Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

Geothermal Water Cooling Systems in Tunisia - Design and Practice

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Keywords: Cooling systems, mechanical draft, evaporative natural draft, atmospheric cooling, thermal performances.

ABSTRACT

Southern Tunisia is better known for its direct use of geothermal water in agriculture and domestic ends. The temperature of the geothermal water exhausting from the boreholes is quite high for its use in irrigation purposes, water temperatures range from 45 to 70°C. This is the reason to use cooling towers, widely practiced all over the region. Inefficiencies in the cooling process of these towers are noticed that result in a low thermal efficiency of the heat-exchanger surfaces with insufficient ventilation, excessive consumption in energy, presence of layers of sediment, proliferation of algae, corrosion problems, and important steam and heat loss release in the atmosphere. Careful and accurate analyses of cooling tower designs are desirable to develop rationally the concept of an optimized cooling geothermal water system convenient for irrigation purposes in South Tunisia conditions.

In this paper we describe and identify the main different cooling systems designs used in the south of Tunisia and we investigate factors relevant to the implementation of geothermal water-cooling systems including economical consideration, technical and operational appropriateness

1. INTRODUCTION

In Tunisia, geothermal resources have been known since ancient times when they were widely utilized to support establishments for therapeutic hot bathing. In last decades, an application of geothermal energy was applied where low temperature geothermal water is used as a source of heat. Agriculture applications in the south part areas characterized with a cold winter season that ordinarily prevents crop production and processing. Beyond their direct application for heating, geothermal water constitute the main water resources potential for agriculture use.

Most agronomic crops are sensitive to episodes of high water temperature and their use directly may damage crop leaves in most environments (Kobayashi *et al.* 2003). Vulnerability of crops to damage by high temperatures has driven the use of cooling towers for dropping temperature to an appropriate level for crop growth estimated in the range between 30 to 32°C (Ben Mohamed, 2003).

First generation of cooling towers began in 1960's, the first unit was built in El Kebayett localized in the region of El Hamma. As with all pioneering activities in a new technology, the use of cooling systems was beset with problems. These concern low thermal efficiency of the heat-exchanging materials and the significant amounts of deposits on the piping systems. These were relatively simple to overcome in the case of the Tunisian geothermal resources owing to the fact that geothermal water emerges from the reservoir at temperature rang from 45 to 70°. As such it could be cooled in more or less conventional towers, albeit ones built with appropriate conception and materials to allow for problems of corrosion and efficiency.

It was not until 1980's, however, that the mechanical draft cooling towers was first introduced for geothermal water cooling in order to improve thermal efficiency process. The accomplishment of this feat was credited to the national program for oasis management of south Tunisia.

These systems used dynamic ventilation to extract atmospheric air. It consists of a fan to extract intake air, a heat transfer medium, a water basin, a water distribution system, and an outer casing. The excessive consumption in electrical energy and the important steam and heat loss release in the atmosphere constitute the main constraints for the cooling process.

From 1997's, new generation of cooling systems are established in the area, thus marking the beginning of the diversified designs and conception of cooling process avoiding the mechanical draft cooling towers: Spiral, cascade, multiple ponds…

Owing to the different designs of cooling systems distributed widely in the region and the potential of cooling efficiency, these systems will be investigated in the present work to meet the expected future conception with reference to conditions in Southern Tunisia.

In this paper potential and exploitation of geothermal aquifers are reported and discussed. Also, it outlines the technical details related to main cooling designs currently under exploitation in the southern part of Tunisia. Description and identification of the technological solutions available for cooling systems and the assessment to exploit the thermal aquifers typical of this region are also discussed. A new approach to improve efficiency of cooling systems incorporating main research topics, leading to high efficiency of geothermal cooling systems, is reviewed.

2. GEOTHERMAL WATER RESOURCES

South Tunisia can be divided into the following major geothermal aquifers *(Fig 1)* :

The Continental Intercalaire, CI,- extends over an area of 600 000 km^2.in the hole 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) and temperature reaching 70°C. The geothermal water resources have been estimated for 550 Mm3/year with a TDS range from 2.5 to 5g/l (H Zebidi, 1991.)

The Complexe Terminal CT, with geothermal aquifers, lies 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.

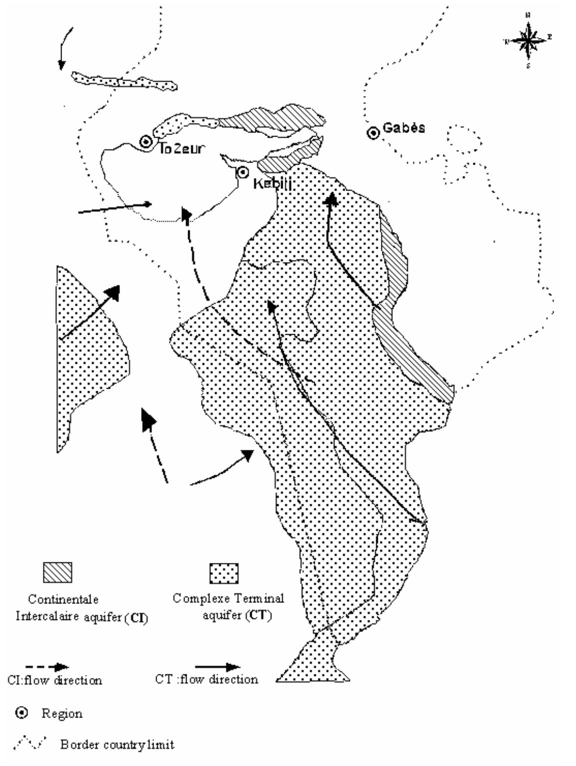

Figure 1 : Geothermal water resources in the south of Tunisia

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.1.

Table 1 : 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 %

Sources: Economie eau 2000

The geothermal aquifers are being utilized at rates exceeding their sustainable yields. The complex terminal reservoir is of particular concern because it is the most over utilized aquifers. Over pumping rate in this aquifer has exceeded 110 MCM/year in 2001. Actually, at the combined withdrawal rate of all non renewable geothermal aquifers approaches 636 MCM per year, a rate equal to 116% of their sustainable yield.

The over pumping from complex terminal aquifer in the 1980s and 1990s has exceeded the safe limit. It is feared that this unpleasant experience will be repeated in the other aquifers if they are not rescued through proper management.

Withdrawal from non-renewable fossil aquifers shall be made carefully and after elaborate studies and investigations. A lifetime will be assigned for each of these aquifers and an abstraction rate specified accordingly.

Priority shall also be given to the sustainability of existing irrigated agriculture where high capital investment had been made. In particular, greenhouses irrigated from groundwater shall continue to receive an amount sufficient for their sustainability with the use of advanced irrigation methods.

Expropriation of use rights arising from legal use of geothermal groundwater established on borehole drilling for greenhouse heating projects shall not be made without clear higher priority need, and against fair compensation. In fact, water extracted for these projects during cold winter period exceeds 10 times the crops needs for irrigation Chaibi and Attia (2003). A contingency plan shall be made and updated for the purpose of allocating the water from privately operated wells for use in the heat agriculture application projects.

3. COOLING SYSTEMS DESIGNS

In south Tunisia, most geothermal cooling water plants are built for agriculture applications. Inefficiently in the cooling process will result in a low thermal performance with insufficient ventilation, excessive consumption in energy, presence of layers of sediment, proliferation of algae, corrosion problems, and important steam and heat loss release in the atmosphere. These plants are very diversified in designs and conception.

The discussion about geothermal water cooling designs can be classified into three main categories: the mechanical draft cooling towers, using fan to extract atmospheric air, evaporative natural draft cooling towers, and empirical systems with various designs based on contact with atmospheric air.

3.1. The mechanical draft cooling towers

The widely used mechanical draft cooling is the one using the cross flow induced draft cooling towers. In this system, as shown in *Fig 2*, the fan is located downstream from the fill at the top exit.

Fig 2 : The mechanical draft cooling tower

The fill, usually composed of palm trees, is installed at the same level as the air intake. Atmospheric air is drawn by the fan from side louvers and moves horizontally through the fill. Geothermal water is evenly sprayed from nozzles and distributed over the fill and falls down into the water basin. Air is extracted across and comes in contact with the water film.

Because of the evaporation of small portion of the cooling water, about 1 percent of the water flow, the temperature of the water gradually decreases as it falls down to the fill countercurrent to the extracted air (humidifies, air washers and cooling towers) .

Water vapor is absorbed evenly by the air stream. Large droplets entrained in the air stream are collected drift eliminators. Finally, the air stream is discharged at the top exit. The evaporative cooled water falls into the water basin and flows to canals for irrigation purposes.

The cross flow induced draft cooling tower has a greater air intake area. Because of the cross flow arrangements, the tower can be considerably lower than the other mechanical draft cooling towers categories, therefore, requires a lower pump head. However the risk of recirculation of tower exhaust air increases.

3.2. Evaporative natural draft cooling towers

Cooling water sprays over the fill in wood or concrete slab, from top and falls down to the water basin. Air moves across the fill and comes in direct contact with the water.

Because of the evaporation of the water, its temperature gradually decreases as the flows down along the fill in the counter-flow arrangement with the air. Finally, the air stream is discharged from the side louvers surrounding the tower.

Because the tower is not equipped with fan, circulation of tower exhaust air is inefficient compared to that of the mechanical draft tower. Also, in windy days, very frequent in the region, larger water droplets are lost in the ambient air due to the great air intake area of the tower.

Thus, the disadvantages of this type of cooling tower are the uneven distribution of the air flowing through the fill, which is caused by the static ventilation. In addition, the natural ventilation may recapture a portion of the warm and humid exhaust air. Evaporative natural draft cooling towers, often called aerial ventilation tower, have been used to overcome the extra cost of electrical energy consumptions caused by fan use.

3.3. Atmospheric cooling types

Although most atmospheric cooling systems, widely built empirically all over the south region, are similar to the basic principle, it seems that the subject has captured many scientists' fancy and imagination. The result has been the production of the wide variety of designs and pilot plants which have been able to cool geothermal water. These cooling devices are classified mainly as cascade or spiral system.

In cascade system, cooling water go through successive vertical falls *(Fig.3),* before being collected in the main basin composed by several reservoirs communicated with pipe at their bottom level. The cooling water transited successively over these reservoirs is collected finally in the water basin to be supplied for irrigation areas.

Because the cooling process is based mainly on the reservoir surface contact with atmospheric air, the decrease in water temperature is considerably low.

In spiral system, geothermal water is circulating through a concrete canal in spiral shape. In its transition, the water is evaporatively cooled by contact with atmospheric air. This system has been improved by introducing a better ventilation of the device. Cooling water falls over successive concrete slabs before falling down to the spiral canal. Because of the evaporation of the water in falling process, temperature gradually decreases before reaching the spiral canal. For a better evaporative cooling effect, water is deviated to seguia (open canals) after completing its circulation into spiral canals.

Figure 3: Cascade type

3.3. Operational problems

Aside from economical problems associated with the operating of cooling systems, a number of technical problems can cause operational difficulties. Some of these are related to local conditions, while others are dependent on the physical design of the cooling system.

These difficulties usually result in reduced efficiency rather than outright failure but, since the cooled water temperature is already rather elevated, any reduction can be a serious matter for geothermal water users. Given a good basic design for solar desalination devices, the following tasks and problems should be considered.

- Water vapor loss: Vapor losses are considerable in geothermal cooling systems. They occur mainly through evaporation into the exhaust air stream. Evaporation provides for 80 percent of the cooling. Within the evaporation, water droplets and bubbles could escape from cooling tower. They are estimate to be 4% of the total water flow rate which correspond to 10^6 m^3 $year^{-1}$ Kairawani et al (2004). These drift emissions are made up to large and small water droplets and bubbles. Large drops and bubbles are relatively heavy and may settle or condense in the vicinity of the cooling towers. Small bubbles and droplets travel further and can be lost outside the system. In order to operate efficiently, cooling systems should have an appropriate design to avoid loosing water vapour in the ambient. These collecting water losses from geothermal water cooling devices could partly solves water scarcity problems and also induces tourist and agriculture development in the region.

- Scale and corrosion prevention: geothermal waters include small quantities of organic materials and dissolved gasses, but the majority of the dissolved materials are inorganic salts. Salts are compounds made up of positive metallic ions or radicals bonded to negative ions. Many of these salts are quite soluble in geothermal water and are derived from rocks in the earth's interior.This continual load of dissolved salts is deposited during cooling process. Deposits contains nearly all the salts that were in the original solution are trapped in the cooling device components mainly at the tower fill (heat exchanging surfaces) and piping system. Proper water treatment practices could improve heat transfer efficiency and greatly extends the life of the cooling systems. This is accomplished by keeping corrosion and scale buildup at a minimum and maintaining systems at a minimum of corrosion. Keeping heat transfer surfaces clean greatly reduces the systems energy consumption especially for mechanical cooling systems.

- Organism accumulations: The growth of algae and other microflora particles in the water aeration orifices generally reduce cooling process particularly for mechanical cooling towers. It is important that the entire cooling tower be readily accessible to clean out these growths and wash off areas on which organism deposits have formed.

- Availability of spare parts: lack of spare parts could affect the operating system and contribute to the abandonment and/ or the destruction of the cooling tower device. Many mechanical cooling towers have been converted to natural cooling towers due to the lack of the availability of spare parts related to the ventilation equipment or have been associated, for economical reasons, with replacement of equipment by local ones.

4. COOLING SYSTEMS PERFORMANCE

Proper analysis of operating cooling systems has to consider all parameters affecting their performance. For cooling towers, these parameters concern the: water-air ratio, fill configuration (heat exchanging surfaces), and water distribution system. In atmospheric cooling types, the parameters are mainly based on the geometrical characteristics of the systems.

In the following analysis, there is no attempt to investigate technical performance explicitly for each process, but only an effort to show general performances including the effective removal of the total heat rejected and the temperature difference between entering and the leaving cooling water temperature characterising every cooling systems. However, indication of the important operating factors and their roles may be identified by a limited analysis.

4.1. The Mechanical draft cooling towers

The efficiency results obtained from the present technique are illustrated in *Figs.*4 and 5 with the actual size of a sample cooling tower in this example. The efficiency is characterized by the heat flux lost by the hot water during its passing through the exchanger. It is given by the following formula:

$$\Phi = \rho\, Q_e\, Cp\, (T_{in} - T_{out}) = \rho\, Q_e\, Cp\, \Delta T \qquad (1)$$

where Φ, Q_e, Cp ,T_{in} T_{out}, are heat flux, volumetric fluid flow rate, calorific capacity, inlet and outlet temperature.

The geothermal water temperature gap is given by :

$$\Delta T = T_{in} - T_{out} \qquad (2)$$

The bench cooling tower, built in the 80's, used generally in south Tunisia, is considered with the following specifications:

- Dimensions: 11.5*(5.4*12)
- Fill: Heat exchanger: palm wood
- Ventilation : Air fan: 15KW

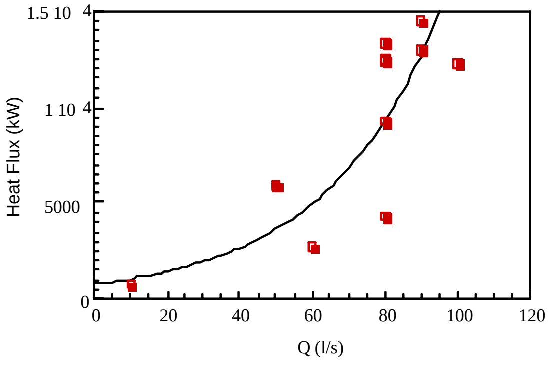

Fig 4: Variation of the heat flux versus the geothermal water flow rate (Mechanical draft cooling towers)

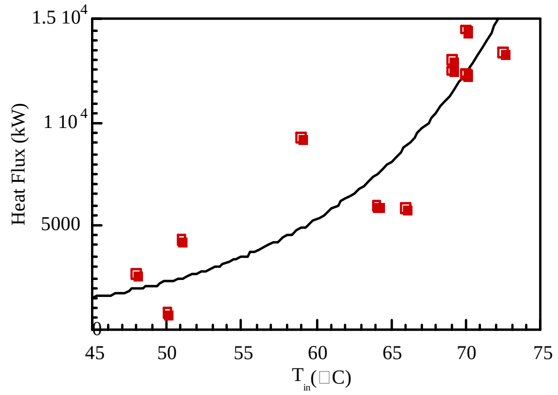

Fig 5: Variation of the heat flux versus the inlet geothermal water temperature (Mechanical draft cooling towers)

According to the *Figs 4 and 5* it can be seen that the heat flux recovered in the exchanger increases significantly when the flow rate or the inlet temperature of geothermal water increases. This tendency can be explained by the increase of the convective heat transfer coefficient between the pulverized water and the air flow with these parameters. A heat flux of 1,5 10^4 kW can be obtained for an inlet water temperature of 70°C and a flow rate of 100 l/s.

These results highlight the importance of the two parameters temperature and flow rate for the cooling system performances.

During the field test, measurements were taken for each water flow rate entering the cooling tower and its outlet temperatures. Seven sets of the measured of average water temperature at entering and leaving the cooling tower for different water flow rates and a fixed inlet water temperature of about 70°C are illustrated in *Fig.6.* It can be observed that the cooling water temperature increases as the water flow into the tower.

The average difference is about 33° for an average water flow of 73l/s. the lowest absolute difference is 29°C and the largest difference is 37°C for respectively water circulating rate of 100 and 60l/s. The greater the water circulating rate, the smaller total heat removed from cooling water Milosavljevic and Heikkila (2000).The water flow rate and the flow rate of air should be constant for the design requirement of the mechanical cooling tower (Soylemez 2001).

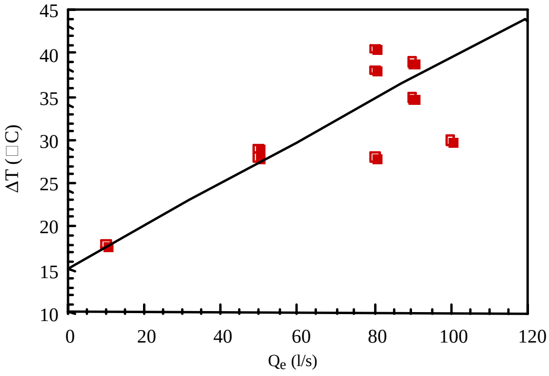

Fig 6: Variation of the geothermal water temperature gap versus the geothermal water flow rate (Mechanical draft cooling towers)

The major disadvantage of this kind of cooling system is the high quantity of water lost in the atmosphere. *Fig 7* shows the variation of the amount of evaporated water m_{ev} versus the geothermal water flow rate. This figure shows that 180 m^3 of water can be lost by day when the flow rate is about 100 l/s.

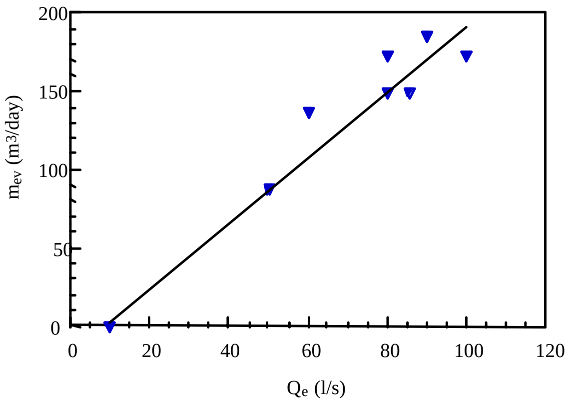

Fig 7: Influence of the geothermal water flow rate on the water waste by evaporation (Mechanical draft cooling towers)

4.2 Evaporative natural draft cooling towers

A total of 10 data sets from different natural cooling towers were taken under various operating conditions. The difference of inlet and outlet measured temperatures are illustrate *in Fig. 7,* where as the calculated output variables are mass of evaporated vapour. The ranges of the water inlet temperature operating conditions employed in this investigation are 60-65 °C. The dimensions of the tower are the same as the mechanical tower and the heat exchanger materials surfaces.

Fig 8 shows a decrease in the difference between the inlet and the outlet cooling water temperature with water flow rate. However, the rate of decrease is different and significant in some parameters. For example, when heat exchanger is different from concrete to palm wood, which means a decrease cooling water from 28°C to 21°C, about 25%.

Regardless of the scattering of data and the small range of change of inlet air humidity ratio, the trend of the cooling efficiency parameter agrees with that expected. It can be seen from the figure profile that an increase in water flow by 2 times decreases the rate of cooling temperature by about 35%. This result leads to a decrease in efficiency of the system. The average difference is about 22° for an average water flow of 37 l/s.

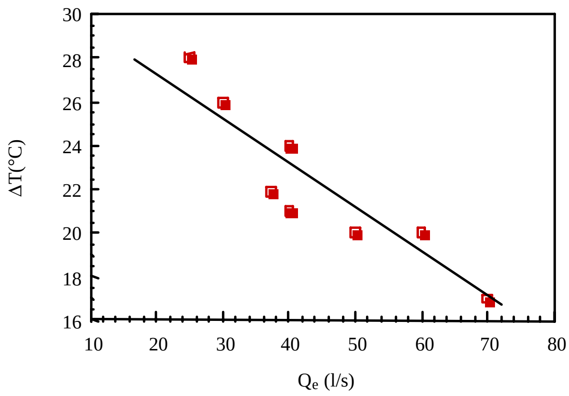

Fig 8: Variation of the geothermal water temperature gap versus the geothermal water flow rate (Evaporative natural cooling towers)

The influence of the geothermal water flow rate Q_e on heat flux lost by the geothermal water inside the exchanger Φ is plotted in *Fig* 9. The experimental results obtained show a continuous increase in the amount of heat flux when the water flow rate increases. This increase is more pronounced for a low flow rates. For high flow rates Φ increases slightly and reach a maximum of 5000 kW for Q_e = 60 l/s. This value is much lower than obtained with the mechanical draft cooling towers (15000 kW). However, the energy consumption of the latter system is much more important.

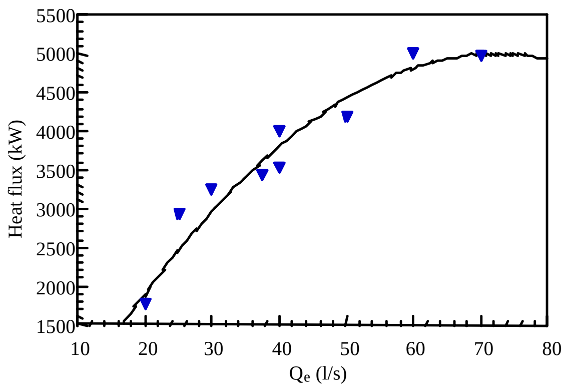

Fig 9: Variation of the heat flux versus the geothermal water flow rate (Evaporative natural cooling towers)

4.3. Atmospheric cooling towers

Efficiency of this cooling capacity of the spiral process depends mainly on the geometrical characteristics of the heat exchanger surfaces that should meet the required total heat release at the water cooled system. The geometrical characteristics are indicated mainly by the lengths of the water transition through the open canals.

For cascade cooling process, the number of cascade basins and water falls constitute the main factors for cooling efficiency. which include both the contact atmospheric surface and the depth of water falls.

An increase of the process cooling capacity may be attributable to a longer spiral canals or a higher number water falls or both. For a range circulating water flow rate between 20 and 50l/s an increase of cooling efficiency may caused by a better geometrical system configuration.

Fig 10 shows a plot of the observed data related to the difference between inlet and outlet water cooling against the circulating water flow rate for different configuration atmospheric water cooling processes. The cascade process gives the lowest absolute difference with a an average value of 6°C and the largest difference is about 34°C for water circulating rate of 35l/s in the spiral process having the length transition higher than 3000 ml.

The effect of the spiral canal length on the cooling efficiency is shown in *Fig.* 10. As expected, the average cooling rate, ΔT, decreases by about 10°C when spiral canal length is increased by 2500 ml . Therefore, it corresponds to a decrease in water temperature of 0.004°C/ml.

Length canals for spiral cooling system have a direct effect on cooling efficiency. A longer canal with higher number of falls has a greater surface area per unit length, which means more contact surfaces, a longer contact time, and ultimate contact between air and water.

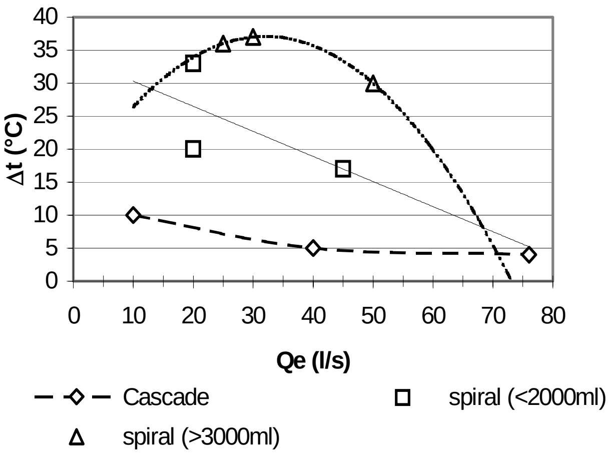

Fig 9: Effect of configuration on cooling performance (atmosphericl cooling towers)

5. RESEARCH DEVELOPMENT

The present investigation shows that the use of cooling geothermal water systems is confronted to several problems. To solve these problems the following research fields should be developed:

- Makeup water pretreatment: Scale prevention and removal: . Pretreatment of makeup water to cooling towers reduces the chemical treatment requirements for scale and corrosion control. Pretreatment reduces dissolved solids in the makeup water through precipitation and flocculation, softening and ion-exchange. Suspended solids are removed by clarification and filtration. Pretreatment may not be economical for cooling towers those used in agriculture purposes but is advantageous for industrial cooling towers.

- Improvement of the construction materials: Using inert construction materials. Polyethylene (PE) and stainless steel (SS) are relatively non-reactive. Therefore PE and SS towers would require relatively lesser quantities of scale and corrosion inhibitors.

- Increasing the heat and mass transfer efficiency of cooling towers: Increasing the heat and mass transfer efficiency of cooling towers. Efficiency can be enhanced by improving the design of the cooling towers. One example is to avoid designs where sunlight can shine directly on the water; adding to the cooling load an promoting biological growth. Increasing the efficiency will result in the usage of small towers that need less treatment chemicals.

- Increasing the efficiency of drift eliminators for mechanical draft cooling towers (such as waveform and advanced interlaced monofilament eliminators) claim to reduce drift by 80%. However, even these eliminators are not capable of capturing most of the smaller droplets and bubbles.

- Significantly improved local materials for heat exchanging: Use of local materials for heat exchanging surfaces. The palm wood, available in oasis areas, combine the advantages of higher exchange surfaces, economical and may be viable alternative in the case of agriculture cooling towers for agriculture purposes.

- Economical consideration

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