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# Investigation of using molten salt as heat transfer fluid for dry cooled solar parabolic trough power plants under desert conditions

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ABSTRACT

This research aims mainly at further investigate technical options to reduce the cost of electric power production from concentrating solar power plants in hot arid regions. The work also aims to minimize water consumption due to its scarcity in such regions by means of investigating the utilization of dry cooling option. However, dry cooling system increases the parasitic power consumption of the power plant and this is bound to reduce the overall system efficiency. In arid regions, this loss in efficiency is compensated by the abundance of solar radiation that results in a better solar field efficiency. Furthermore, this study investigates the effect of using alternative heat transfer fluid in the solar circuit instead of synthetic oil. For this purpose, an optimization of a solar parabolic trough power plant coupled with dry cooling system has been performed using the simulation software "SAM". The optimization is carried out by varying the solar field size, the thermal energy storage system, the size of the power block (steam turbine) and the type of the heat transfer fluid. This was done in order to find out the best combination that gives lowest power production cost. The power plant was simulated in two steps with different combinations; while "Therminol VP I" was used in the first step, as heat transfer fluid, in the second step, "Therminol VPI" was replaced by "Molten Salt". The obtained results prove that plants with large solar fields (solar multiple of 2) and large thermal energy storage systems (7.5 full load hours) perform better and can generate power at lower costs compared with smaller plants. The investigation of alternative heat transfer fluid shows that molten salt is more cost effective than synthetic oil in parabolic trough power plants. The obtained Levelized Cost Of Electricity of the best power plant optimized configuration is 17.24 c€/kWh$_e$ and 13.8 c€/kWh$_e$, for plants with "Therminol VP I" and "Molten Salt" as heat transfer fluid, respectively. The optimization results with "Molten Salt" as heat transfer fluid show excellent results regarding the dry cooled solar power plants. This show good technical and economic potentials in future designs.

## 1. Introduction

The high consumption rate of fossil fuels is a global pressing issue and needs to be tackled in order to improve economies and the environment. Stressing issues related to the consumption of fossil fuels include the increase in commodity costs, increasing competition over resources and worrying environmental concerns related to the increasing of carbon dioxide concentration in the atmosphere. Alternative energy resources are being investigated and implemented on large scales. For areas with high solar radiation such as those in the desert regions of the Middle East and North Africa, the utilization of solar energy on utility scale has established itself in recent years as an efficient possible pro-environment alternative. The concentrating solar power (CSP) plants can play a fundamental role to make the required shift from a carbon economy to green one. The CSP technologies represent an effective power-generating alternative. The most attractive characteristic of these technologies is their ability to accommodate thermal energy storage (TES) system that can store the surplus thermal energy collected during excess production periods for later use during other periods, when the sun does not shine. Generally, integrating a TES into CSP plants increases plant operation reliability to deliver power on-demand (dipatchability) at advantageous economic terms. If compared with other renewable energy technologies, such as Photovoltaic and wind, CSP plants are more advantageous in terms of capacity factors and their operation profile which supports the grid stability.

Amongst CSP technologies, parabolic trough technology is the most commercially and technically proven and mature technology with up to 76.6% market share of the installed CSP capacities [1]. A recent study Sargent and Lundy [2] concluded that the solar parabolic trough power plants will continue to dominate the international market compared to

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**Nomenclature**

| | |
|---|---|
| $A_{ap}$ | solar field aperture area, $m^2$ |
| $C_{env}$ | environmental cost of carbon dioxide (CO2) rejected, € |
| $CF$ | capacity factor, % |
| $C_{inv}$ | costs of project installation, € |
| $C_{O\&M}$ | operating and maintenance costs, € |
| $Cp_{htf}$ | specific heat of the heat transfer fluid, kJ/kg K |
| $CRF$ | capital recovery factor |
| $DNI$ | direct normal irradiance, $W/m^2$ |
| $E_{TES}$ | thermal capacity of the storage system, $kWh_{th}$ |
| $f_{backup}$ | fossil filling fraction, ($0 < f_{backup} < 1$) |
| $F_{fou,mirror}$ | fouling of the mirror |
| $F_{fou,glass}$ | fouling of the envelope glass |
| $F_{traking}$ | factor takes into account all the remaining losses as tracking |
| $H_{in,s}$ | enthalpy at the inlet of the solar field, kJ/kg |
| $H_{out,s}$ | enthalpy at the outlet of the solar field, kJ/kg |
| $H_{in,turbine}$ | enthalpy at the inlet of the turbine, kJ/kg |
| $K(\theta)$ | incidence angle modifier (0.1) |
| $k_d$ | annual discount rate |
| $LCOE$ | levelized cost of electricity, $c€/kWh_e$ |
| $\dot{m}_{htf}$ | mass flow rate of the heat transfer fluid in the solar field, kg/s |
| $N$ | depreciation operating period of the installation, year |
| $ND$ | days number in a year |
| $\dot{q}_{backup}$ | thermal energy produced by the backup system, $kWh_{th}$ |
| $\dot{q}_{dump}$ | dumped solar thermal energy, $kWh_{th}$ |
| $\dot{q}_{inc,s}$ | solar energy incident on the aperture area of the solar field, $kWh_{th}$ |
| $\dot{q}_{loss,piping}$ | thermal energy lost by the piping, $kWh_{th}$ |
| $\dot{q}_t$ | thermal energy produced by the backup system to reach the thermodynamic state, $kWh_{th}$ |
| $\dot{q}_{th,in,pb}$ | thermal energy input of the power block, $kWh_{th}$ |
| $\dot{q}_{th,out,s}$ | thermal energy produced by the solar field, $kWh_{th}$ |
| $T_{out}$ | outlet heat transfer fluid temperature of the solar collector assembly, °C |
| $T_{\max}$ | maximum temperature at which heat transfer fluid may out of the solar collector assembly, °C |
| $W_{des}$ | design cycle thermal requirement, kW |
| $\dot{W}_{el,aux,condenser}$ | condenser auxiliaries consumptions, $kWh_e$ |
| $\dot{W}_{el,net}$ | net electric production, $kWh_e$ |
| $\dot{W}_{el,net,pb}$ | net electrical energy output of the power block, $kWh_e$ |
| $\dot{W}_{el,pumps}$ | stands for condensate and feed water pumps consumption, $kWh_e$ |
| $\dot{W}_{el,turb}$ | steam turbine electric power output, $kWh_e$ |
| $\eta_{cycles,des}$ | design point cycle efficiency, % |
| $\eta_{net,pb}$ | net power block efficiency, % |
| $\eta_{op,tot}$ | solar field total optical efficiency, % |
| $\eta_{overall}$ | overall energy efficiency, % |
| $\eta_{piping}$ | piping thermal efficiency, % |
| $\eta_{shadowing}$ | fraction of the solar field surface actually radiated, % |
| $\eta_{th,s}$ | solar field thermal efficiency, % |
| $\rho_{clean}$ | density, $kg/m^3$ |
| $\gamma$ | intercept factor |
| $\tau_{glass}$ | transmittance |
| $\alpha$ | absorbivity |
| $\theta$ | incidence angle, ° |
| $\Delta_{TES}$ | total number of desired storage hours, h |

*Abbreviation*

| | |
|---|---|
| CSP | concentrating solar power |
| HTF | heat transfer fluid |
| MENA | Middle East and North Africa |
| PB | power block |
| SAM | solar advisor model |
| SF | solar field |
| SM | solar multiple |
| TES | thermal energy storage |

other CSP plants (solar towers power plants, the dish power plants and the Fresnel power plants) with an expected market share of around 66% in 2020 and 45% in 2030. The most known solar parabolic trough power plants are those of the Solar Energy Generating Systems (SEGS) power plants in California [3], the Nevada Solar One (NSO) and, most recently, the ANDASOL power plants in southern Spain [4]. In the latter, power plants are considered by many researchers and developers as a base for further investigation and development. Each ANDASOL power plant has the capacity of 50-$MW_e$ and uses the synthetic "Therminol VP I" oil as heat transfer fluid (HTF) to transfer the solar thermal energy from the solar field to the power block (PB).

Investigations on the solar parabolic trough power plants showed that generally several of its components and configuration options, e.g. collector type, solar multiple (solar field size), HTF type, storage capacity, turbine capacity and cycle design, etc, influence their thermal and electrical performance and hence their economics [5].

Many researchers across the globe are making great efforts to improve the techno-economic performance of solar parabolic trough power plant technology. Seitz et al. [6] investigated the economic impact of latent heat TES system with phase change material in the parabolic trough solar power plants for direct steam generation. Some studies sought to improve the performance of parabolic trough technology by applying different HTFs. The great majority of these studies and projects used a water-steam or synthetic oil as HTF in the solar field. Kumar and Reddy [7] carried out a study on solar parabolic trough field where water-steam and synthetic oil were used as HTF in the solar field and presented the feasibility of the power plant with those different HTFs. Feldhoff et al. [8] conducted a comparative study on solar parabolic trough power plants using water-steam and synthetic oil as HTF with an integrated TES system in terms of design, yield and investment. One other comparative study was realized by Marif et al. [9] to compare and evaluate the performance of the solar parabolic trough power plant using two different types of HTFs: water-steam and oil. The techno-economic performance of solar parabolic trough power plants composed of a TES system and a wet cooling system was studied by García et al. in [10]. In his study, synthetic oil "Therminol VP I" is used as HTF and the obtained results are compared to those data of "Andasol I" power plant which is currently in operation in southern Spain. The simulated values show a good accord with the experimental values.

Furthermore, recent studies focused on the optimization of the thermodynamic performance of the parabolic trough plants by using different heat transfer medium within the receiver. These include the use of Nano-fluids as HTF. Toghyani et al. [11] examined the performance of solar parabolic trough power plants with a TES system using four different Nano-fluids in the solar collector system, namely CuO, $SiO_2$, $TiO_2$ and $Al_2O_3$. This study reveals that by increasing the volume fraction of Nano-particles, the exergy efficiency of the system increases accordingly. Mwesigye et al. [12] studied "$Al_2O_3$-Therminol VP I" Nano-fluid. The study shows that using Nano-fluids improves the thermal efficiency of the parabolic trough solar field by up to 7.6%. Mwesigye et al. [13] improved research by carrying out a study on "Copper-Therminol VP I", "Silver-Therminol VP I" and "$Al_2O_3$-Therminol VP I" Nano-fluids. Results show that "Silver-Therminol VP I" Nano-fluid gives the highest thermal efficiency of the parabolic trough solar field of about 13% owing to its comparatively better thermal

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