**Assessment of different configurations for combined parabolic-trough (PT) solar power and desalination plants in arid regions**

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**Abstract:**

The combination of desalination technology into concentrated solar power (CSP) plants needs to be considered for the planned installation of CSP plants in arid regions. There are interesting synergies between the two technologies, like the possibility of substituting the condenser of the power cycle for a thermal desalination unit. This paper presents a thermodynamic evaluation of different configurations for coupling parabolic-trough solar power plants and desalination facilities in a dry location representing the Middle East and North Africa (MENA) region. The integration of a low temperature multi-effect distillation (LT-MED) plant fed by the steam at the outlet of the turbine replacing the condenser of the power cycle has been simulated and compared with the combination of CSP with a reverse osmosis (RO) plant. Furthermore, an additional novel concept of CSP+D has been evaluated: a low-temperature MED powered by the steam obtained from a thermal vapour compressor using the exhaust steam of the CSP plant as entrained vapour and steam extracted from the turbine as the motive vapour of the ejector. This new concept (LT-MED-TVC) has been analyzed and compared with the others, evaluating its optimization for the integration into a CSP plant by considering different extractions of the turbine.

**Keywords:** Solar energy, Concentrating solar power (CSP), System integration, Thermodynamic simulation, Steam cycles, Desalination

## 1. Introduction

Many projects are currently under discussion and preparation to make possible large concentrating solar power (CSP) plants developments in arid regions, such as the Desertec initiative [1]. These regions suffer from a serious lack of fresh water availability, which could jeopardize the deployment of the CSP plants. The integration of desalination technology into CSP plants to produce water and electricity at the same time, could solve the water and energy problems in many of the world's arid areas [2]. Combining CSP and Desalination facilities (CSP+D) benefits the identification of technological synergies that could reduce the cost of combined power and desalination production against independent plants. In addition, the cost effectiveness is also expected to improve by making better use of a common infrastructure and the economy of scale of the steam turbine [3]. Finally, considerable additional savings of greenhouse gas emissions come from the production of fresh water, since the majority of desalination plants are currently fed by fossil fuels.

Several studies on different basic integrated power and desalination plants (IPDP) configurations have been published ([4], [5], [6], [7], [8]). However, not so many deal with solar power plants. The potential of CSP plants coupled with desalination systems (RO and MED) has been shown for the Middle East and North Africa (MENA) region ([9], [10]). Besides all the potential benefits of combining power and water production shown, the integration of desalination processes and technologies into CSP plants is not yet a straightforward issue and many technological aspects remain to be discussed. The CSP+D concept needs, obviously, facilities to be located near the sea, where land cost and availability could be a significant problem. Moreover, the solar direct normal irradiance (DNI) is normally lower on areas close to the sea, which makes CSP plants most optimal locations to be separated from the coast. To solve all of these issues, specific scientific research, techno-economic analysis and demonstration plants are needed to define the best concepts and schemes of the integration of a desalination plant into a CSP plant.

More specifically, a thermo-economic analysis has been performed for the combination of parabolic trough power plants for electricity production with MED and ultrafiltration/RO plants in two sites in Israel (Ashdod) and Jordan (Aqaba) [11]. An analysis was carried out taking into account the same fresh water production and electrical power generation capacity. The results showed that the CSP+RO setup has economic benefits in comparison to the CSP+MED configuration using a wet cooling system for the power block. Another technical and economic study for water desalination and CSP power plants in different MENA countries has been presented but this time considering a dry cooling system for the turbine ([12]). For each location, four configurations were analyzed, combining two types of solar technologies (parabolic trough and linear Fresnel reflector) and two types of desalination processes (LT-MED and RO). The main result was that in most cases studied the solar field required for the CSP+RO was larger than for the CSP+LT-MED, due to the higher electrical consumption of the RO overcompensating the lower thermal efficiency of the turbine of the MED case.

This paper presents a thermodynamic evaluation of different configurations for coupling parabolic-trough (PT) solar power plants and desalination facilities in a MENA location (Abu Dhabi). The typical configurations of combining CSP with a RO desalination plant and a low-temperature MED plant fed by the steam at the outlet of the turbine have been studied. However, an additional concept of CSP+D has been evaluated for the first time in this kind of analysis: a low-temperature MED powered by the steam obtained from a thermal vapour compressor. In this case, unlike in the typical thermal vapour compression MED process (TVC-MED), the entrained vapour to be used in the steam ejector comes from the exhaust steam of the CSP plant instead of an intermediate effect of the desalination plant. Within this concept (LT-MEDTVC), different schemes must be studied: a system that uses the high exergy steam from the high pressure turbine outlet as motive steam in the TVC, and others that use steam extracted at different pressures from the low pressure turbine as the motive steam in the ejector.

## 2. Methodology

### *2.1. Description of the systems*

The systems under consideration are described in Figures 1-4. They each consist of a parabolic trough concentrating solar power (PT-CSP) plant based on a Reheat Rankine cycle with water as the working fluid. The solar plant consists of parabolic-trough (LS3 type) collectors aligned on a north-south orientation and a thermal storage tank to provide additional operation when solar radiation is not available. The collectors track the sun from east to west during the day to ensure it is continuously focused on the linear receiver. Different desalination systems have been considered for combination with this CSP plant. A dry cooling system is considered for condensing the exhaust steam form the turbine in the power block, which is the usual means in arid areas, since the typical wet cooling towers consume between 2 and 3 metric tons per MWh ([13]).

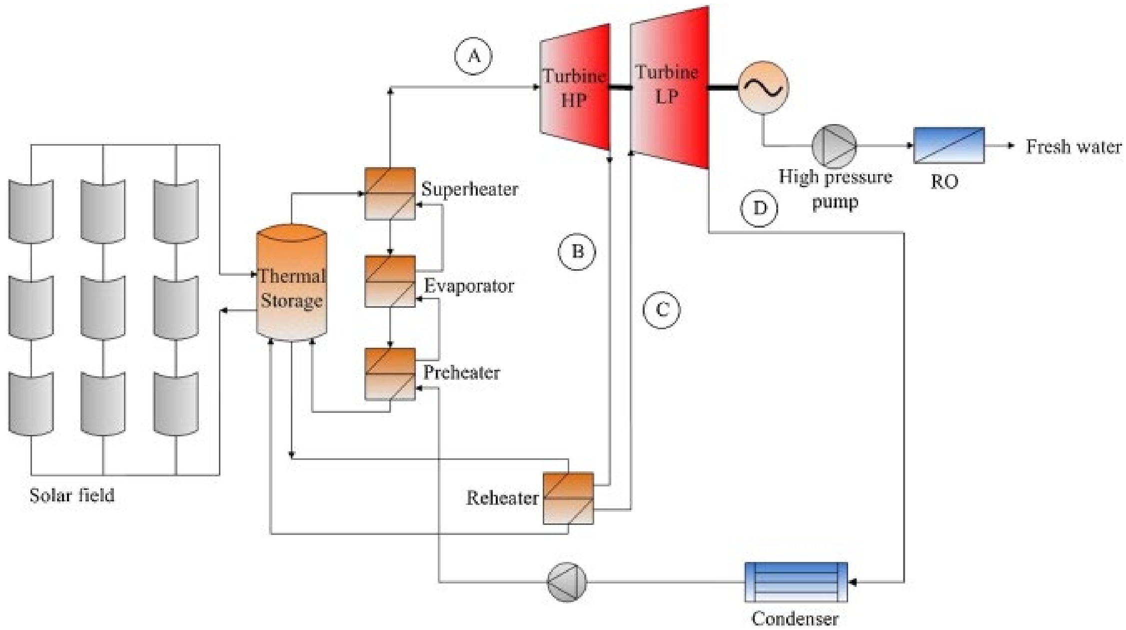


Fig 1. Diagram of configuration #1 (RO unit combined with a PT-CSP plant).

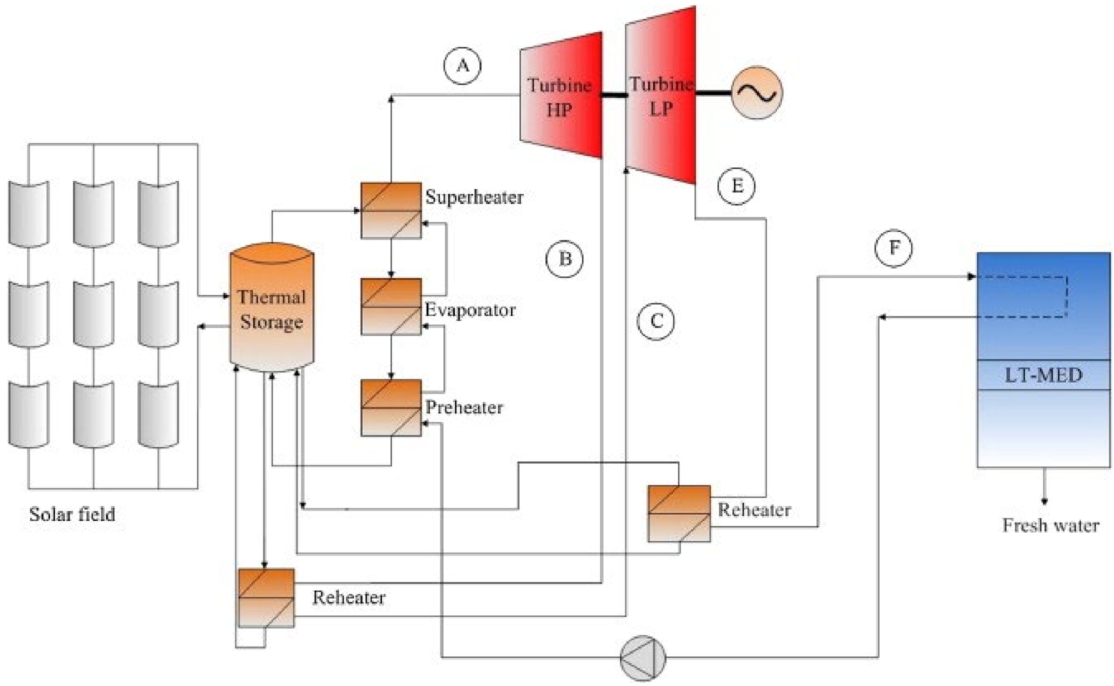


Fig 2. Diagram of configuration #2 (LT-MED unit integration into a PT-CSP plant).

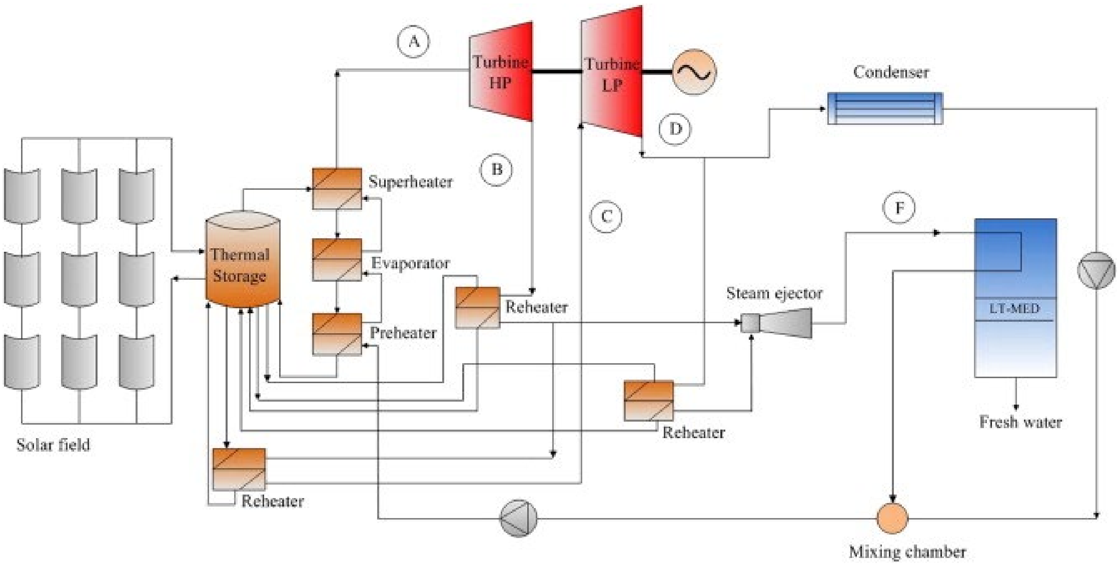


Fig 3. Diagram of configuration #3 (LT-MED-TVC unit integration into a PT-CSP plant using motive steam from the HP turbine outlet).

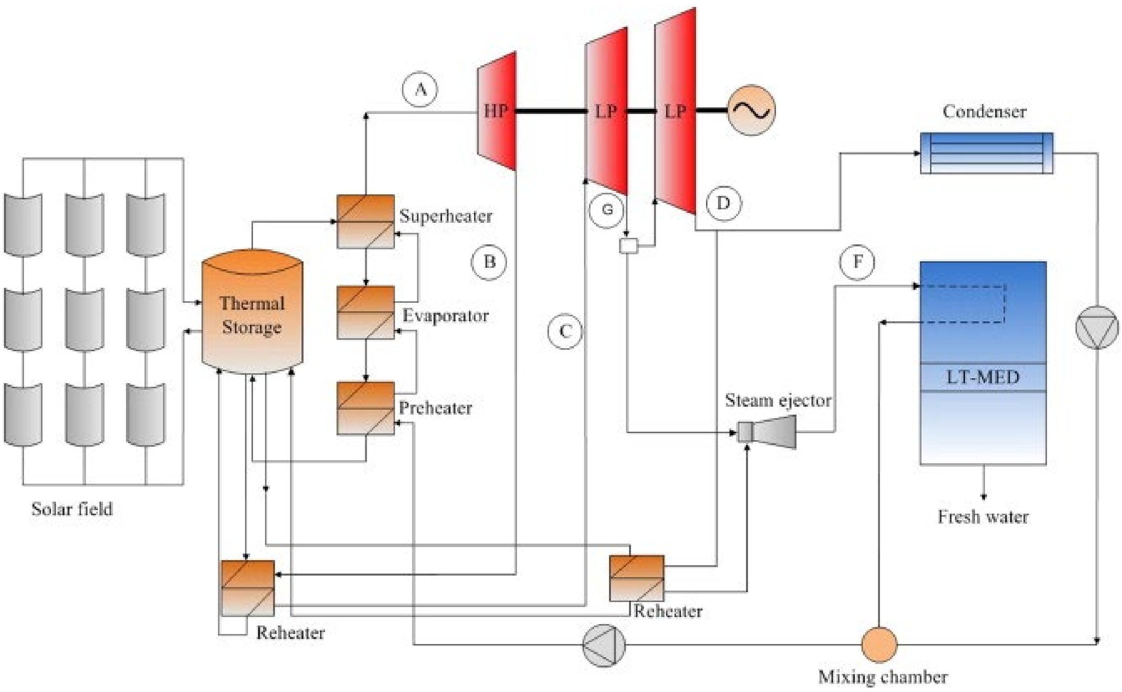


Fig 4. Diagram of configuration #4 (LT-MED-TVC unit integration into a PT-CSP plant, with extractions from the LP turbine used as motive steam).

The PT-CSP technology is the same in all the configurations assessed. Steam at point A is generated from the thermal energy collected by the solar field. It is subsequently sent to a high pressure (HP) turbine where, after suffering an expansion process is extracted at B in order to reheat it. The reheated steam is left to its expansion through a LP turbine to obtain the required power. The expansion is up to state point D in all cases except that of Fig. 2, where the expansion is only up to state point E.

Configuration #1 corresponds to the basic combination of a reverse osmosis (RO) desalination plant with a PT-CSP plant. In this case (Fig. 1) the desalination process is driven by the power output from the CSP plant. This configuration has the advantage that the desalination process is completely independent from the power generation and can be even separated geographically.

Configuration #2 corresponds to a low temperature multi-effect distillation (LT-MED) integrated into a PTCSP by replacing the conventional cooling unit of the steam cycle. In this case (Fig. 2), the desalination plant is fed by the low temperature steam from the turbine outlet (at state point F) after being reheated to obtain saturated steam without increasing the temperature. In this case the exhaust steam is considered at a slightly higher pressure than in the previous case, as it must feed the LT-MED desalination plant at 70ºC.

Configurations #3 and #4 consider low-temperature multi-effect distillation powered by a thermal vapour compressor (LT-MED-TVC) (Figs. 3-4). The integration of a LT-MED-TVC unit has a huge interest, since it is useful for the coupling of any thermal desalination process to a power plant and not only for a MED process. In this case, unlike the conventional thermal vapour compression process (TVC-MED), the entrained vapour to be used in the ejector comes from the exhaust steam from the LP turbine instead of an effect of the MED unit. As for the motive steam, two scenarios have been considered, using part of the HP turbine outlet steam or extracting from the low pressure (LP) turbine at different pressures. In configuration #3 (Fig. 3), part of the steam at state point B is used as motive steam in the steam ejector after passing trough a reheater to achieve saturation conditions. In addition, one part of the exhaust steam from the turbine at D is used as entrained vapour in the ejector. The resulting compressed vapour from the ejector is injected into the first effect of the distillation unit at F, driving the thermal desalination process. Configuration #4 (Fig. 4) follows a similar concept, but in this case a fraction of superheated steam extracted from the LP turbine at G is used as motive steam in the ejector.

The operating conditions considered in the schemes proposed are indicated in Table 1. These values have been used as inputs for the subsequent simulations. The net power of the CSP plant has been considered in all configurations to be 50 MWe, which is the normal size of a commercial parabolic trough CSP plant ([14]). The size of the desalination plants has been determined by dimensioning the LT-MED in order to replace the condenser of the power plant in configuration #2 (all the exhaust steam coming from the LP turbine is used to drive the desalination plant producing fresh water). Once the right size of the LT-MED has been determined considering 24 h operation, the same size has been assumed for the desalination plants considered in the other configurations. As can be observed in Table 1, another common condition for all the proposed configurations is that the steam is allowed to be expanded up to 58ºC (0.18 bar), except in configuration #2 where the expansion is up to 70ºC (0.31 bar). This is the result of the use of dry air condensers, which is the only feasible option for solar power plants in these arid regions [4], unlike the wet cooling towers that are used in other regions to achieve maximum performance.

Table 1. Operating conditions defined for the schemes shown in Figs. 1, 2, 3 and 4.

| Point in the diagram | Parameters | Values |
|---|---|---|
| A | Pressure and temperature | 371ºC, 104 bar |
| B | Pressure | 17 bar |
| C | Pressure and temperature | 371ºC, 17 bar |
| D | Temperature | 58ºC |
| E | Temperature | 70ºC |
| F | Temperature | 70ºC |
| G | Pressure | 2, 4, 6, 10, 16 bar |

*2.2. Analysis of the systems*

In this section, both the integrated power and desalination facility, and the solar field are analyzed.

2.2.1. Integrated power and desalination facility analysis

A steady state model has been made by proposing a set of nonlinear, algebraic equations for each cycle and implementing them in the Engineering Equation Solver (EES) software. The thermodynamic state points used are those of Table 1. For each cycle, the net output thermal capacity (thermal power to be provided by the solar field), overall efficiency, and thermal power dissipated in the condenser have been calculated.

Actual expansion and compression processes in the turbines and pumps, respectively, have been considered in the model. An isentropic efficiency of 85% has been assumed for all the turbines and pumps. The actual steam enthalpy at the outlet of the high and low pressure turbines has been calculated through:

$$\eta_{st} = \frac{h_{inlet} - h_{oulet}}{h_{inlet} - h_{outlet,i}} \tag{1}$$

where $\eta_{st}$ is the isentropic efficiency, $h_{inlet}$ is the enthalpy of the steam entering the turbine, $h_{outlet}$ is the actual enthalpy at the outlet of the turbine and $h_{outlet,i}$ is the ideal enthalpy of the steam leaving the turbine. In the case that some steam is extracted from the turbine (Fig. 4), the enthalpy of the extracted steam has been calculated with the assumption of linear condition line in the h-s diagram between the inlet and the outlet of the turbine:

$$\frac{h_m - h_{outlet}}{h_{inlet} - h_{outlet}} = \frac{s_m - s_{outlet}}{s_{inlet} - s_{outlet}} \tag{2}$$

where $h_m$ and $s_m$ are the enthalpy and the entropy at the point where the steam extraction is done.

In all case studies, the analysis has been carried out considering a net power production of the plant ($P_{net}$) of 50 $MW_{e.}$ The net power production of the plant is calculated as the gross turbine output ($P_{turb}$) minus the power required by the pumps ($P_{pumps}$) and the desalination plant ($P_{desal}$):

$$P_{net} = P_{turb} - P_{pumps} - P_{desal} \tag{3}$$

For the calculation of the power required by the desalination plant, a specific electric consumption of 2.5 kWh/m$^3$ has been considered in the case of the MED plant, and 5.6 kWh/m$^3$ for the RO, which are the estimated values for Abu Dhabi [9]. In both cases 24 h operation has been taken into account.

The steam flow required by the MED desalination plant has been calculated by:

$$q_{steam} = \frac{FWF \times \rho}{GOR} \tag{4}$$

where *FWF* is the fresh water production in $m^3$/day, $\rho$ is the fresh water density in kg/$m^3$ (at 35 ºC and 1 bar) and *GOR* is Gained Output Ratio, which is defined as the amount of distillate produced for every mass unit of steam supplied to the distillation unit. A *GOR* of 9.8 has been considered in all cases of MED technology.

To calculate the steam ejector flow rates (both motive steam and entrained vapour flow rates), a semi- empirical model developed by El-Dessouky has been used ([15]). The model makes use of the field data collected over 35 years by Power ([16]) for vapour entrainment ratios of steam jet ejectors. The entrainment ratio is the flow rate ratio of the motive steam and the entrained vapour, and can be calculated from the following correlation:

$$Ra = 0,296\frac{(P_s)^{1,19}}{(P_{ev})^{1,04}}\left(\frac{P_m}{P_{ev}}\right)^{0,015}\left(\frac{PCF}{TCF}\right) \tag{5}$$

where $P_m$, $P_s$ and $P_{ev}$ are the pressures of the motive steam, compressed vapour and entrained vapour respectively, *PCF* is the motive steam pressure correction factor and *TCF* is the entrained vapour temperature correction factor. The following two equations have been used to calculate *PCF* and *TCF*:

$$PCF = 3\times10^{-7}(P_m)^2 - 0,0009(P_m) + 1,6101 \tag{6}$$

$$TCF = 2\times10^{-8}(T_{ev})^2 - 0,0006(T_{ev}) + 1,0047 \tag{7}$$

where $P_m$ is expressed in kPa and $T_{ev}$ in ºC. Finally, the overall efficiency has been calculated by:

$$\eta_{global} = \frac{P_{net}}{NOTC} \tag{8}$$

where *NOTC* is the net output thermal capacity, which is given by:

$$NOTC = P_{pcs} + P_{RH} \tag{8}$$

where $P_{pcs}$ and $P_{RH}$ are the power required by the power conversion system (consisting of a pre-heater, an evaporator and a superheater) and by the reheaters of the cycle, respectively.

2.2.2. Parabolic trough field analysis

Considering the *NOTC* of the system, the solar field size has been determined by a computer model developed in MATLAB. For this purpose, a model has been used for the collector based on its thermal losses, its efficiency curve and energy balances ([17], [18], [19]). The model input parameters are listed below:

- North-South orientation.
- Design point: 22th September (radiation at solar noon=849.728 W/$m^2$, ambient temperature=38.4ºC).
- Thermal storage capacity for 24-h solar operation at design day (fossil backup when the solar radiation is not available).

- The net output thermal capacity of the power block.
- Inlet temperature to the solar field: 295°C.
- Outlet temperature from the solar field: 390°C.

The simulation was carried out for a location in Abu Dhabi, in the United Arab Emirates (Longitude: 54.420 East; Latitude: 24.470 North). With around 1925 kWh/$m^2$·yr DNI radiation ([20]), this site is a good representative for CSP plants in arid areas. Radiation and ambient temperature data have been taken from an available typical meteorological year (using Meteonorm DNI profiles but normalized with the real measurement of the annual average of the DNI given above). The parabolic trough solar field is based on the commercial LS-3 type collector, i.e. an aperture area of 545 $m^2$ and a length of 99 m. The peak optical efficiency for this type of collectors is 76% and the thermal oil that circulates through the absorber tubes is Monsanto VP-1 (its properties are determined using Monsanto software).

## 3. Results and discussion

Firstly, the analysis of the power block corresponding to configuration #2 has been carried out in order to determine the maximum water production. The results obtained are shown in Figure 5. A water production of 48498 $m^3$/day is obtained when all the steam from the turbine outlet at 70ºC (56.94 kg/s) feeds the MED unit. This value has been taken as a fixed input parameter for the rest of configurations analyzed within this work.

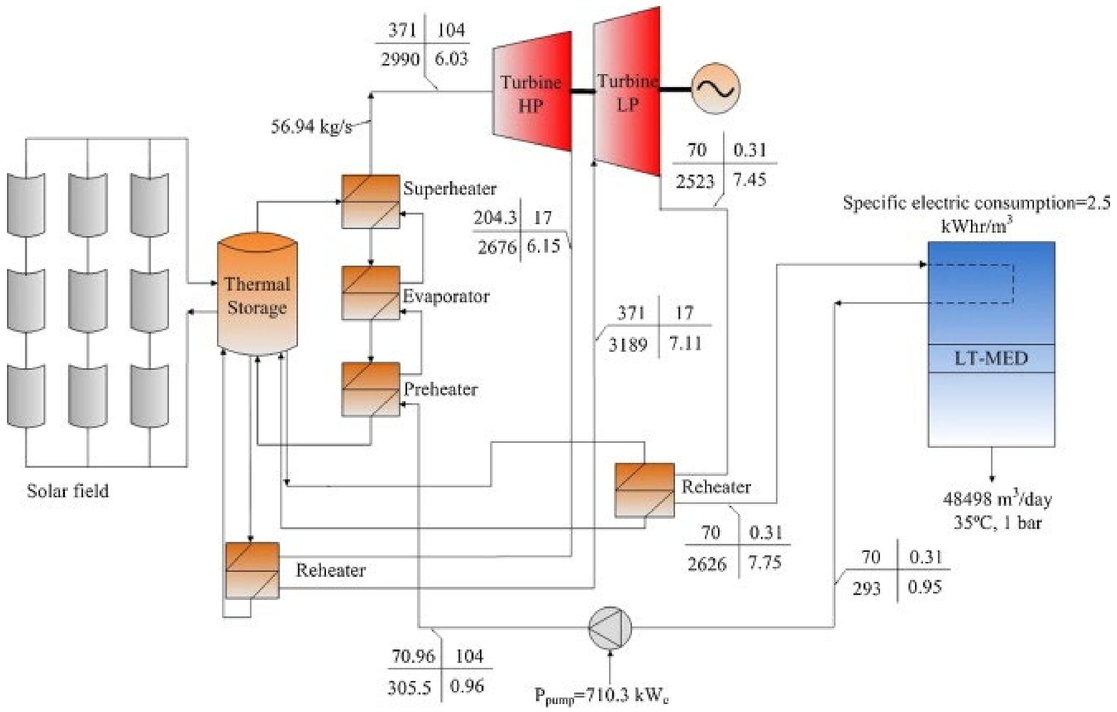


Fig 5: Results obtained in the simulation of configuration #2 (LT-MED plant integration into a PT-CSP plant).

Secondly, simulations have been performed for configurations #1 and #3. The results obtained are depicted in Figures 6 and 7. In the first case, more steam than in configuration #2 must be generated, as more total power needs to be generated in the CSP plant in order to feed the RO desalination plant while keeping the same global production of 50 MWe. In the second case (Fig. 7), even more steam must be generated for the HP turbine (72.62 kg/s), since 27.11 kg/s are later used as motive steam in the ejector. Subsequently, only 45.51 kg/s enter the LP turbine. Out of that, since 29.82 kg/s are used as entrained vapour in the ejector, only 15.69 kg/s are sent eventually to the condenser. On the other hand, in configuration #1, all the steam from the LP turbine outlet (59.07 kg/s) must be condensed.

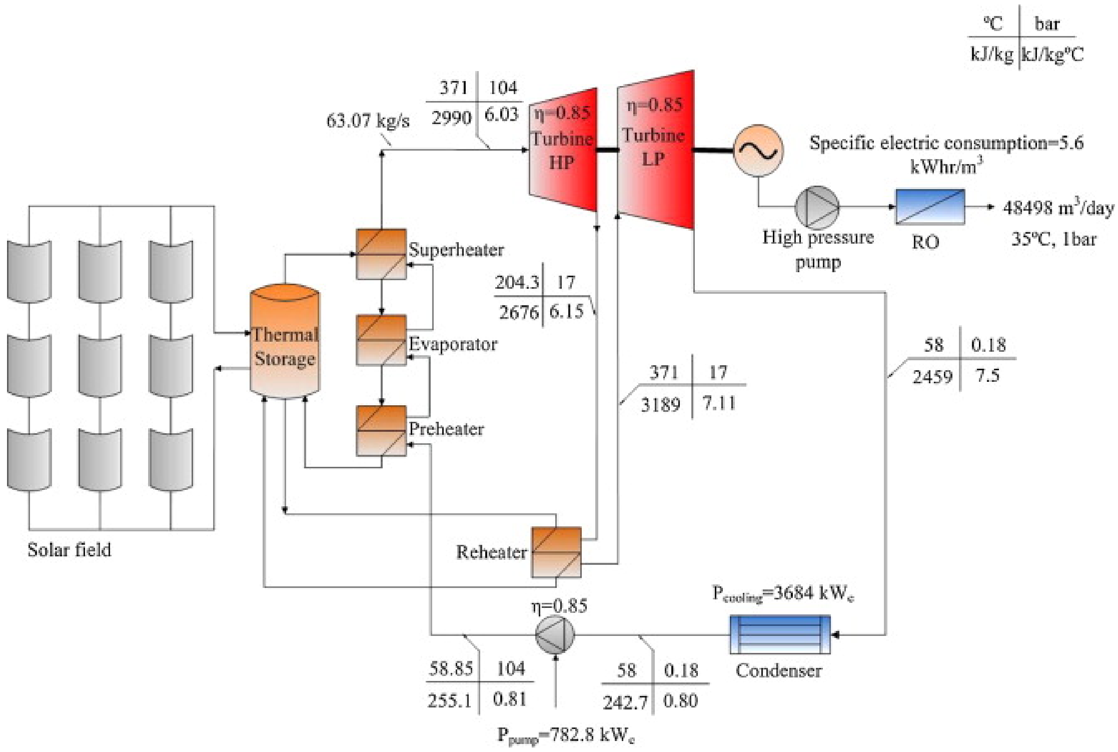


Fig 6: Results obtained in the simulation of configuration #1 (RO plant combined with a PT-CSP plant).

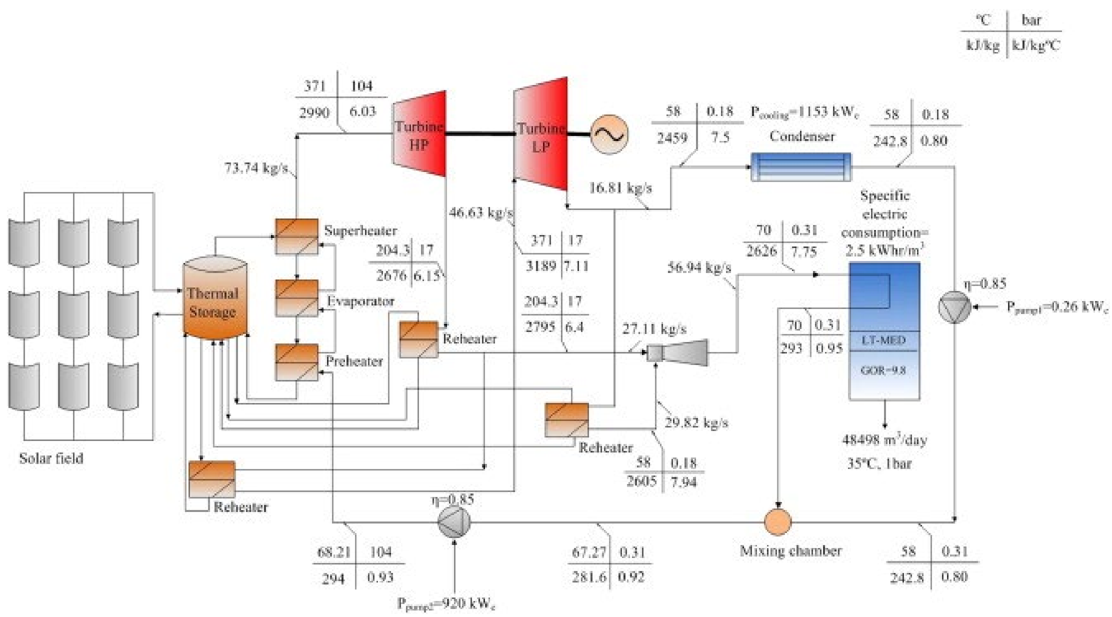


Fig 7: Results obtained in the simulation of configuration #3 (LT-MED-TVC plant integration into a PT-CSP plant).

Table 2 presents a summary of the net output thermal capacity (*NOTC*), the overall efficiency and the size of the required solar field from the simulations of Figures 5-7. It also shows the cooling requirements, which have been assessed as the fraction of the steam flow rate that leaves the LP turbine and cools in the condenser.

Table 2. *NOTC*, overall efficiency, cooling requirements, number of collectors per row, number of rows and aperture area resulting from the simulations of the configurations #1, #2 and #3 as shown in Figs. 5-7.

| Configuration | NOTC ($MW_{th}$) | Overall Efficiency (%) | Cooling requirements (%) | Number of collectors per row | Number of rows | Aperture area ($m^2$) |
|---|---|---|---|---|---|---|
| #1 | 193 | 25.9 | 100 | 2 | 932 | 1,015,880 |
| #2 | 188 | 26.6 | 0 | 2 | 908 | 989,720 |
| #3 | 227 | 22 | 34.5 | 2 | 1098 | 1,196,820 |

On one hand, it can be observed that configuration #2 needs the lowest *NOTC* and therefore the smallest solar field. In other words, the decrease in the efficiency of the power production for this configuration due to the higher pressure of the exhaust steam is less than the extra power that the CSP plant must generate in configuration #1 for the RO desalination process. This result, together with the fact that this configuration eliminates the cooling requirements of the power cycle, leads to conclude that LT-MED is more competitive than RO in the MENA regions, as opposed to other regions where wet cooling is used and RO desalination plants have lower specific consumption ([11]). However, it is also true that the integration of a LT-MED into a PT-CSP plant by replacing the cooling unit has a major disadvantage in the fact that the desalination plant must be very close to the turbine, since the exhaust steam has very low density and therefore pipes with very large diameters are needed to conduct the steam to the desalination plant. This is why the thermal compression of the steam (LT-MED-TVC) has also been analyzed.

The results show that configuration #3 needs a larger *NOTC* than #1 and #2, since it uses high exergy steam to feed the steam ejector, which results also in a decrease of the overall efficiency of the power production. However, if we compare with configuration #1, it can be seen that configuration #3 requires less cooling. This makes the integration of a LT-MED-TVC plant into a PT-CSP plant an attractive prospect. However, the concept must be optimized with a more efficient configuration in terms of the heat extraction. This is the case of configuration #4, for which several simulations have been carried out considering extractions from the LP turbine at different pressure conditions (point G in the diagram shown in Figure 4). The results obtained have been compared to those of configuration #1 and represented in Figures 8-11.

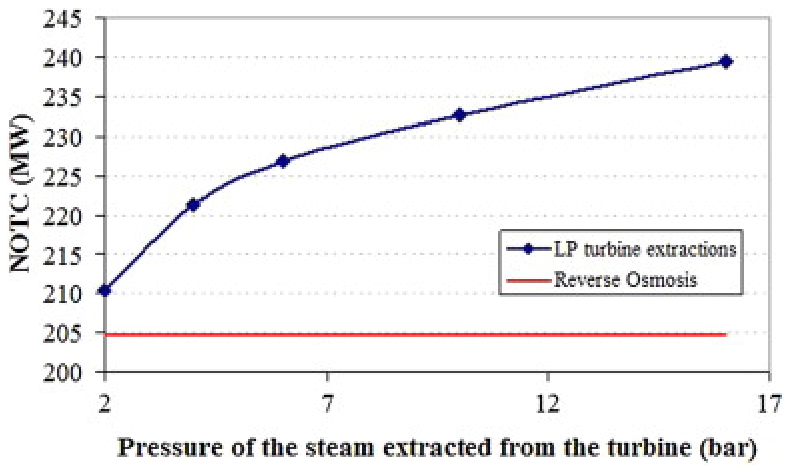

Fig 8. NOTC for different pressures of the steam extracted from the LP turbine in configuration #4 and its comparison to the NOTC needed in configuration #1.

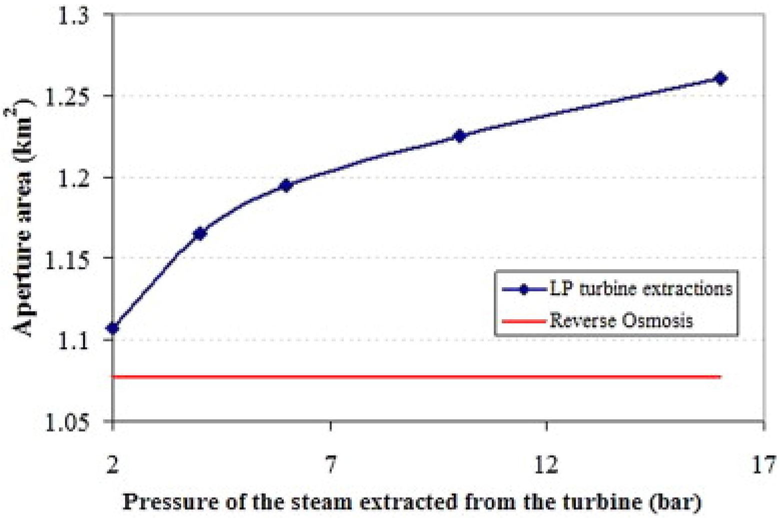

Fig 9. Aperture area for different pressures of the steam extracted from the LP turbine in configuration #4 compared to that of configuration #1.

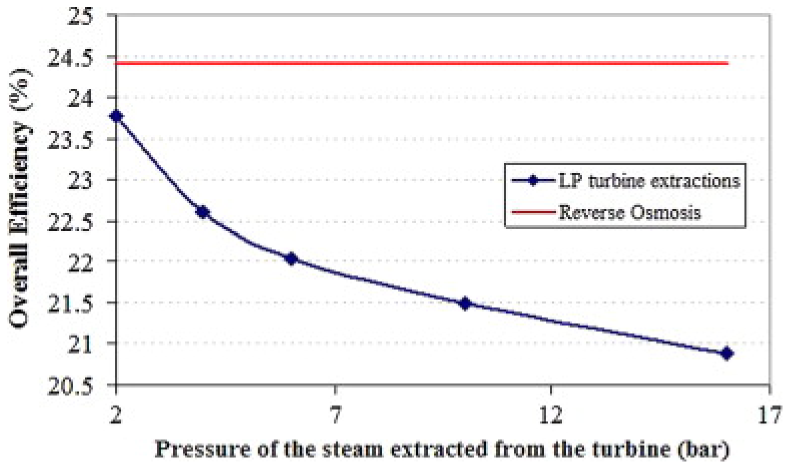

Fig 10. Overall efficiency for different pressures of the steam extracted from the LP turbine in configuration #4 compared to that of configuration #1.

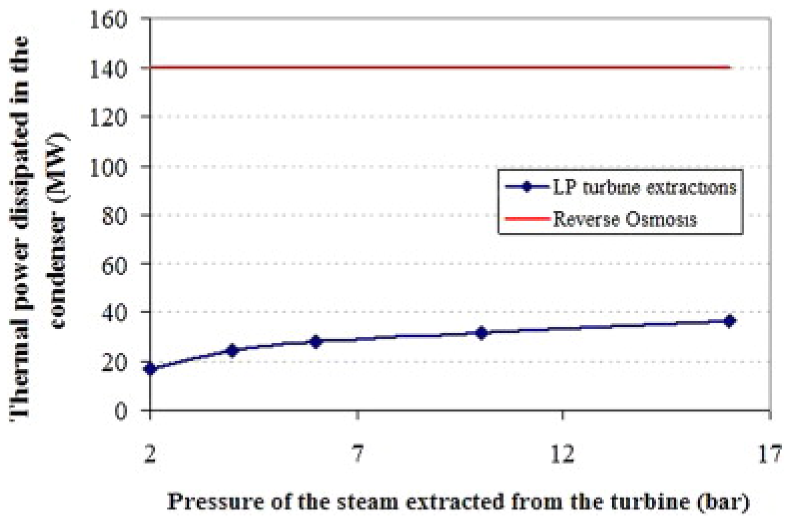

Fig 11. Thermal power dissipated in the condenser for different pressures of the steam extracted from the LP turbine in configuration #4 compared to configuration #1.

The *NOTC* required and the aperture area increase with the pressure of the steam extracted from the LP turbine (Figs. 8 and 9 respectively). Also, the lower the pressure of the steam is, the larger the overall efficiencies of the system result (Fig. 10). Moreover, energy losses to the ambient due to the cooling process of the power cycle are much lower at all cases in configuration #4 than in configuration #1 (Fig. 11), although they increase with the pressure of the steam extracted from the turbine.

As can be observed in Figures 8-11, only the case of extraction from the LP turbine at pressures around 2 bars configuration #4 results more efficient than configuration #1. In current turbines of solar PT power plants, extractions are available only at certain pressure levels (i.e., at 2 and 10 bars [14]). Figures 12 and 13 show the detailed simulations results of configuration #4 for these two cases respectively. The thermal power dissipated in the condenser is of 15 MW and 29.4 MW, respectively, in contrast to configuration #1, which is of 132 MW. That means that the cooling requirements are 11% and 22%, respectively. Furthermore, as shown before the configuration presented in Figure 12 is more efficient thermodynamically than configuration #1.

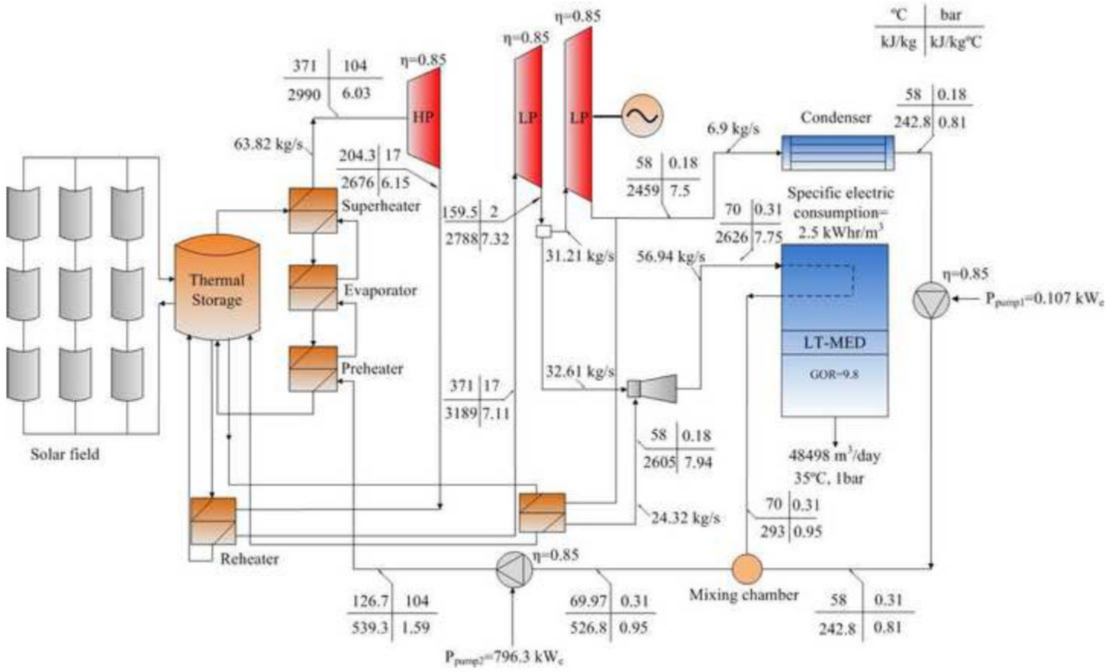


Fig 12: Results obtained in the simulation of configuration #4 using the steam extracted from the LP turbine at 2 bar as motive steam in the ejector.

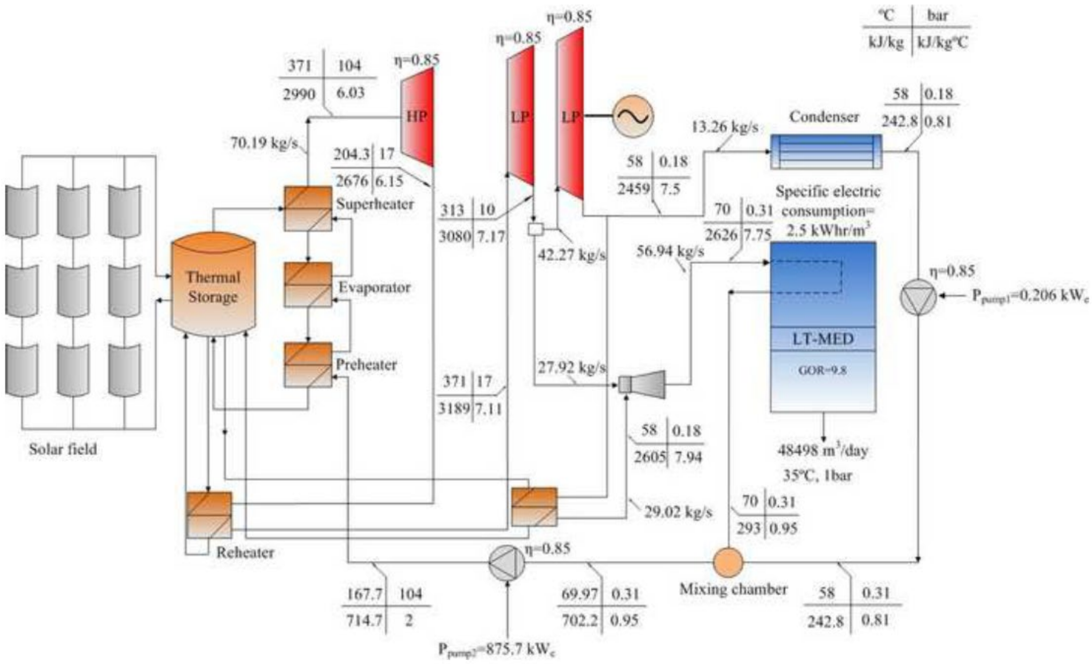


Fig 13: Results obtained in the simulation of configuration #4 using the steam extracted from the LP turbine at 10 bar as motive steam in the ejector.

## 4. Conclusions

A thermodynamic analysis of several configurations of CSP+D plants has been carried out within this work. The systems have been modelled for the ambient conditions of arid regions which impose dry cooling in the power plant. In all cases, 50 MWe and 48498 m3/day have been considered as net power and water production respectively, and 58ºC (0.18 bar abs) the exhaust steam outlet turbine conditions. The results show that for the simulated conditions, the integration of a LT-MED unit into a PT-CSP replacing the condenser of the exhaust steam of the turbine is more efficient thermodynamically than the coupling of the CSP plant with a RO desalination plant and needs a smaller solar field for the same production of electricity and water. Although by using the steam from the outlet of the turbine to feed the LT-MED plant the power production is reduced, the reduction is smaller than in other regions where the cold-end temperature is lower because wet cooling can be performed.

A novel configuration of MED plant with thermo-compression, named LT-MED-TVC, has also been evaluated within this study. In this configuration, low pressure vapour feeding the steam ejector comes from the exhaust steam of the low pressure turbine instead of any stage of the MED unit. Several conditions have been considered for the motive steam that drives the ejector, from the outlet steam of the high pressure turbine to several intermediate extractions in the low pressure turbine.

When the motive steam comes from the HP turbine, the integrated CSP+D plant requires a larger solar field than the combination of CSP+RO. However, the energy losses to the ambient are lower for the LT-MEDTVC configuration, since the plant cooling needs decrease from the CSP+RO case.

When the motive steam comes from extractions from the LP turbine, the efficiency is improved, the more the lower the pressure of the extracted steam is. For a value of 2 bars, the integration of the LT-MED-TVC desalination unit into the CSP plant is more efficient thermodynamically than the CSP+RO. Actual extractions in commercial plants take place at 2 and 10 bars. Therefore, in the first case the integration of a MED plant with thermo-compression can also be a valid option for a CSP+D configuration in arid regions.

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**Nomenclature**

| | |
|---|---|
| *CSP+D* | concentrating solar power and desalination |
| *DNI* | direct normal irradiance |
| *EES* | Engineering Equation Solver |

| | |
|---|---|
| *FWF* | fresh water flow rate ($m^3$/day) |
| *GOR* | Gain Output Ratio |
| $h_{inlet}$ | enthalpy of the steam which enters the turbine (kJ/kg) |
| $h_m$ | enthalpy at the point where the steam extraction is done (kJ/kg) |
| $h_{outlet}$ | actual enthalpy at the outlet of the turbine (kJ/kg) |
| $h_{outlet,i}$ | ideal enthalpy of the steam which leaves the turbine (kJ/kg) |
| *HP* | high pressure |
| *IPDP* | integrated power and desalination plants |
| *LT-MED* | low temperature multi-effect distillation |
| *LT-MED-TVC* | low temperature multi-effect distillation powered by a thermal vapour compressor |
| *LP* | low pressure |
| *MENA* | Middle East and North Africa |
| *NOTC* | net output thermal capacity (MW) |
| *PCF* | motive steam pressure correction factor |
| $P_{desal}$ | power required by the desalination plant (MW) |
| $P_{net}$ | net power production of the CSP+D system (MW) |
| $P_{pcs}$ | power required by the power conversion system (MW) |
| $P_{ev}$ | pressure of the entrained vapour (kPa) |
| $P_m$ | pressure of the motive steam (kPa) |
| $P_{pumps}$ | power required by the pumps (MW) |
| $P_{RH}$ | power required by the reheaters of the cycle (MW) |
| $P_s$ | pressure of the compressed vapour (kPa) |
| *PT* | parabolic trough |
| $P_{turb}$ | gross turbine output (MW) |
| $q_{steam}$ | feeding steam flow rate to the desalination plant (kg/s) |
| *Ra* | entrainment ratio |
| *RO* | reverse osmosis |
| $s_m$ | entropy at the point where the steam extraction is done (kJ/kg°C) |
| *TCF* | entrained vapour temperature correction factor |
| *TVC-MED* | thermal vapour compression multi-effect distillation |
| $\rho$ | fresh water density ($kg/m^3$) |
| $\eta_{st}$ | isentropic efficiency of the turbine |