

Analysis of the Feasibility of Combined Concentrating Solar Power with Multi Effect Desalination for Algerian Coast

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Abstract- The combined solar tower concentrating power plant (CSP) with multi effect distillation (MED) unit was studied in this work. Five sites in the coastal zones of ALGERIA are examined based on dynamic modelling, which was performed by TRNSYS 17 software, in order to investigate the feasibility of this type, an economic analysis was done. The MED unit is incorporated to replace the condenser in the power block system (cogeneration by exploiting the heat ejected by the condensation of the steam in the power block). The Technico-economic results obtained show that the cogeneration in the concentrating solar tower power plant can produce the electricity and the fresh water for the different zones tested in good proportion. In the proposed study, the produced fresh water quality with MED unit is not affected with the solar radiation intermittence and fluctuation in partial load, in which, only the quantity of produced water varied according to the steam flow entered in the MED unit. The obtained results for the examined sites show that the Algerian coast is suitable for the technology of CSP-MED.

Keywords Seawater Desalination, Concentrating Solar Tower CSP, Heliostats field, Multi effect Distillation, Levellised cost.

1. Introduction

The consumption of energy and water increased proportionally with the technological and industrial development, the scarcity of water drive the widespread use of seawater desalination. The Middle East and North Africa (MENA) region, in fact is the most water scarce region of the world. High population growth rate, urbanization and industrialization, coupled with natural water scarcity in this region are leading to serious deficits of freshwater availability [1].

Seawater desalination is a technology that offers the potential to alleviate the problem of fresh water shortage. Desalination is the process of deleting or cleaning the salt

from the seawater or brackish water. The desalination process is divided into two types: by the filtration and by evaporation.

The desalination by filtration method uses reverse osmosis membrane RO in which the feed water is pressurized (60 bar to 80bar) and applied to one side of membrane [2]. The filtration method uses the electricity to operate. Evaporation process is based on the thermal method of desalination; they use a heat source (fossil or renewable source). The important desalination processes driven by thermal energy are the multi stage flash MSF and multi effect distillation MED.

The main advantage of thermal processes desalination is the use of the thermal power directly without converting to electricity, in which the efficiency of the thermal cycle is

very high that the electricity production cycle. In addition, the water quality produced by MED is about 10 ppm [3] while by membrane is 200-250 ppm [4].

Algeria, one country in MENA region, has included seawater desalination as part of its action plan objectives in the coastal zones. Many units are installed, the lasted one is located at MACTAA Oran (North West of Algeria) with 500 000 m³/day which use the Reverse osmosis technology. The conventional power plant (steam or gas turbine) used to assure the power electric needs for the operation of the 13 desalination units in Algeria coastal zones. The exploitation of renewable energy sources to produce electric energy and fresh water is commonly considered a very promising way to reduce the pollution and the environmental impact [5,6]

However, all conventional desalination technologies face a big drawback because they are intensive fossil fuel systems that cause environmental hazards. Many places in the world are short of water, but some of them are located in coastal zones and have good level of solar radiation that could be used to drive desalination processes [7]

Algeria has a potential solar importance, with 2500 hours of sun in year and 1700kWh/m² in year (see table 1), it is classed in the best favorite zones to install the solar CSP plant.

Many efforts have been devoted for using the renewable energy (wind and solar) for the desalination in the coastal regions as well as in arid regions. In this sense, Abdeslame Dehmas and al [9] have presented an analysis of wind power plant with capacity of 10MW to power 5000 m³/day seawater reverse osmosis desalination in the region of Ténès, Algeria.

An economic analysis of the environmental benefits was done. The adapting of the wind intermittence and fluctuation are not presented. Later, Triki and al [10] have studied the feasibility of using 1 MW stand-alone wind turbine to power a brackish water reverse osmosis desalination unit (BWRO). An electric battery is used to cover the intermittence and fluctuation of the wind and to assure the desalination plant operation during 24hours/day. The proposed installation is tested for three southern Algerian zones (Adrar, Timimoun and Tindouf). The LWC was found to be 0.66 \$/m³ at Adrar, 0.7 \$/m³ at Timimoun, and 0.75 \$/m³ at Tindouf. On the other hand, Mahmoudi and al [11] have proposed a new brackish water greenhouse desalination unit powered by geothermal energy in Algeria. Geothermal energy is used to heat the greenhouses and to provide fresh water needed for irrigation. About the research of desalination in Algeria using solar thermal energy, Several paper have been published by different authors focusing on small size direct solar desalination using solar energy is still in arid area in southern Algeria.[12,13,14,15,16]

Recently, Palenzuela and al [17] investigate the potential of low temperature multi-effect LT-MED distillation and thermal vapor compression multi-effect distillation TVC-

Table 1: Solar potential in Algeria zones [8]

Region	Coastal region	Highlands	Sahara
Area (%)	4	10	86
Sunshine average (hour/year)	2650	3000	3500
Solar energy received (kWh/m ² .year)	1700	1900	2650

MED coupled with a concentrating solar power plant parabolic trough, The results show that the combination with LT-MED is more efficient thermodynamically than with TVC-MED.

Casimiro and al [18] present the adding of a new functionality to the System Advisor Model (SAM) to simulate the cogeneration of water and electricity with (CSP), and Forward Feed Multi-Effect-Desalination plants. The results show that the usage of multi effect desalination MED unit system in cogeneration with a CSP plant can be feasible and has the potential to be economically interesting.

Hassabou and al [19] have used a transient numerical analysis and techno economic assessment of a concentrated solar thermal system to drive a Multi-Stage Flash desalination plant with 5000 m³/day capacity in MersaMatruh city on the Mediterranean coast of Egypt. A cost analysis carried out to explore the potential of CSP-driven MSF and additionally for Reverse Osmosis (RO) desalination technology driven by concentrated solar power in comparison with fossil-fired desalination. The results of this analysis show that associated cost of Multi-Stage Flash CSP-MSF (thermal process) is approximately 3 times more costly than both CSP-RO and fossil-fired systems.

Three different technical mainstreams were addressed in the study of the combined concentrating solar power and desalination CSP&D: decentralized desalination plants are directly powered by concentrating solar thermal collectors in small-scale; concentrating solar power stations providing electricity for reverse osmosis desalination (CSP/RO), and finally combined generation of electricity and heat for thermal multi-effect desalination systems (CSP/MED) [20].

Casimiro and al [21] present a pre-study on the feasibility of the usage of CSP technologies to power desalination units (CSP + D), a description of a new model created and implemented in TRNSYS environment has been done.

From the above researches about the use and the feasibility of renewable energy to aid desalination in Algeria, all researchers have never considered the effect of the combining CSP solar power plant and multi effect distillation (MED) unit to the best of our knowledge. However, the key aim in this work is to investigate the feasibility of combining CSP solar power plant and multi effect distillation (MED) in Algerian coastal zones. The current investigations are performed using technico-economics analysis for different

sites located from west to the east of the coast (AinTemouchent, Mostaganem, Tenes, Boumerdes and Jijel).

2. Description and Methodology

The system under consideration is described in fig 1. The system consists of a concentrating solar tower power plant (CSP) based on a superheated ranking cycle where steam is the working fluid. The solar plant consists of heliostat mirrors field distributed around the tower. In this tower, the receiver is located, and the heliostats track the sun in tow axis during the day to ensure continuously focused sunlight on the receiver.

For the desalination unit the MED technology is considered for combination with the solar tower CSP power plant. In this case, the desalination process operates via the thermal power evacuated by the condenser of the power block system.

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In the study case, the MED desalination process operates via the thermal power evacuated through condensation of the steam come from the turbine in the power block system

The MED unit replaces the condenser in the conventional Ranking cycle. The steam comes from the turbine (70°C of temperature and pressure of 0.31 bar) condensates in the first effect of the MED plant and after the condensing, it continues the Ranking cycle passed with the pump and the steam generator. On the other hand, the seawater evaporates by latent heat of condensation of the steam.

2.1 The multi effect unit

The steam flux condensing at temperature of 70°C [22] in the first effect of MED unit, in which the seawater evaporates. The fresh water production is directly related with the steam flow divided by the turbine, in this case on used relationship to evaluate the water production by the MED unit. One parameter necessary to evaluate the fresh water production is the Gained Output Ratio or GOR, is a measure of how much thermal energy is needed in a desalination process. The definition is as follows:

$$q_{Steam} = \frac{FWF * \rho}{GOR} \tag{1}$$

Where FWF is the fresh water production in m³/day, the fresh water density in kg/m³. GOR is the gained output ratio, this parameter defined as the amount of distillate produced for every mass unit of steam

supplied to the distillation unit. In this study case, the GOR has been considered of 9.8 [22]

The performance ration PR defined using the (eq.2), this parameter is used for evaluating the performance of MED plant [23].

$$PR = \frac{Distillate\ flow\ rat\ (kg / s) * 2300(KJ / s)}{Power\ Input\ in\ first\ effect(KW)} \tag{2}$$

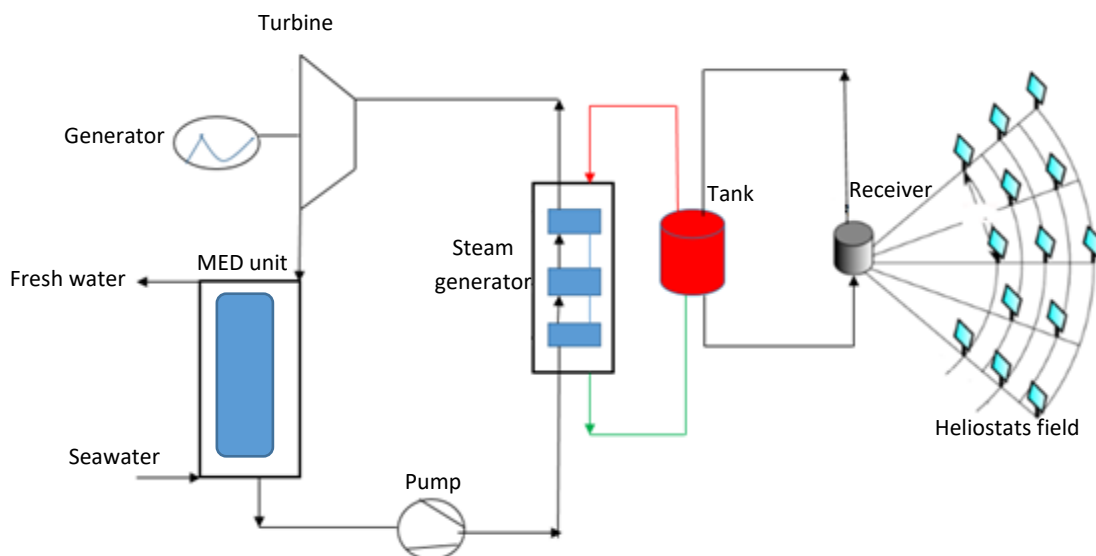


Fig. 1. Diagram of the MED unit integrated into a concentrating solar tower CSP plant

In this case, we calculate the fresh water produced according to the steam mass flow existing, and the MED plant assumed to operate only during the periods when the Ranking cycle is operating.

2.2 Power bloc system

The power block represents steam turbine super heat ranking cycle, the temperature of the steam in the inlet of the turbine is 380°C, and the pressure is 100 bar. In this work, the power produced is fluctuated with the solar radiation, because the necessary thermal energy driven by the solar receiver, the system is working only in the sunlight hours without storage or hybrid system.

In TRNSYS software, we used STEC bibliography for the dynamic simulation of the concentrating solar tower, each component is injected in the simulation studio and the various components communicated by constraints [24]. The steam enthalpy in the outlet of the turbines has been calculated through:

$$\eta_{st} = \frac{h_{in} - h_{out}}{h_{in} - h_{out,i}} \quad (3)$$

The power collected with the heliostats field is evaluated by:

$$Q = A_{field} \cdot \rho_{field} \cdot I \cdot \eta_{field} \cdot \Gamma \quad (4)$$

Using the surface area, the reflectivity coefficient of mirror, the direct solar radiation, and the field efficiency, the net power driven by the receiver is evaluated by the equation:

$$Q_{net} = \alpha Q_{inc} - Q_{conv} - Q_{rad} \quad (5)$$

where the subscripts *inc*, *conv*, and *rad* stand for the incident power, the power losses to convection, and the power losses to radiation, whereas α represents the optocale efficiency of the heliostats field.

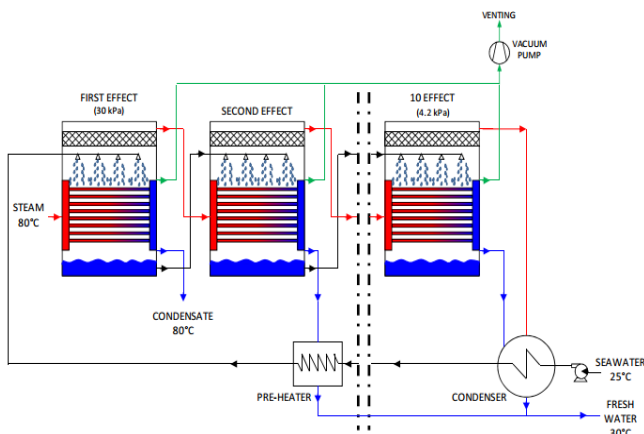


Fig.2. Principle of The multi effect desalination unit [25]

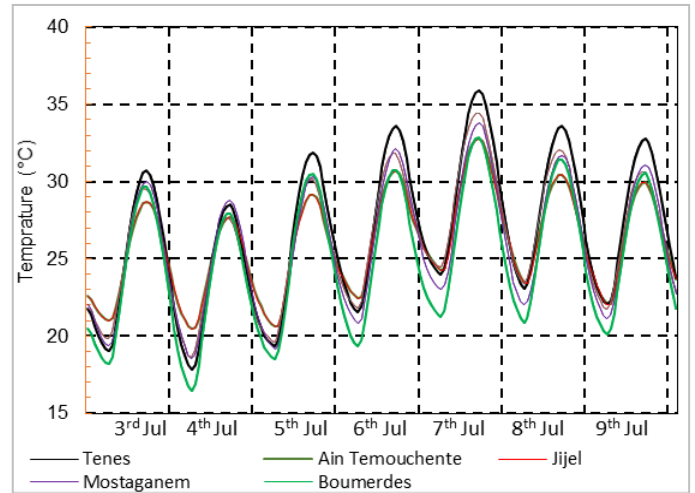


Fig. 3. Temperature variation in the different selected.

The efficiency of the solar receiver is the ration of the power net transferred to the power bloc system with the incidence power.

$$\eta = Q_{net} / Q_{inc} \quad (6)$$

3. Climatic and Radiometric Condition of the Five Coastal Zones Studied

3.1 Temperature ambient and direct radiation DNI

Fig 3 illustrates the status of the ambient temperature variation for the five sites studied from 03 to 09 July. As shown in this figure, the temperature ambient varied between 15°C in the night and 35°C in the day. For the solar power plant, the thermal losses in the receiver of the solar tower are inversely proportional with the ambient temperature.

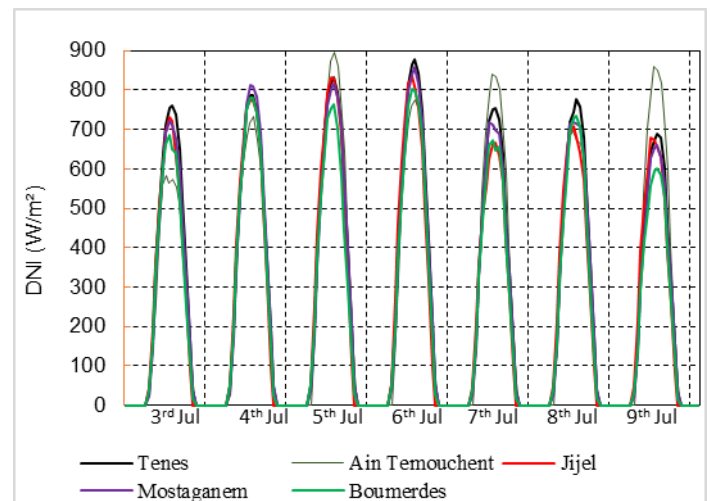


Fig.4. Direct solar radiation DNI (from 03to 09 July) for

3.2 Direct normal radiation DNI

As shown in fig 4, the variation of the direct radiation for the different areas examined, the direct normal radiation DNI exceeds 600w/m² and reached the value of 900w/m². For the concentrating solar power plant the DNI one factor necessary to the dimensioning of the heliostats field area, the DNI and the heliostats field area are reversely proportional. the sunshine duration is around 12 hours per day.

3. Results and Discussion

4.1 Temperature in the different element in the plant (solar receiver; tank, turbine)

In this work, the CSP plant operates only in the sunny times, the thermal storage and hybridization not taken into account. Therefore, the absence of fossil source justifies that this type of plant installation is environmentally friendly.

As observed in the figure below (fig.5) the heat transfer fluid (HTF) entered in the receiver at temperature of 220°C and exit with temperature of 570 °C. In the dark period and in the night when the direct solar radiation DNI equals zero, the HTF fluid stocked in the tank at temperature of 220°C to avoid the freezing in the pipe (molten salts).

In this study, in the modeling we used in TRNSYS a receptor solar with imposed temperature (fixed temperature), but the mass flow of hot HTF come from the solar receiver varied according of the available solar energy provided from the heliostats field.

In other part in the solar heat recovery steam generator (SHRSG) the work fluid inlet in the economizer at 73°C and quite the superheated at 380°C with fixed pressure of 100 bar. The steam mass flow also fluctuates with the solar power availability.

4.2 Net electric power produced by the system

Fig 6 clarifies the hourly power produced by the CSP solar tower power plant in the period (3rd - 9th July) for different selected coastal sites examined. It is observed that the produced power varied according the direct solar radiation DNI; the power at maximum solar radiation exceeds 10MW in some days. However, in the sunrise and sunset the DNI and the power are minimal, the thermal storage technologies permit to produce the electricity some hours in the nigh, in this work the power plant operates without thermal storage. In addition, fig 7 summarizes the arithmetic average of net power produced by the solar tower CSP plant for one day. The average duration of insolation is around 12 hours. The variation of the produced power in the TENES region is more stable in the studied days compared with the other regions (see fig 6). The obtained results in fig 7 shows the total daily electric power produced in MWh per day for the different areas. The daily power produced in each zone is as follow: 72.4MWh/day in TENES, for AIN TEMOUCHENT 53.8 MWh/day, 64.9 MWh/day in JIJEL, 66.7MWh/day in MOSTAGANEM, and 61.2MWh/day in BOUMERDES.

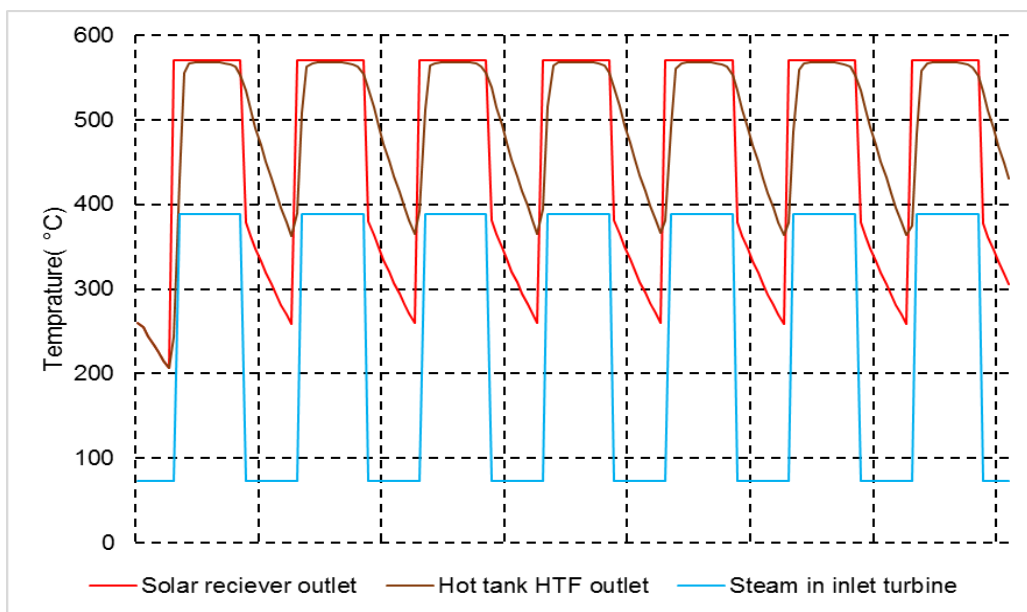


Fig. 5. Temperature value in the receiver solar tower and the power block system

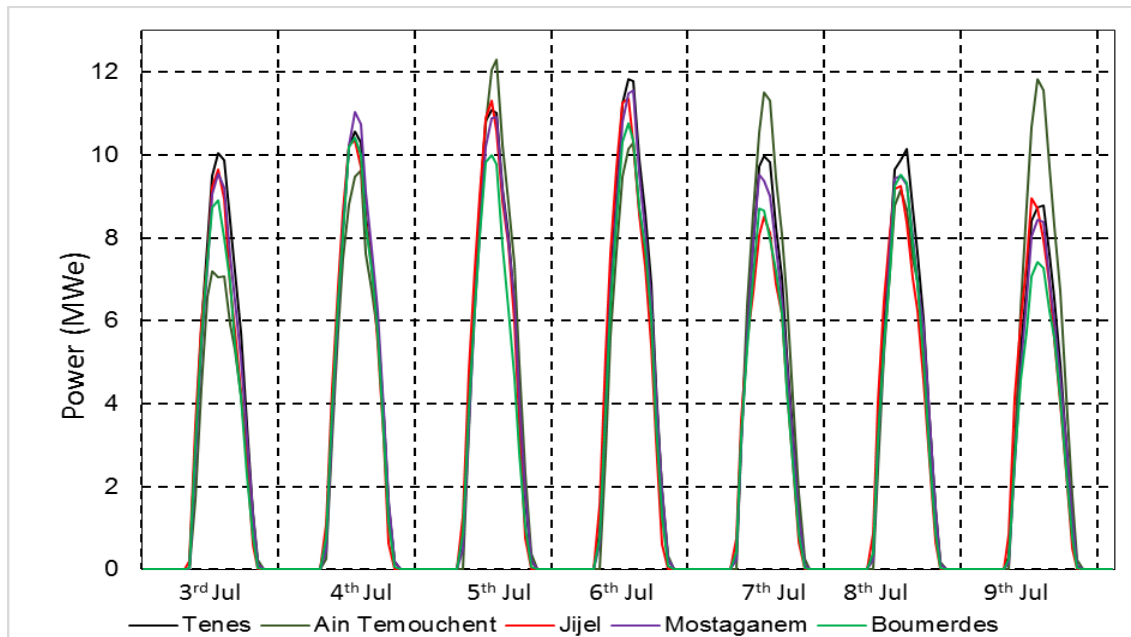


Fig.6. Instantaneous power production in the different examined area

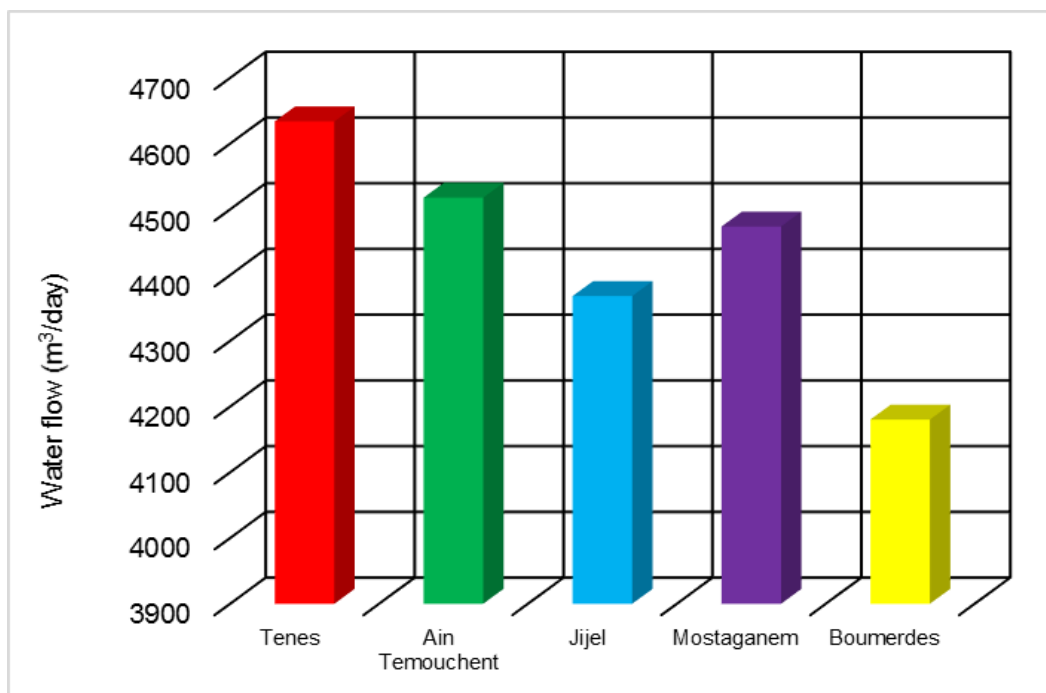


Fig.7. The arithmetic average daily net electric power produced for each zones

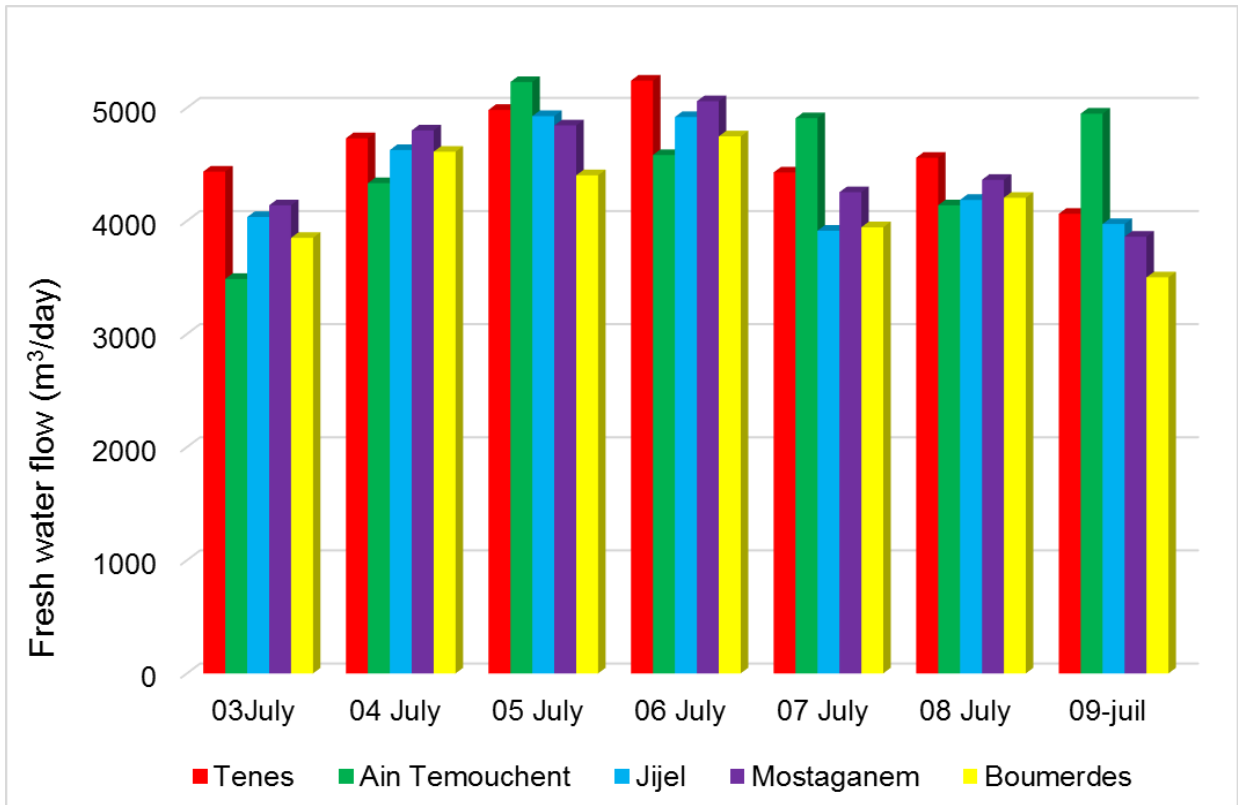


Fig.8. Daily water production from 03rd to 09th July in the selected sites.

4.3 Production of water by the MED desalination plant

Fig. 8 illustrate the quantity of produced water per day in the period 3rd to 9th July for the examined sites, it is observed that the quantity of water produced exceeds 4000 m³/day in the majority days, and some days it reaches more than 5000m³/day, especially for Tenes, Ain Temouchent, and Mostaganem.

Moreover, the arithmetic average of daily fresh water produced by the MED unit is displayed in the fig 9. This figure reveals that the obtained fresh water production is around 4634m³/day for TENES, 4518m³/day for AIN TEMOUCHENT, 4368m³/day for JIJEL, 4474m³/day for MOSTAGANEM, and 4180m³/day for BOUMERDES.

It has been mentioned previously that the produced water depends on the available steam flow rate introduced in the MED unit, this steam also affecting by the intermittency and fluctuation of the direct solar radiation DNI. It can be clearly seen from the fig 9 that the region of TENS has a high production compared with the other area.

4.4 Economic analysis: Levelised cost of electricity and water

The essentially parameters required to calculate the levelised cost are: the investment cost, operation and maintenance cost, additional fuel cost, and the annual production of electricity or water, in this case we have not considered the additional fuel. The parameter in the table used to evaluate the cost of each component in the solar

tower and desalination plant based on data published by [26,27].

The economic model of the electricity and water costs calculated by the equation (Palenzuela and al 2015):

$$LEC = \frac{CRF * k_{investment} + k_{operation\&maint\enece} + k_{fuel}}{E_{net}} \quad (7)$$

$$LWC = \frac{CRF * k_{MED-investment} + k_{MED-operation\&maint\enece}}{FWA} \quad (8)$$

The CRF capital recovery factor calculated using the correlation published by Palenzuela and al [26].

Table 2. Unitary cost of the different components

Component's	Cost
Tower receiver capital cost	200(\$/kW)
Power block capital cost	1000 (\$/kW)
Operation and maintenance cost	65 (\$/kW-year)
Heliostat mirror area	148 m ²
Heliostats cost	126 \$/m ²
MED unit capital cost	1230 (\$/m ³ /day)

Table 3 summarizes the result of levelled electricity and water cost (LEC and LWC) for the different zones, the results of the economic analysis in the different areas selected considering the CSP-MED plant working only 12 hour in day considering the power fluctuation and intermittence.

The results in the table 3 reveal that in the TENES zone equal 0.87(\$/kWh) of the LEC and LWC=0.93(\$/m³) this is more favorable compared with the other zone. The other zones classified as follows (fig10): AIN TEMOUCHENT LEC=0.89(\$/kWh), LWC=0.93 (\$/m³), MOSTAGANEM LEC=0.9(\$/kWh) LWC=0.97(\$/m³), for JIJEL LEC=0.93(\$/kWh) and LWC=0.99(\$/m³), finally BOUMERDES zone LEC=0.98(\$/kWh) LWC=1.04(\$/m³).

In the work of Palenzuela and al [25], the combination of LT-MED and parabolic trough solar power plant studied, for the (configuration 01) under ALMERIA climate (Mediterranean zone). The LEC obtained is 18.73c€/kWh and for the LWC is 0.96€/m³, compared with the obtained economic result in this work.

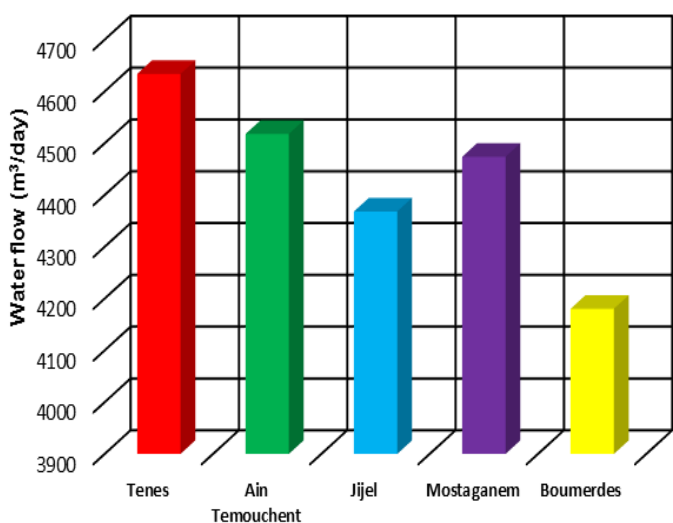


Fig. 9. Arithmetic average fresh water production in one day.

Table 3- results of the cost of the electricity and water

	LEC (\$/kWh)	LWC (\$/m ³)
TENES	0.87	0.93
AIN TEMOUCHENT	0.89	0.96
JIJEL	0.93	0.99
MOSTAGANEM	0.90	0.97
BOUMERDES	0.98	1.04

It is clear that the levelised water cost is in the approximately same, however for the levelised electricity cost in the study case is higher than the result of Palenzuela and al [26], this variation is justified with the type of technology of CSP used, because the parabolic trough is more cheaper compared to the heliostat and the tower receiver. In addition, this discrepancy is due to the scale effect, as we have compared our plant of 10 MWe to the plant of Palenzuela et al (2011) of 50 MWe.

Moreover, considering TENES zone as a reference to the percentage difference in the LEC and LWC as following: (2.3% in LEC and 3.2% LWC AIN TEMOUCHENT), and (LEC 6.9% in LEC and 6.4% LWC JIJEL), (LEC 3.4% in LEC), 4.3% LWC for MOSTAGANEM),and (7.8% LEC ; 11.8 % LWC for BOUMERDES zone) more than of the cost for TENES zone.

It is remarkable that the difference in the LEC and LWC between the selected zones is too small, within a range not exceeding 12%. Then we can say that the Algerian coastal zones are favorable for this type of installation CSP-MED because the selected areas represent a sweep across of the Algerian coast. Three sites in western Algeria (AIN TEMOUCHENT, MOSTAGANEM, TENES) where there exist several conventional desalination plants. One in the centre (BOUMERDES) and one in the east (JIJEL). Finally, we conclude that all the Algerian coasts are suitable for CSP-MED combined plant, economically as shown before, technically by adaptation with the intermittence and the partial load without affecting the quality of fresh water. And Socially, because it answers to the shortage of drinking water, and environmentally through the reduction of using fossil resources.

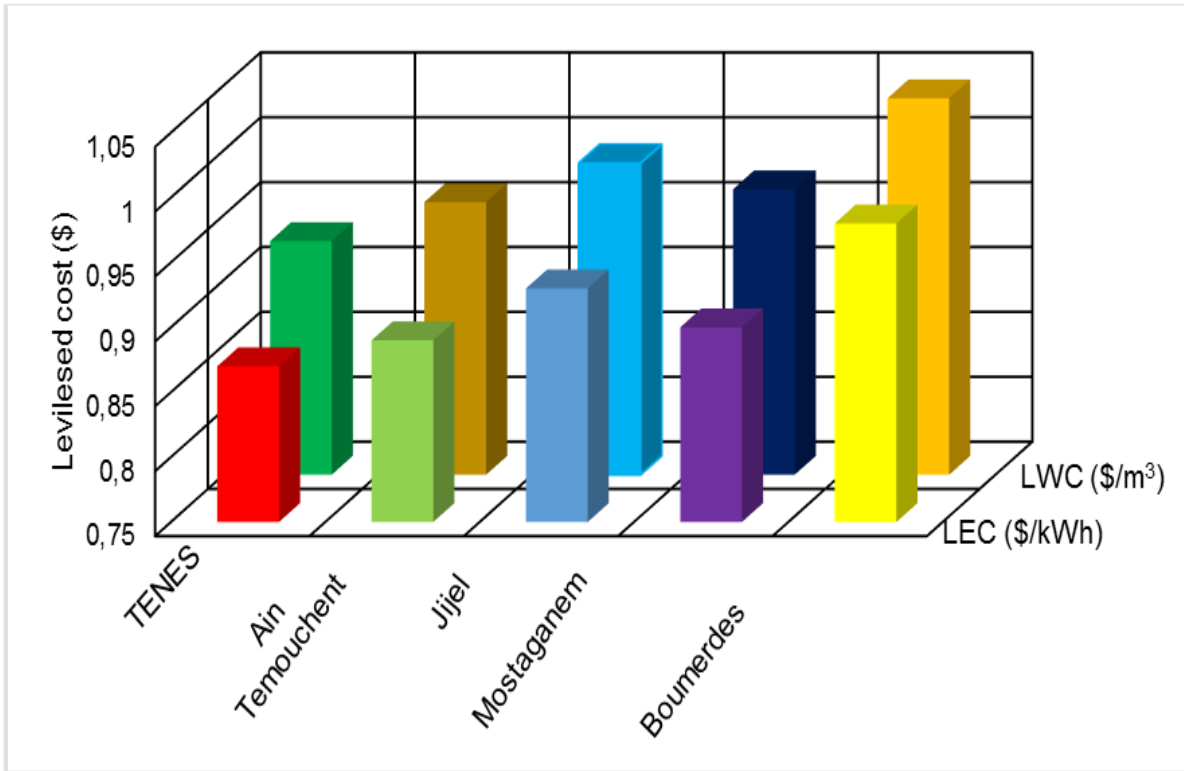


Fig. 10: Levelised cost of the produced water and electricity.

5. Conclusion

The desalination technology with solar energy is the best solution to the scarcity in the potable water in the arid areas as well as and semi-arid regions. The present work concerns the technico-economic analysis of the combination of central receiver tower plant with multi-effect desalination (MED) unit, where the configuration MED unit replaces totally the condenser in the ranking cycle. In which the steam flow provided from the turbine condensates in the first effect of the MED desalination unit. The proposed configuration offers flexibility and can secure the production of fresh water at almost all operating conditions from low load up to the maximum one, without hybridization or storage system.

The considered solar tower plant has a power nominal of 10MWe and 710 heliostats each one with surface of 148 m². For the CSP plant, we have performed the simulation by using TRNSYS 17 and the STEC bibliography components. In the receiver of the solar tower the temperature outlet is fixed at 570°C, and depending on the solar energy concentrated with the heliostats field we calculate the of HTF flow in each hour. Moreover, the main equation of the model of the MED is injected directly in the TRNSYS studio.

The economic results obtained of the analysis have been validated with the results of the study. The parametric study shows that the TENES zone is more favorable for this technology of CSP-MED compared to the other sites.

The main reason of using the MED technology in the proposed study does not have a problem of the solar radiation intermittence and fluctuation in partial load in the quality of produced water. Only the quantity of produced water varied according to the available steam flow, this is not in the case of reverse osmosis unit powered with energy renewable plants.

The selected areas represent a sweep across the Algerian coast. We have chosen three sites in the west as there are several conventional desalination plants, one site in the centre and one in the east. The technico-economic results show that the Algerian coast is suitable for this type of installation CSP-MED which is adaptable with the intermittence and the partial load. This technology is more socially suitable, because it gives a solution to the shortage of drinking water, and as well as environmentally through the reduction of the use of fossil resources.

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