StudyOn The Thermal Performance Of Flat Plate Solar Air Collectors With Dust Deposition On The Transparent Covers

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ABSTRACT

Transparent covers of solar air collectors, which are exposed to the ambient, are easily deposited by dust and ash in the atmosphere. Transmittances of transparent covers can be decreased by dust deposition surfaces and it directly results in poor thermal performances of solar air collectors. The present study analysed the effect of dust deposition on two types of single pass flat plat solar air collectors with smooth airflow channel and with rectangular fin structure. Based on the differential equations of thermal balance**,** transient thermal characteristics of the solar air collectors through a typical day were predicted by dynamic meteorological conditions. Optical properties of both clean transparent covers and dust deposition cover surfaces were considered in the numerical calculation. It was demonstrated that, calculated thermal efficiencies of the two types of collectors were in good accordance with the measured data when fouling ratio of 40% was considered in the calculation. Accordingly, daily averaged thermal efficiencies of the solar air collectors with smooth airflow channel and with rectangular fin structure were respectively decreased by 23.4% and 31.6% due to dust deposition of transparent covers.

KEYWORDS

Flat plate solar air collector,Dust deposition surface, Thermal performance, Transient model，Fouling ratio

INTRODUCTION

Solar air collectors are more and more popular for space heating and drying processes due to their advantages of no extra storage equipment, simple maintenance, freeze resistance and less corrosion compared with solar hot water heating systems. Because of lower thermal efficiencies of general flat plate solar air collectors, many researches have been done to improve the thermal performances of solar air collectors. In order to enhance the convective heat transfer between the flowing air and the absorber plate,

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various types of absorber plates were used in the studies, such as roughness elements (Bhushan and Singh, 2010), cross-corrugated plates(Lin et al., 2006, Liu et al., 2007), v-groove absorber plate(Karim and Hawlader, 2006), or using fins attached over and under the absorber plate to provide extended surface(Tanda, 2011). Besides, double pass is another way of enhance air-side heat transfer of the collectors by inserting the absorber plate into the air conduit to divide it into two channels so as to extend heat transfer area(Yeh and Ho, 2009, Ho et al., 2005, Chamoli et al., 2012). Furthermore, El-Sebaii and Al-Snani(2010) presented the effect of selective coating on thermal performance of flat plate solar air heaters from the view point of radiation heat transfer. It could be seen that, most of the previous studies focused their attention on the absorber plates of the collectors. And it seems heat transfer effect between the absorber and the air conduit is the primary impact factor for the thermal performances of solar air collectors.

Moreover, optical properties of the transparent cover also play a non-negligible role on collector performance. The properties directly determine the absorbed solar radiation S by the collector absorber plate. In the present study, it is tried to demonstrate the effect of dust deposition on the thermal performances of flat plate solar air collectors with smooth airflow channel and with rectangular fin structure. Dynamic thermal characteristics of the collectors were numerically predicted by transient model with dynamic meteorological conditions of a typical day. Numerical results were compared with the measured data to analyse the effect of the dust deposition.

NUMERICAL MODEL

The cross-section schematic graph of flat plate solar air collectors with smooth airflow channel and with rectangular fin structure are shown in Figure 1. And the heat processes among the collector elements are also given in the graph. The meanings of the symbols in the graph can be found in the nomenclature list at the end of the paper.

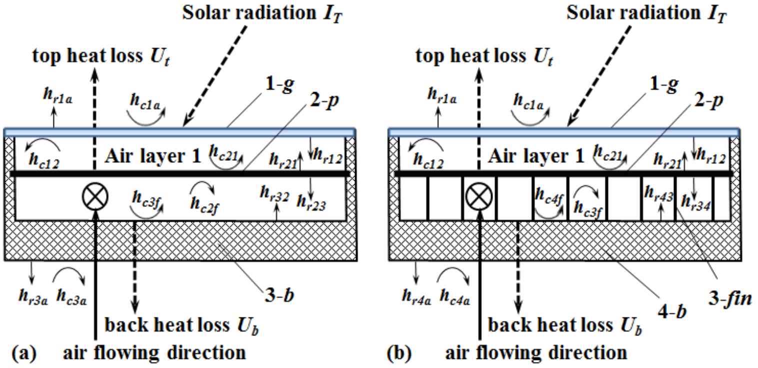

Figure 1. *Cross-section schematic view of flat plate solar air collectors and heat transfer processes: (a) with smooth airflow channel; (b) with rectangular fin structure*

For the sake of modelling convenience, it is necessary to make some hypotheses and lumped parameter method is adopted. Based on the hypotheses, thermal balance equations for the single pass solar air collector with rectangular fin structure are described as follows.

For the glass cover 1

$\rho_1 c_{p1} V_1 \frac{dT_1}{d\tau} = \alpha_1 I_T A_g + (h_{c21} + h_{r21}) A_a (T_2 - T_1) - (h_{c1a} + h_{r1a}) A_g (T_1 - T_a)$(2)

For the absorber plate 2

$\rho_2 c_{p2} V_2 \frac{dT_2}{d\tau} = (\tau\alpha) I_T A_a - (h_{c21} + h_{r21}) A_a (T_2 - T_1) - \eta_o h_{c3f} (A_{fin} + A_{pr})(T_2 -$

$T_f) - \eta_o h_{r34} A_g (T_2 - T_{4top})$ (3)

whereT_{4top} denotes average temperature of the top surface of back insulation. The total surface efficiencyη_o of the absorber plate 2 with root surface area of A_{pr} and fin structure 3 with surface area of A_{fin} are considered as

$$\eta_o = 1 - (1 - \eta_f) \frac{A_{fin}}{A_{fin} + A_{pr}}$$

And the temperature of the fin structure T_3 can be calculated from

$T_3 - T_f = \eta_f (T_2 - T_f)$ (4)

$$\eta_f = \frac{th(m(H_2 + \delta_{fin}))}{m(H_2 + \delta_{fin})}, m = \sqrt{2h_{3f}/\lambda\delta_{fin}}$$

For the air stream through the collector conduit

$c_{pf} H_2 \frac{\partial T_f}{\partial \tau} + (\dot{m}_f c_{pf}/W) \frac{\partial T_f}{\partial x} = \eta_o h_{c3f} \frac{A_{pr} + A_f}{A_a} (T_2 - T_f) + h_{c4f} \frac{A_g}{A_a} (T_{4top} - T_f)$(5)

For the back insulation

$\rho_4 c_{p4} V_4 \frac{\boldsymbol{dT_{4top}}}{\boldsymbol{d\tau}} = \eta_o h_{r34} A_g (T_2 - T_{4top}) + h_{c4f} A_g (T_f - T_{4top}) - U_b A_g (T_{4top} - T_a)$(6)

wherethe back loss heat coefficient U_b is calculated by

$U_b = \lambda_b / D_b$ (7)

Thermal balance equations for the flat plate solar air collector with smooth airflow channel are simple to the case with rectangular fin structure and are omitted here.

Detailed description can be found byTchinda(2009).Moreover, Heat transfer coefficients for the collector elements can be found by Yang et al.(2012).

NUMERICAL METHOD

A variable step Runge-Kutta Method was adopted and a Matlab program was compiled and executed to solve the differential equations (2)-(6) numerically. Time interval of two minute was taken here to calculate the dynamic thermal performance of the collectors. The calculation was started with hypothesis of quasi-steady-state heat transfer at the initial time. For every time interval, dynamic meteorological conditions were considered to realize transient thermal characteristic simulations of the collectors.

CALCULATION CONDITIONS

The contour sizes of both of the flat plate solar collectors are 1m×2m and the thickness of the metallic frame is 1cm. The height of the airflow channel is 10cm. For the fin structure, the height of the fins is 10cm, and the span of the fins is 5cm. The collector slope angleβ is40°. Galvanized iron with an absorptance of 0.81 and emittance of 0.90 is used for the absorber plate. The thermal conductivity of the back insulation is 0.046 W/（m^2 K）. Transparent covers of the flat plate solar collectors are 5mm polycarbonate materials. Extinction coefficient$K$ of the cover material is 16m^{-1}. For the transparent cover with clean surface, its transmittance τ_g, absorptance $\alpha_g$and reflectance ρ_g are 0.829, 0.077, 0.094, respectively. As the real transparent covers are fouling surfaces deposited by dust and ash, fouling ratio *fr* of the surfaces are introduced to describe the fouling extent of the covers. And dust deposited on the surface is treated to grey body with an absorptanceα_{dust} of 0.8(Holman, 2010). Thus the transmittance τ_{fcs}, absorptance $\alpha_{fcs}$and reflectance ρ_{fcs} of the fouling cover surface can be calculated by equations (9)-(11). When 20% of total solar radiation is absorbed and reflected by dust deposition,τ_{fcs},α_{fcs},ρ_{fcs} are 0.664, 0.221, 0.115, respectively. When 40% of total solar radiation is absorbed and reflected by dust deposition,τ_{fcs},α_{fcs},ρ_{fcs} are 0.398, 0.453, 0.149, respectively. In addition, incidence angles of the beam radiation over the day are calculated by day of the year *n*, latitude, hour angle, collector slope and surface azimuth angle. And the optical properties are modified by the effect of incidence angles and specific modified method was given by Duffie and Beckman (1991).

$$\tau_{fcs} = (1 - fr) * \tau_g \qquad (9)$$

$$\alpha_{fcs} = (1 - fr) * \alpha_g + fr * \alpha_{dust} \qquad (10)$$

$$\rho_{fcs} = (1 - fr) * \rho_g + fr * (1 - \alpha_{dust}) \qquad (11)$$

The meteorological conditions of the typical day of April 28th, 2011 in Beijing were taken for numerical calculating and were shown in Figure 2. The experimental study of the collectors was reported by Ming et al.(2012) and the measurement was conducted on April 28th, 2011, in the Rural Energy and Environment Laboratory (REEL) ofTsinghua University, a research facility located in the suburb of Beijing.The real transparent covers were fouling surfaces and the experiment set-up and test procedures could be found in the literature.

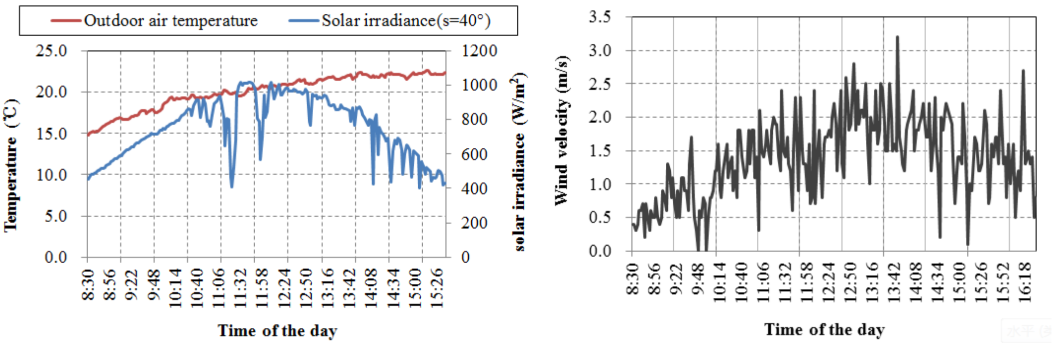

Figure 2.*Meteorological conditions of April 28th, 2011, in Huairou region of Beijing (Ming et al.,2012)*

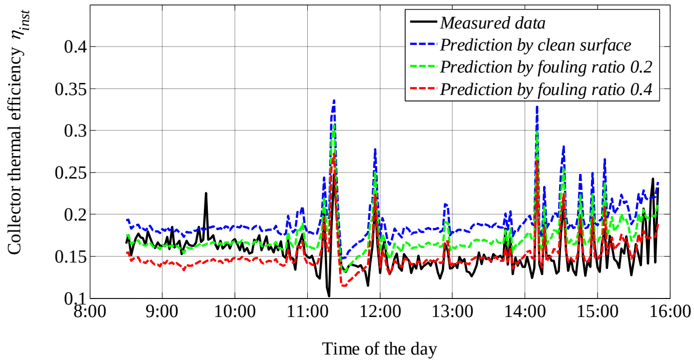

Figure 3.*Comparison of calculated collector thermal efficiencies with measured values for solar air collector with smooth airflow channel*

RESULTS AND DISCUSSION

For the flat plate solar collector with smooth airflow channel, three calculated cases are considered, namely, clean transparent cover, fouling surface with *fr* = 0.2 (20% of total solar radiation is absorbed and reflected by dust deposition) and fouling surface with *fr* = 0.4. Figure 3 shows the comparison of calculated collector thermal efficiencies by transient model with measured values for solar air collector with smooth airflow channel. It can be seen the change trends of the calculated collector thermal efficiencies are fairly the same with the measured values. But the magnitudes of the three calculated cases are different from each other. The measured value of averaged collector thermal efficiency based on the solar radiation period of the typical day is 0.152. And the calculated values of clean cover, fouling surface with *fr* = 0.2 and *fr* = 0.4 are separately 23.4%、11.0%、-2.6% higher than the measured value. It is evident the case of fouling surface with *fr* = 0.4 is in good agreement with the measured data.

Figure 4 shows the comparison of calculated collector outlet temperatures with measured values for solar air collector with smooth airflow channel. The deviation of the calculated case with clean cover is the largest and the case with fouling surface with *fr* = 0.4 is the smallest. In order to demonstrate the error distribution of the calculated cases, relative error analysis of instantaneous thermal efficiencies predictions with clean cover and fouling surfaces with *fr* = 0.4 for the collector with smooth airflow channel are shown in Figure 5. For the case with *fr* = 0.4, about 95% data points of calculated thermal efficiencies locate in the experimental error limit of ±20%. Whilethe error limit of the calculation with clean cover case is about -5% to 35%. It can be seen the error distribution of case with fouling cover surface with *fr* = 0.4 is symmetric and more reasonable than the case with clean cover.

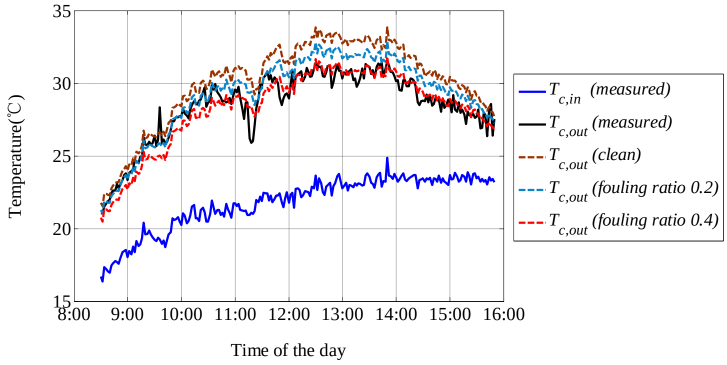

Figure 4. *Comparison of calculated collector outlet temperatures with measured values for solar air collector with smooth airflow channel*

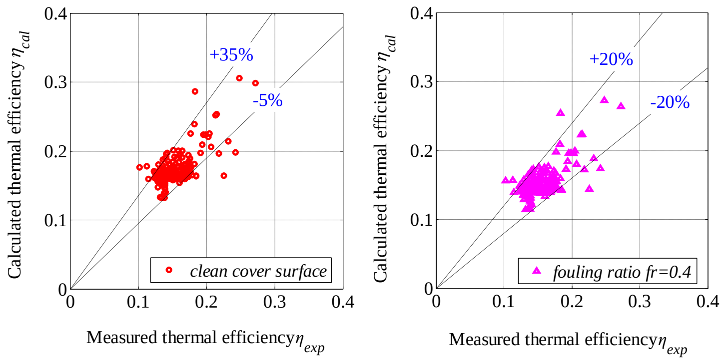

Figure 5.*Relative error analysis of instantaneous thermal efficiencies with clean and fouling cover surfaces fr = 0.4 for the collector with smooth airflow channel*

For the flat plate solar air collector with rectangular fin structure, cases of clean cover surface and fouling surface with *fr* = 0.2 and *fr* = 0.4 are also compared. Figure 6 gives the contrast curves of calculated and measured thermal efficiencies versus the daytime. Similar change trends are also found between the calculated and measured values. Average thermal efficiency of the measured value throughout the solar irradiation period is 0.295. And the calculated values of average thermal efficiencies of cases with clean surface and fouling surface with *fr* = 0.2 and *fr* = 0.4 are 31.6%, 17.0%, 1.42% higher than the measured value, respectively. Figure 7 gives the comparison of calculated and measured outlet temperatures. It is shown the prediction with fouling ratio 0.4 is more adjacent to the measured values. Relative error analysis of instantaneous thermal efficiencies with clean cover and fouling ratio 0.4 compared with corresponding measured data for the collector with rectangular fin structure is shown in Figure 8. About 95% data points of calculated thermal efficiencies locate in the experimental error limit of ±15% for the prediction with fouling ratio 0.4. While the error limit of the prediction with clean cover is extremely asymmetric. Therefore, dust deposition is needed to consider in the collector thermal performance predictions.

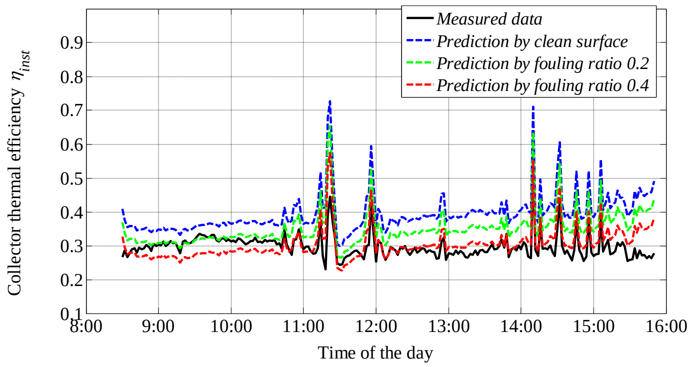

Figure 6.*Comparison of calculated collector thermal efficiencies with measured values for solar air collector with rectangular fin structure*

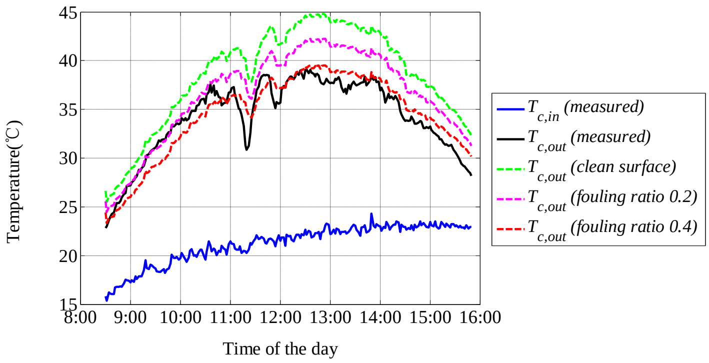

Figure 7. *Comparison of calculated collector outlet temperatures with measured values for solar air collector with rectangular fin structure*

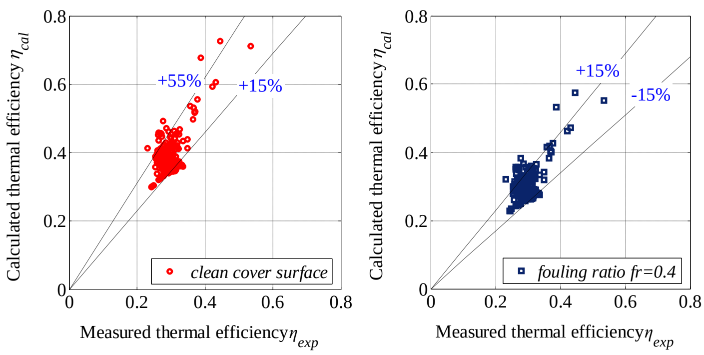

Figure 8. *Relative error analysis of instantaneous thermal efficiencies with clean and fouling cover surfaces fr = 0.4 for the collector with rectangular fin structure*

CONCLUSION AND IMPLICATIONS

Dynamic thermal performance prediction of flat plate solar air collectors with smooth airflow channels and with rectangular fin structures were conducted and compared with the experimental data. It could be concluded that, for both of the solar air collectors, the calculated results with 40% of total solar radiation absorbed and reflected by dust deposition were in good agreement with the measured data. Furthermore, the daily averaged thermal efficiencies of the solar air collectors with smooth airflow channel and with rectangular fin structure were decreased by 23.4% and 31.6% respectively due to dust deposition on the transparent covers. It could be seen that, transparent covers of the collectors should be cleaned frequently in order to prevent absorbed solar radiation by the absorber plate and reduction of solar thermal efficiencies.

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