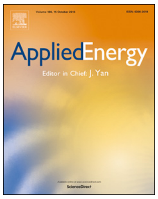
Applied Energy 225 (2018) 413–423

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy



# Wind barriers optimization for minimizing collector mirror soiling in a parabolic trough collector plant

M.A. Moghimi[a,*], G. Ahmadi[b]

[a] Clean Energy Research Group, Department of Mechanical and Aeronautical Engineering, University of Pretoria, Pretoria, South Africa
[b] Department of Mechanical and Aeronautical Engineering, Clarkson University, Potsdam, NY 13699-5725, USA

## HIGHLIGHTS

- Wind barrier optimization is an effective approach for reducing plant mirror soiling.
- A wind barrier is optimized for minimizing mirror soiling in a parabolic trough collector plant.
- Optimum wind barrier directs large amount of particles (> 86%) to pass over the solar field.
- Very small fraction of particles (> 0.8%) is deposited on the mirrors with optimum wind barrier.

## ARTICLE INFO

*Keywords:*
Wind barrier
Mirror soiling
Computational fluid dynamics
Optimization
Parabolic trough collector
Atmospheric boundary layer
Particle deposition
Turbulent
Discrete phase method

## ABSTRACT

Wind barriers, according to their sizes and shapes, can effectively control, shift and even modify the airflow field in their downstream. These structures can accelerate the wind flow over the mirror field and move the airborne particles away from the mirrors. For example, in concentrated solar power plants it is highly desirable to engineer the system in a way that fewer particles are deposited within the solar field, in particular, onto mirror surfaces. Therefore, design optimization of dust barriers could significantly impact the mirror soiling and favourably reduce the cleaning water consumption of a solar power plant. This study focuses on the optimization of a solid wind barrier around a parabolic trough collector plant for their protection against dust soiling. The presented simulation results show that an optimum solid wind barrier is able to direct large amount of particles (in this study, more than 86%) to pass over the solar field with very small fraction (around 0.8%) being deposited on the mirrors. In addition, it was found that the barrier wall is more effective in deflecting the larger particles from the solar field.

## 1. Introduction

Concentrated solar power (CSP) is a type of solar technology which focuses the impinging solar rays onto reflector surfaces (Heliostats/mirrors), which eventually transfers the sun energy to a working fluid for generating power. The most developed form of CSP plants is the parabolic trough collectors (PTC), which is the most mature CSP technology. In 2016, Chaanaoui et al. [1] analyzed the information of world operational installed capacity of CSP plants which were publicly available in literature. They reported that 3.5 GW out of 4.2 GW operational installed CSP plants are PTC.

Therefore, improving the performance of PTC plants is one of the interesting topics in the field of CSP and is widely discussed in literatures. Researchers' approaches in tackling this issue are focusing on enhancement of either thermal or optical performance of receivers. Regarding with thermal performance improvement, adding nano-particles to conventional Heat Transfer Fluid (HTF) of PTC plants [2–5] and placing insert-in heat transfer enhancer in the absorber tube receiver (metal foam [6], porous disk [7], perforated plate [8], helical fins [9], rectangular longitudinal fins [10]) are among the recent approaches suggested in literature. Regarding with optical performance improvement of PTCs, researchers mainly focus on reducing cosine loss in the system. Their approaches to tackle this issue are tilting receiver in the conventional single axis tracking PTC plants [11–15], or using two-axis tracking system for PTCs [16–19] and some novel ideas like PTC plant with rotatable axis tracking [20]. As one may note, the suggested approaches are mostly in the early stage of R&D (research and development) and requires long track of investigations to be approved by industry and be implemented in the PTC plants. The state of the art of this study, is presenting an effective practical and easy-implemented

---

[*] Corresponding author.
*E-mail address:* mohammad.moghimiardekani@up.ac.za (M.A. Moghimi).

https://doi.org/10.1016/j.apenergy.2018.05.027
Received 31 January 2018; Received in revised form 24 April 2018; Accepted 5 May 2018

approach to improve the performance of current PTC plants as proven technology. This approach must be as simple as possible that not even the future plants consider it in their design but the operational ones can utilize it. Therefore, this study looks at the performance improvement of PTC plants from a different view angle.

In practice, the performance of PTC plant depends on the high reflectivity of mirror surfaces and in particular their surface cleanness (avoiding mirror soiling). According to Niknia et al. [21], 1.5 g/m$^2$ dust deposition can reduce the instantaneous and average performance of the PTC plant, respectively by 60% and 37%. Therefore, controling mirror soiling can be an interesting attributor in the performance improvement of a PTC plant.

In the conventional PTC plants mirror are regularly cleaned to keep the plant performance in acceptable range. The most effective mirror cleaning systems use 0.2–1 L of water per square meters of collector areas. This is relatively high level of water consumption especially for desert areas that are perfect locations for CSP plant due to high DNI (Direct Normal Irradiance) and available number of sunny days, but with little precipitations. For example, in the PTC project of NOOR I, in Morocco, each individual mirror is washed every seven days and more than 36.5 million litres of demineralized water are consumed every year [22]. In addition, the plants in desert-like regions are exposed to frequent dust storms and sand depositions which require more often mirror cleaning schedules. Table 1 lists some global CSP regions of interest and shows how harsh those regions could be for a CSP plant in terms of annual fallen dust rate, which eventually ends up as dust deposition.

Commercially, mirrors of PTC plants are washed with one or several of the following systems: mechanically controlled high-pressure jet washing, mechanically controlled brush washing, deluge style washing, manual brush washing, manual high-pressure jet washing and robot washing [24]. However, these methods require significant amount of water for washing mirror surfaces. Therefore, researchers came up with various chemical or mechanical ideas to save water consumption for mirror cleaning in CSP plants. These include, anti-soiling coating, paved roads instead of dirt roads in plants, stowing the mirrors in storm, electrostatic repulsion of mirrors, mirror shaker (a mechanical vibrator which shakes off accumulated dusts on mirrors) and erection of wind barrier [22].

One of the simplest and economical approaches for reducing mirror soiling is the optimal design of wind barriers. For security reasons PTC plants are usually enclosed with wire mesh fences. However in sandy places like deserts, the fences are replaced by solid walls so that they can act as wind barrier and dust protection as well. However, studies on the effects of wind barriers on the aerodynamic loads and/or particle deposition in the PTC field are rather scarce [25,26]. Presence of a wind barrier causes the formation of a separation bubble that deflects the wind to flow above the mirror field and consequently, move the airborne particles to a height so that they deposit beyond the solar field. That is the barrier creates a sheltering effect for the solar mirror field. Therefore, according to their dimensions, shapes and designs, the wind barriers can effectively control, shift and even modify the wind flow pattern downstream and impact the particle deposition on mirrors. To the best of authors' knowledge, there is no comprehensive study on optimization of wind barriers for controlling particle deposition in PTC fields.

In this work the effects of the presence of a solid wind barrier equipped with flap at the tip on the wind flow field as well as the transport and deposition of particle are studied using a computational modelling approach. Simulations were performed for a range of barrier heights, flap angles and sizes. It was shown that an appropriately designed barrier can reduce the particle deposition in the solar field. Particular attention was given to the optimization of the wind barrier in order to engineer the airborne fate over a solar field and minimizing the number of particles fall within the field, in particular being deposited onto mirror surfaces.

**Table 1**
Fallen dust rates for various CSP plants [23].

| Country | Location | Fallen dust [tons/km$^2$/year] |
|---|---|---|
| Iraq | Khur Al-Zubir | 75.92 |
| Iraq | Um Qasir | 193.47 |
| Oman | Al-Fahal | 89 |
| Saudi | Arabia Riyadh | 392 |
| Palestine | Dead Sea | 45 |
| Chad | North Dianena | 142 |
| Nigeria | Kano | 137–181 |
| Greece | Crete | 10–100 |
| USA | Arizona | 54 |
| USA | Nevada | 4.3–15.7 |
| USA | California | 6.8–33.9 |
| Libya | Libya | 155 |
| Morocco | Tan Tan | 175 |
| Morocco | Boujdour | 219 |
| Mauritania | Dakhla | 191 |
| Mali | Niger river | 913–10446 |
| Australia | Namoi valley | 16.9–58.2 |
| China | Shapotou | 372 |

## 2. Computational domain, fluid flow and problem formulation

### 2.1. Problem layout

Fig. 1 shows the schematic sketch of the investigated PTC field. The field includes six trough receivers with fixed mirror pitch and aperture. To minimize mirror soiling in the field a wind barrier is placed in the direction of the prevailing wind. The barrier includes a solid wall and an inclined flap at its tip. The barrier is erected in a certain distance from the first mirror surface (the leftmost curved surface in Fig. 1). Finding optimum barrier specifications is the goal of this study. These specifications include barrier height, flap length, flap angle and barrier distance from the first collector which are respectively annotated as $l_2$, $l_3$, $\theta$ and $l_1$ in Fig. 1.

For this study, the length and the height of the computational domain were set, respectively, as 62.5 m and 20 m. To accurately capture the realistic and physical conditions of the prevailing wind, the fully developed atmospheric boundary layer (ABL) profiles were imposed on the inlet of the computational domain which will be discussed in more details in the following section.

### 2.2. Fluid flow and particle conditions

To accurately model particle depositions on the mirrors of PTC field, the airflow and particle transport and deposition need to be properly modelled. Attentions need to be given to the prevailing wind inlet condition and the particle interactions with mirror surfaces. Here a fully developed atmospheric boundary layer (ABL) profiles was used for the inlet wind velocity and an approximation for particle deposition on the mirror surface is described.

#### 2.2.1. Atmospheric boundary layer (ABL) profiles

Since the PTC field is exposed to an atmospheric wind, use of the correct model of the inlet mean flow velocity and turbulence intensity profiles is just as critical as accurate modelling of the geometric feature of the computational domain. Here the fully-developed atmospheric boundary layer (ABL) profile is used. This will allow using a short distance upstream of the PTC field rather to introduce the infinitely large terrain upstream, that saves the computational efforts. However, it is crucial to have sufficient space before the wind barrier; otherwise, due to blockage effect the simulation over predicts the results. Good practice rules in CFD recommend the minimal distance of any object from the inlet surface to be about 5 times the dimension of the object. Therefore, in this study, a distance of 12.5 m was introduced between