunisia are the result of normal conductive heat flow in the crust. This means that, in general, high-temperature geothermal resources are not expected to be found in Tunisia, the only exception or question mark is the northern part of the country (Stefánsson, 1986).

The region of Kebili, with a total area of 2.2 million hectares, is located in the southwestern part of the country and characterized by two aquifers, the largest in Tunisia (the medium aquifer or CT: Complexe Terminal, and the deep aquifer or CI: Continental Intercalaire). These aquifers are the most important resources for the development of agriculture in the region, but they are rarely considered as renewable resources.

GEOTHERMAL UTILIZATION

About 1,500 L/s are exploited from geothermal resources; 95% is utilized for agricultural purposes: 78% for oases and 17% for greenhouses. The remaining part (5%) is used for bathing (hammams)(Figure 2), tourism (hotels and pools), washing and animal husbandry. Figure 3 shows the different direct geothermal uses in the area.

Figure 2. The swimming pool at Ras-Elaîn locality.

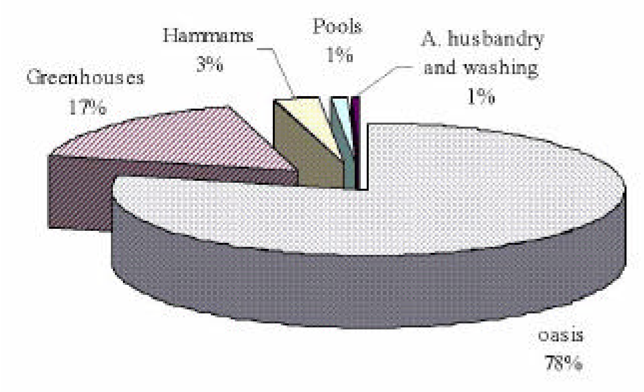

Figure 3. Direct geothermal uses in Kebili area.

IRRIGATION OF OASES

The region of Kebili, located in the southwest of the country, is characterized by desert climate (arid). The annual precipitation is irregular and generally less than 100 mm. The maximum temperature is about 55EC (July) and the temperature range (the difference between maximum and minimum temperatures) is very high. These difficult conditions require a large amount of water to maintain the humidity inside the oases system. The oasis area is estimated at 15,500 hectares (51% of the total area in the country) and the oasis system is classified into three levels: (a) the first level which is called the upper level is composed of date palms, the second one or the middle level is composed of trees under date palms (apple, fugue, grape, apricot, grenade, etc.) and the third one or the open field is composed of grass and vegetable cultivation. These three levels constitute the oasis system and are generally managed at the same time and irrigated with the same water. The cultivation of these three levels together makes a microclimate, commonly called "oases' microclimate." People go there in the summer time for relaxation.

Date Palm Importance

In recent years, large quantities of hot water have been identified in the country by drilling. This discovery is mainly a spin off from groundwater drilling, and in other cases related to exploration drilling for oil. Due to climatic conditions in the country, clean water is one of the most valuable substances, at least in the southern part (desert). The groundwater is mainly used for agricultural purposes (95%) and principally for the irrigation of oases (78%). All the resources taken from the Complexe Terminal (CT) are used for irrigation. Geothermal resources were exploited for the first time to provide a complete water supply for old oases, which have a high density and low productivity, in order to create new ones. The main target was to develop the oases sector in the south of the country by means of the rehabilitation of old oases and the installation of new ones (new farmers). The government's policy in the beginning of 1980's was oriented to encourage farmers. In that way, the operation consisted of pulling up the non-productive date palms to replace some of them by another more productive variety with good quality, intended for export. This was expected to generate more income for the farmer (micro-economy) but a large quantity of old varieties disappeared (Figure 4).

Figure 4. Dates production (Deglat Nour variety intended for export).

Date palms occupy the first place in the agricultural activity of the region due to their social and economical interest. The social interest is due to the large number of farmers depending directly on this activity (about 30,000 farmers) and also families that are depended directly or indirectly. More than 80% of the population lives on this sector. The government policy for a stationary population has been reached. It is important to acknowledge the high level of employment generated by this sector. The economical interest is related to its profitability and the good income for its farmers and consequently the favorable contribution to the commercial balance. Indeed, the dates' sector occupies the third place in the total agricultural export of the country after olive oil and fishing. In the year 2000, the total production of dates in Tunisia was estimated at 100,000 tonnes. The region of Kebili produced 58,000 tonnes. Generally, the region contributes on average, more than 55% of the total product. About 31,000 tonnes were exported mostly to the European countries producing an income of 78 million dinars (US$52 million or 59 million Euros).

Water Cooling and Irrigation

The water temperatures varies from 27EC to 73EC. Generally, water less than 40-45EC is used directly for irrigation or cooled by means of multiple ponds (five ponds in the region) or cascaded as shown in Figure 5. By this cooling system we can lower the temperature by only 3-4EC.

The maintenance operation is limited to the removal of soil deposited by wind. When the temperature exceeds 45EC, the water is cooled by means of atmospheric towers before being used for irrigation (Figure 6). In normal conditions, we can drop the temperature to 30-32EC, but when the ventilation doesn't function properly, the water is dropped to only 40EC. However, these towers have the disadvantage of losing water via evaporation, estimated at 2-6% of the total flow rates and are expensive to operate (10,000-15,000 dinars annually [US$6,700 to 10,000, or 7,600 to 11,400 Euros]) which is includes the costs of electricity, maintenance and gardening.

Figure 5. The water cooling system (Cascade of Oum Elfareth)

Figure 6. The water cooling system (Atmospheric tower)

The irrigation in the region is by the submersion method and all the area is irrigated (no localized irrigation). In this case, water is transported through a ditch to parcels causing high water wastage caused by evaporation and infiltration due to the physical characteristics of the soil (light soil, sandy, salty soil). For economic purposes, the government encourages farmers to install and utilize PVC pipelines for irrigation by subsidizing 40-60% of the total investment. Since 1994, the beginning of the water management project, over 5,000 ha were equipped for more than 7,000 farmers and 22 water organizations. The Tunisian policy in the agricultural field and especially in its hydraulic aspects was oriented in the beginning of 1990's to give more importance, responsibilities and decision making to the local organizations. In that way, 98 organizations involved in the use of water resources, called GIC, are operating in the region and they contribute effectively to the management and the distribution of water. In the same policy of water management, a project called APIOS (to improve the irrigated areas in south oasis) started in 2001 by the installation of concreted canals for the irrigation and drainage systems. The project covers 7,500 ha of oases with a total cost of 30 million dinars (US$20 million or 22.5 million Euros) co-financed by a Japanese company. The objectives of the project are to improve the irrigation frequency, to increase the oasis's efficiency and productivity, and to enhance the value of the water resources.

HEATING AND IRRIGATION OF GREENHOUSES

In addition to irrigation of the oasis, the geothermal water is used for heating plastic greenhouses. The utilization of geothermal energy recently started in the country as an experiment conduced by the National Agronomic Institute (INAT) in Mornag and in Chenchou localities. The results of this experiment were very encouraging and led to the idea of a geothermal utilization project in agriculture (PUGA-project, TUN/85/004) financed by the UNDP. In comparison with unheated greenhouses, the geothermally heated greenhouses generate better quality and higher yields. It also resulted in earlier ripening of crops.

In 1986, the government started to use geothermal energy in greenhouses in southern Tunisia. After one year, many demonstration projects in several places had been established with the collaboration of the Energy Agency (AME) and the Rural Development Programme (PDRI). The locality of Limagues, in the region of Kebili was the first place where plastic houses were implemented (1 ha). At the same time, the company ''5th Season'' stocked the first part of a large project (5 ha). Furthermore, in 1991 a second project for greenhouse development was begun in cooperation between the governments of Belgium and Tunisia. The exploitation of geothermal resources for heating and irrigating greenhouses on the edge of the desert seems to represent a promising alternative for the development of this sector.

Starting with one ha as an experiment in 1986, the total area of geothermally heated greenhouses in Tunisia has increased considerably. Indeed, the area reached 21 ha in 1988 and 33 ha in 1989 in which 51 and 54% were respectively in the region of Kebili. In 1992, the total area covered was 67 ha in which 43% were located in this region. The total area continues to increase, reaching 75 ha in 1996 and near 80 ha in 1998, in which the region represents, respectively, 38% and 40% of the total. Today, the total area is 102 ha, in which 40% are located in the Kebili area. Figure 7 shows the evolution of the greenhouse area in the country and in the region.

It is very clear that the significant increase was from 1987 to 1990. Plastic houses were attributed in the beginning to small farmers with two units of houses allocated for social aspects and financed by the PDRI programme. The first experience was in the Limagues zone where one ha was planned in 1986. Further, the areas reached 11 ha in 1988 and 18 ha in 1989. Since 1990 this sector has stagnated in the range of 28 ha, but started increasing again in 2000 and reach 40 ha. The development of the greenhouse sector was very

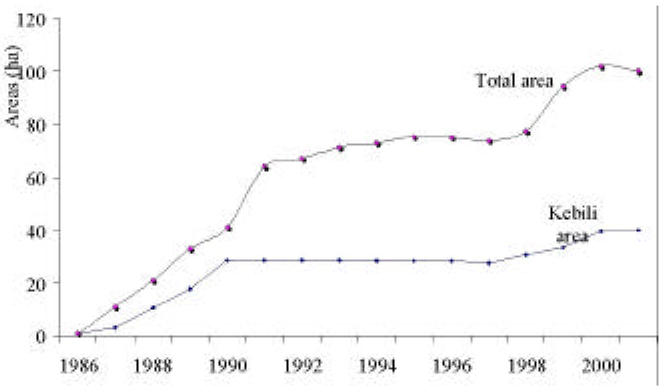

Figure 7. The evolution of the greenhouse area.

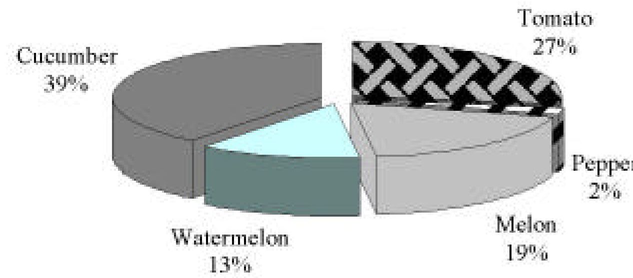

Figure 8. The crop composition (2001).

fast, at least for some farmers starting with two houses, holding now 5-6 greenhouses and sometimes 10 greenhouses. In some cases, outside the greenhouse project, farmers have parcels in which they practice oasis cultivation.

The utilization of the geothermal resources will, without a doubt, increase in the near future by the application of the remaining part of the greenhouse strategy. By the end of 2002, 14 ha (280 greenhouses) will be added in the region reaching a level of 54 ha, which represents an increase of 35%.

The Utilization of the Areas

Utilization of the greenhouse area in the Kebili region is based on three cultivations, the first, from late August to December, the second from late December to June and the third from late August to June (continuous). Harvesting takes place more than once per year and lasts over a nine-month period. The crops produced in 2000 were composed of cucumbers and tomatoes representing, respectively, 40 and 29%, melons (21%), watermelons (8%) and peppers only 2%. In 2001, cucumbers and tomatoes were also the main vegetables crops (66%) due to their commercial value and their marketability. Figure 8 shows the composition in 2001. Inside a greenhouse, several types of crops can be raised simultaneously. Growers, in this way, try to diversify their production in order to minimize the risk.

The Evolution of Productions

Despite some problems handicapping the greenhouse sector in the beginning, such as lack of qualification and poor practices of some farmers, production increased from year to year. This is not always a result of good productivity but sometimes generated by the expansion of areas as mentioned above. But, in comparison with unheated greenhouses, the geothermally heated greenhouses generate better quality and higher yields (see Figure 9).

In the season 2000/2001, the total production from heated greenhouses in the country reached 10,142 tonnes (see Table 1). The region of Kebili contributed with 37% of the total production, after Gabes with 46%.

The production in Kebili region grew from 210 tonnes in 1988 to 1,120 tonnes in 1990 and reached 1,939 tonnes in 1995. From 1996 to 2001, it varied as shown in Figure 10 with an average of 2,830 tonnes per year.

Figure 9. Example of greenhouses production.

Table 1. The Total Production in the Country

Regions	Area (ha)	Production (tonnes)	Contribution (%)
Kebili	39.5	3,7402	36.9
Tozeur	18.25	1,700	16.8
Gabes	41.6	4,657	45.9
Nabeul	3	45	0.4
Total	102,35	10142	100

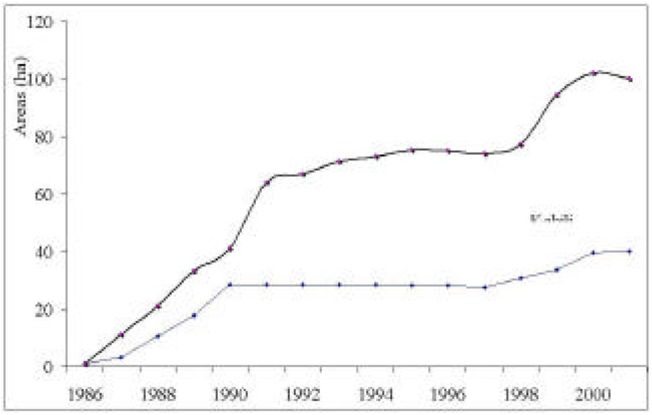

Figure 10. ***The evolution of production in the Kebili region.***

Heating of Greenhouses

Continuous low temperatures at 10-12EC during two successive days disturb the physiological behavior of plants. Paradoxically, temperatures higher than 30-38EC can provoke irreversible damage to crops. Normally, temperature variation should not exceed 5-7EC. In the south this is difficult to obtain, as the risk of temperature variation is frequent. In order to solve this problem, the use of geothermal water is a good solution, which can improve the climate inside greenhouses principally during the night. The heating is through pipes lying on the ground between the plants (Figure 11).

Figure 11. ***A typical greenhouse heating system.***

Several types of pipes have been tried and polypropylene pipes were selected (Mougou et al., 1987). Generally, an average of 8-10 loops are used per house and they are connected to the system by an easily operated valve. During the last years, an economic approach became predominant in Tunisia: the use of simple constructions and heating installations in order to minimize the investment costs. Greenhouse heating in Mediterranean countries is a typical example of an economic approach. The task is not the total conditioning of the inside climate of the greenhouse, but its optimization (Popovsky and Popovska-Vasilevska, 2001).

For heating greenhouses in the Kebili region, 12 wells are operating to supply 17 different sites. An area of 40 ha (800 greenhouses) is heated with a total flow rate of 258 L/s and a water temperature varying from 45 to 73EC.

As mentioned above, the greenhouses in the region consume 17% of the total geothermal water, and about one - third of the total flow rate of the wells supplying the sites is intended for the greenhouse heating. The rest is mainly used for oases irrigation. In the region and during the cold period, the need for heating is estimated to be 6.45 L/s per ha, which corresponds approximately to the recommended flow rate (6 L/s/ha or 0.3 L/s per greenhouse), but this amount depends strongly on the temperature of the water and the climate conditions. The need for greenhouse heating is only six months, mostly during the night. Farmers start heating in November-December and stop it in April. The duration lasts 14 hours per day. This means that they open the heating system in the afternoon when they finish working and stop it the next morning when they reach the farm (Ben Mohamed, 1995). Similarly, the total volume of water needed per season for heating is approximately 58,500 m^3/ha.

Irrigation of Greenhouses

After the thermal water has been used for heating it is collected in concrete ponds for subsequent use for irrigation. These ponds need to be large to store all the cooled water until it is used for irrigation. In some projects, farmers utilize very small and simple ponds with plastic linings, which are cheaper and very practical. Their dimension varies from 40 to 80 m^3. Generally, these ponds are used for the irrigation of an open field area close to greenhouses. The need for water irrigation during the growing period is very low (0.6 L/s/ha or 5,500 m^3/ha) compared to heating. In the region, only 10% of the total heat flow rate is used for irrigation (30 L/s). In that way, farmers utilize a local system. Water circulates inside a perforate pipeline lying on the ground. The chemical composition of the geothermal water used in irrigation must be monitored carefully to avoid adverse effects on plants because of the high salinity in the region (from 2.3 to 4.4 g/L).

The Return Water

Geothermal water is used both for heating and irrigation. From the borehole, water goes directly through pipes lying on the ground inside the greenhouse for heating. After that, it is cooled in ponds outside, and then used for irrigation. As mentioned above, only 10% of the total amount of water is used for irrigation. The need for heating and irrigating a greenhouse is respectively estimated at 0.3 and 0.03 L/s. The rest or the return water which represents 90% (0.27 L/s) should supply the oases surrounding the area, but this is often difficult to achieve.

Greenhouse heating occurs during the night, while irrigation occurs during the day. Therefore, it is necessary to store the return water in ponds to be used later for irrigation purposes. This is why two types of ponds should be installed in a greenhouse project. The first is a big one to store the return water from greenhouses for oasis irrigation. The storage capacity should be at least equal to the total volume of return water for two or three nights (Saïd, 1997). The second pond is smaller and used for irrigation of crops inside the greenhouses. In order to facilitate the water supply to the oasis, the storage pond should be located a relatively high level. Otherwise, water must be pumped and farmers will pay an additional cost. It is important to note that the location of a greenhouse project near the oasis is preferred and a combination greenhouse-oasis must be considered in the future for using return water. Figure 12 shows the proposed connections between a greenhouse project and an oasis.

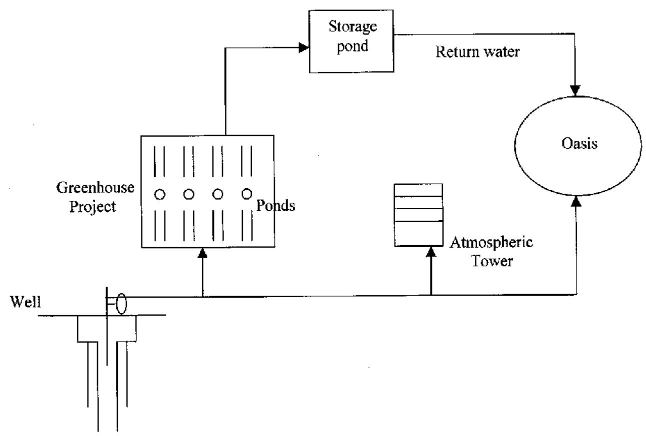

Figure 12. Proposed configuration for using the return water.

Due to poor design of some greenhouse projects, hot water sometimes cannot reach the ponds. Therefore, farmers dispose of the water close to the fields and often in the drainage system producing a large waste of water resources. Normally the return water should supply the old oases or the new ones close to the greenhouses project, but, generally, there are conflicts between users. The total amount of water returned from the greenhouses to the oases is estimated at 129 L/s, which represent 57 % of the available water.

SOIL DISINFECTION'S

Crops grown under greenhouses can cause infection by nematodes such as *Meloidogyne,* which are parasite on the roots of vegetables. Several methods are used to resolve this problem and they are classified as agronomical, chemical, physical and biological treatments. Resolving this problem chemically has negative aspects, due to:

- Environment (percolation of chemical products), and
- Residues of chemical products in fruits.

In the Kebili area, the physical method is utilized by some farmers. The geothermal water is combined with solar radiation (solarisation) and used to disinfect the soil. The idea is to irrigate the total area of the greenhouse in summer time. The techniques consist of three different steps. The first is to divide the greenhouse area into several small basins to be submerged by hot water. The second is to cover the area irrigated by geothermal water by plastic films. The third is to add a solution of formol 1‰. The plastic keeps the soil temperature as long as possible without any heat losses and improves the efficiency of solar radiation (Saïd, 1997). The experience conduced in the region showed that temperatures of 44EC and 39EC are obtained in the soil at 30 cm depth with a flowrate of 1.33 and 2.03 L/s respectively (Belkadhi, et al., 1993).

ACKNOWLEDGEMENTS

Special thanks are addressed to J. W. Lund of the Geo-Heat Center for his guidance during the preparation of the paper. I would like to express my thanks to my colleagues for their help, especially to O. Chahbani and M. Maâli (irrigated areas division), to B. Ben Bakkar and K. Boujlida (water resources department) and to M.A. Gandouzi (vegetable production division).

REFERENCES

Belkadhi, M. S.; Joost, V. D. and F. Aoun, 1993. "The Effect of the Geothermal Energy and Soil Solarisation on the Nematodes," Revue des Régions Arides, NE 1, I.R.A., Medenine, pp. 91-101.

Ben Dhia, H. and S. Bouri, 1995. "Overview of Geothermal Activities in Tunisia." Ecole Nationale d'Ingénieurs de Sfax, Tunisia, 5pp.

Ben Mohamed, M., 1995. "Analyses and Perspectives of Development of the Greenhouse Production Systems in Kebili Region," Centre International de Hautes Etudes Méditerranéennes, Institut Agronomique de Montpellier, Montpellier, M.Sc. thesis (in French), 145pp.

Mougou, A.; Verlodt, H. and H. Essid, 1987. "Geothermal Heating of Greenhouses in the South of Tunisia. Proposals for a Simple Control," *Plasticulture*, 75, pp. 41-50.

Popovsky, K., 1993. "Heating Greenhouses with Geothermal Energy," International Summer School, Skopje, Macedonia, 326 pp.

Popovsky, K. and S. Popovska-Vasilevska, 2001. "Feasibility of Geothermal Agricultural Projects at the Beginning of XXI Century." *Geo-Heat Center Quarterly Bulletin*, Vol. 22, No. 2, Klamath Falls, OR, pp. 38-46.

Saïd, M., 1997. "Geothermal Utilization for Heating, Irrigation and Soil Disinfection in Greenhouses in Tunisia," Report 13 in : *Geothermal Training in Iceland 1997*, UNU GTP, Iceland, 311-338.

Stefansson, V., 1986. "Report on an Advisory Mission 1986 in Tunisia," United Nations, New York, report, 24 pp.