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Wind engineering analysis of parabolic trough collectors to optimise wind loads and heat loss

J. Paetzold[a,*], S. Cochard[a], D. F. Fletcher[b], A. Vassallo[b]

[a] *School of Civil Engineering, Faculty of Engineering and IT, The University of Sydney, NSW 2006, Australia*
[b] *School of Chemical and Biomolecular Engineering, Faculty of Engineering and IT, The University of Sydney, NSW 2006, Australia*

Abstract

Concentrating Solar Power (CSP) plants tend to be located in open areas. This leads to the power plant usually being subjected to high wind speeds without much shelter or protection. In parabolic trough plants the solar field, the collectors and receiver tubes, are affected by the wind on both the structural, as well as the performance level. The collectors must resist the aerodynamic forces caused by the wind, and the airflow around the receiver tube has a cooling effect on it. The effects of the wind on Parabolic Trough Collectors (PTC) were investigated in a parametric study over a large range of pitch and yaw angles. Three different trough geometries were analysed varying the focal length of the parabola, i.e. the depth of the trough. The data were obtained using the Computational Fluid Dynamics (CFD) package ANSYS CFX 15.0 and validated against experimental data.

An increase of the depth of the parabolic trough increases the maximum aerodynamic forces on the trough. However, a deeper trough has a sheltering effect on the receiver tube, thus reducing the thermal losses due to forced convection. This effect becomes more important the higher the temperature difference between the receiver and ambient air, and it can also reduce the requirements for highly insulated evacuated receiver tubes, which are a significant cost factor in PTC plants.

The highest force coefficients on the PTC are observed at high positive pitch angles and a yaw angle of 0°. While the aerodynamic loads on the trough reduce significantly with an increase in the yaw angle of the approaching wind, the heat flux around the receiver tube only shows a slight decrease in most cases. At some negative pitch angles an increasing yaw angle leads to higher thermal losses, as a vortex, forming at the leading edge of the trough, causes high air velocities around the receiver.

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1. Introduction

Concentrating Solar Power has several advantages over other renewable energy technologies. Its most important benefit is the dispatchability of the generated energy, as the technology lends itself to the efficient implementation of thermal energy storage. Currently wind power and photovoltaics (PV) are more mature technologies, however,

* Corresponding author. Tel.: +61-2-9351-2116; fax: +61-2-9351-3343.
E-mail address: joachim.paetzold@sydney.edu.au

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efficient energy storage is problematic with those technologies. CSP has great potential to play an important role on the path to 100% renewable electricity. In recent estimates of the future of CSP, a growth rate similar to what wind power and PV experienced is predicted for CSP with a time lag of about 20 years behind the development of wind power, and 10 years behind PV [1]. Currently the costs of the generated electricity are still considerably higher than for other technologies, but research efforts aim at minimising the costs. For PTC plants one of the main targets is to achieve higher temperatures, which primarily means to increase the aperture of the troughs to achieve higher concentration ratios.

The two main effects that the wind has on PTC plants are aerodynamic loads on the collectors and cooling of the receiver tube through forced convection from the airflow around the tube. This study investigates these two effects and analyses the airflow around a PTC at a large range of different pitch, as well as yaw, angles. The main focus of this study is the comparison of three different trough geometries that vary in the focal length of the parabola. Validated against experimental data from wind tunnel tests, a series of three-dimensional simulations was conducted with the CFD program ANSYS CFX 15.0.

Most previous studies that investigated the effects of the wind on PTC plants focussed on one specific geometry of the solar trough. Hosoya et al. [2] performed wind tunnel experiments at small model scale on a typical shallow trough geometry at both the individual trough level and the solar field level. Several numerical studies were published recently, all of which investigated a particular geometry of the PTC. Naeeni and Yaghoubi [3], and Zemler et al. [4] performed two-dimensional, steady-state CFD simulations at a range of wind velocities mainly focussing on aerodynamic loads. Both the loads and the thermal effects of the wind were studied by Hachicha et al. [5,6] on the example of the Eurotrough collector [7].

None of the above mentioned numerical studies investigated and compared the effects of different geometries of the parabolic trough. To the authors knowledge the only study investigating the effect of various depths of the parabolic trough collectors was published by Peterka et al. [8]. In experiments in a wind tunnel they performed measurements with balances and pressure taps to determine the aerodynamic loads acting on an individual trough. The experiments were done at small model scale (1:25), and did not include the receiver tube, so thermal aspects of the wind effects were not considered in the study. Sun et al. [9] presented a comprehensive review of studies about the effects of the wind on PTC plants.

Initial results of the present study were presented at the Solar 2014 Scientific Conference of the Australian Solar Council [10] for a 0° yaw angle. This paper focuses on the variation of the yaw angle, and how it affects the forces and thermal effects of the wind on the PTC and the receiver.

2. Methodology

2.1. Computational setup and procedure

The airflow around PTCs was studied using the commercial CFD program ANSYS CFX 15.0 with Reynolds Averaged Navier Stokes simulations using the SST turbulence model [11]. While a scaled down trough was used for the validation against experimental data, the main parametric studies are conducted on full-scale troughs with an aperture D of 5m. A range of pitch angles between −90° (convex side facing the wind) and 90° (concave side facing the wind), and yaw angles from 0° (PTC row normal to the wind direction) to 60° was simulated for three different trough geometries. The focal length of the parabola, f, was varied from $D/3$ (shallow trough), through $D/4$ (medium trough), to a deep trough at $D/5$.

Fig. 1 shows the computational domain with the boundary conditions, axis orientation, and inlet airflow directions. The origin of the coordinate system is located in the mid plane in the centre of the receiver tube. The x-axis is oriented horizontally, normal to the collector row. The y-axis is parallel to the collector row, and the z-axis is oriented vertically. The pitch angle of the trough is defined relative to the 0° position in which the aperture of the trough faces straight upwards in the positive z direction. Positive pitch moves the concave side of the collector and the receiver tube into the wind. An inlet velocity profile according the a category 2 terrain as per AS/NZS1170.2 [12] was applied, defined by the equation $u_{ABL} = 2\times\ln(50z + 1)$, with z being the height above ground in metres. Depending on the yaw angle, α, the inlet velocity components u and v are defined as $u = u_{ABL}\times\cos(\alpha)$, and $v = u_{ABL}\times\sin(\alpha)$. The simulations used incompressible air at 1bar as the fluid with an inlet temperature set to 25°C, while the turbulence intensity was defined