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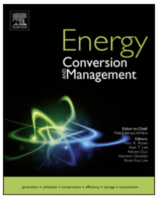

# Dust effect on the optical-thermal properties of absorber plate in a transpired solar air collector

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## ABSTRACT

The extent to which the accumulation of dust inside the collector has the capacity to influence its performance is generally overlooked. The purpose of this study therefore is to provide an understanding of the impact of dust specifically on the absorptivity and emissivity of absorber plate. Characteristics of dust deposition on its surface and associated reductions in absorptivity have been experimentally investigated in Tianjin of China. An empirical correlation is thus proposed and verified to predict the variation of absorptivity with respect to dust accumulation. Then the dusty heat transfer model has been used to estimate the collector performance drop in comparison with a similar clean one operating under the same conditions. It is concluded that the outlet temperature is largely influenced. The maximum value of efficiency drop over test periods is found to be 19.23%. Additionally, the effect of changes in absorber emissivity due to dust on the collector performance has also been studied, which is found to be so small that it can be ignored. The results of this work would improve the predictive capability of current collector simulation model.

## 1. Introduction

Solar energy has been widely used in many fields of human life since it is clean, free and abundant [1–3]. Most published studies have concentrated on the performance enhancement of solar devices in a clean condition [4–6]. However, the effects of dirt and dust accumulation are worth of concern, especially for regions with a high deposition of dust and low frequency and less intensity of rain. Hottel and Woertz [7] investigated the impact of dust accumulation on solar-thermal systems. Their 3-month test was performed in Boston, Massachusetts, and showed an average of 1% loss of incident solar radiation due to dust accumulating on a glass plate with a tilt angle of 30°. Following this pioneering research, many studies have been done about the dust effects on the energy losses. Salim et al. [8] found that a 32% reduction of energy output from the unclean array is achieved after eight months with a fixed tilt angle of 24.6°, at a solar village near Riyadh, Saudi Arabia. In similar studies, Rahman et al. [9] discovered that at the end of the month for the tropical weather conditions in Bangladesh, the output power of PV panels reduces by 34% with a tilt angle of 23.5°. Hassan et al. [10] reported that in the case of a-Si, the depression of efficiency is 66% after six months without panel cleaning. Saidan et al. [11] studied the average degradation rate of the efficiencies of solar modules in Baghdad city of Iraq, respectively 6.24%, 11.8% and 18.74% for one day, one week and one month exposed to dust.

A search of the literature revealed that the extent of dust effect either on the performance of PV module or that of solar thermal devices rely on the dust deposition density, as well as dust characteristics, which are greatly affected by weather conditions and dust sources, such as atmospheric dust deposition, wind speed or direction and humidity et c. In Tehran, Iran, Asl-Soleimami et al. [12] has done a similar work and reported that the energy output of a solar module is reduced by 60% from March 1999 to January 2000. On the other hand, the rate of dust deposition would be greatly impacted by orientation and tilt angle of solar devices. Gholami A et al. [13] reported that after a 70-day test period in Isfahan university of technology, the dust deposition density changes from 4.0599 (g/m$^2$) facing northwest with a 90° tilt angle, to 10.3129 (g/m$^2$) facing north with a 15° tilt angle, and the transmissivity results in a 15%–24.83% reduction. In addition, dust deposition differs from a surface to another. Cabanillas and Munguía [14] studied the dust effects on the performance of PV under natural operating conditions in the city of Hermosillo, Sonora. The results indicated that the density per surface area are respectively 1.177, 1.238, and 2.326 gr/cm$^2$ for the monocrystalline, polycrystalline and amorphous. The maximum reduction in potential is around of 6% for monocrystalline and polycrystalline modules and of 12% for the amorphous silicon. ElShobokshy and Hussein [15] found that compared to coarser

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**Nomenclature**

| | |
|---|---|
| $A$ | area (m$^2$) |
| $c_p$ | specific heat, (J/kg K) |
| $d$ | plenum thickness (m) |
| $H$ | collector height (m) |
| $h_1$ | convective heat transfer coefficient between the glass cover and the surroundings, (W/m$^2$ K) |
| $h_2$ | convective heat transfer coefficient between the glass cover and Fluid 1, (W/m$^2$ K) |
| $h_4$ | convective heat transfer coefficient between the absorber plate and Fluid 1, (W/m$^2$ K) |
| $h_5$ | convective heat transfer coefficient between the absorber plate and Fluid 2, (W/m$^2$ K) |
| $h_6$ | radiation heat transfer coefficient between the absorber plate and backboard, (W/m$^2$ K) |
| $h_7$ | convective heat transfer coefficient between the backboard and Fluid 2, (W/m$^2$ K) |
| $I_c$ | solar radiation intensity (W/m$^2$) |
| $m$ | dust mass on samples (g) |
| $P$ | pitch (m) |
| $Q$ | air volume flow rate (m$^3$/h) |
| $q_{rad}$ | radiant heat from glazing cover to the surroundings (W/m$^2$) |
| $T$ | temperature (K) |
| $v_w$ | outdoor wind velocity (m/s) |
| $W$ | collector width (m) |

*Greek symbols*

| | |
|---|---|
| $\alpha$ | absorptivity |
| $\delta$ | thickness (m) |
| $\varepsilon$ | emissivity |
| $\tau$ | transmissivity |
| $\rho$ | air density (kg/m$^3$) |
| $\lambda$ | thermal conductivity (W/(m K)) |
| $\omega$ | dust deposition density (g/m$^2$) |

*Subscripts*

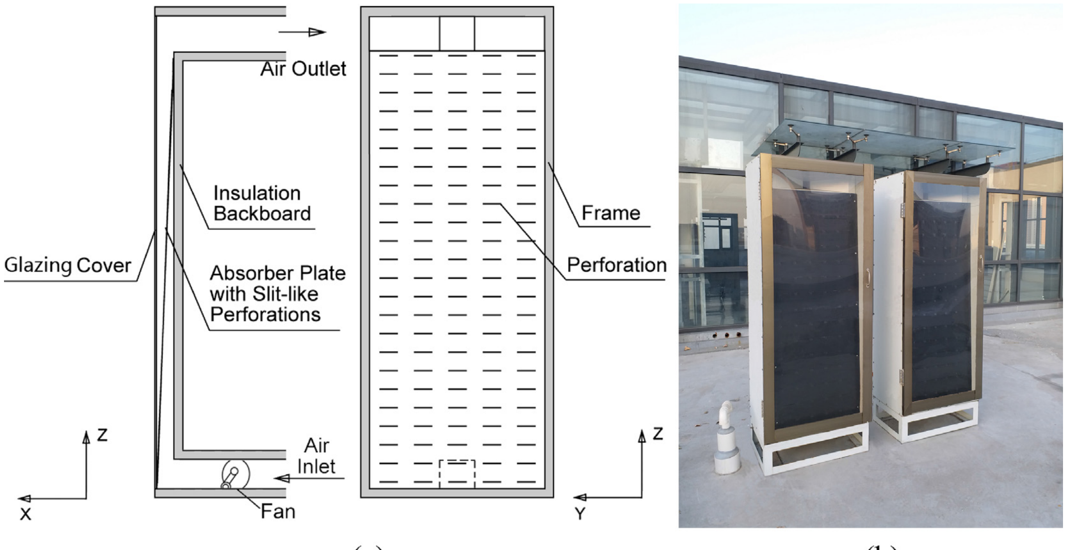
| | |
|---|---|
| a | ambient environment |
| b | backboard |
| f1 | Fluid 1 |
| f2 | Fluid 2 |
| g | glazing cover |
| in | inlet |
| out | outlet |
| p | absorber plate |

particles, fine particulate dust significantly deteriorates the performance of photovoltaic panels.

Furthermore, the irradiance losses caused by the dust are also strongly dependent on the sunlight incident angle and the ratio of diffuse to direct radiations. Zorrilla-Casanova et al. [16] presented that the value of irradiance loss is minimum at solar noon, then increases up to a maximum when incident angle approximately equals to 75°, and then decreases with incident angle increasing. The proportion of the diffuse component in the global radiation is a very important factor in estimating the energy losses due to accumulated dust.

As mentioned above, many studies have been conducted on the adverse effect of dust on the performance of solar devices. The vast majority of these focus on the dust deposition on the outer surface of solar products, i.e. transparent cover, while dust accumulated inside the collector is generally overlooked. However, for solar air collectors, the absorber plate plays a significant role in diverting gained heat to the fluid flowing through the interior of collector. Gao indicated that when the absorptivity from 0.5 to 0.9, the efficiency would increase by 116.7% [17]. So, it's urgent to investigate the extent to which the accumulation of dust has the capacity to degrade the optical-thermal properties of absorber plate. This is the motivation of the present investigation to obtain accurate prediction of absorptivity reduction with dust accumulation on the absorber plate surface in a transpired solar air collector utilizing jet impingement.

The experiments were conducted in Tianjin of China, where the annual mean concentration of PM2.5 is higher ranking 24 among the 190 polluted cities and additionally, the annual rainfall is relatively low. Tianjin is an industrial city located astride the Hai River on the North China. According to the statistical data, the source of dust in the atmosphere of Tianjin is mainly from flowing dust, burning coal, automobile emission and industrial manufacture. Thus, the reported results in the paper may be used for other cities with similar dust source.



(a) (b)

**Fig. 1.** Schematic diagram (a) and experimental apparatus (b).