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# Characterization of solar flat plate collectors

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ABSTRACT

Characterization of solar collectors is based on experimental techniques next to validation of associated models. Both techniques may be adopted assuming different complexities. In this work, a general methodology to validate a collector model, with undetermined associated complexity, is presented. It serves to characterize the device by means of critical coefficients, such as the film (convection) transfer coefficient, plate absortance or emmitance. The first step consists of identifying those significant parameters that match the selected model with the experimental data, via nonlinear optimization techniques, applied to steady state conditions. Second, new correlations must be adopted, in those terms where it is necessary (i.e. film coefficient equations). Finally, the overall model must be checked in transient regime. To illustrate the technique, a tailor-made prototype flat plate solar collector has been analyzed. An intermediate complex collector model has been proposed (2D finite-difference method). Both steady and transient states were analyzed under different operating conditions. Parameter identification is based on Newton's method optimization. For parameter approximation, exponential regression functions through multivariate analysis of variance is proposed among many other alternatives. Results depicted a robustness of the overall proposed method as starting point to optimize models applied to solar collectors.



**Contents**



## 1. Introduction and previous work

Processes of industrialization and economic development require important energy inputs [1]. Fuels are the world's main energy resource and are considered the center of energy demands. However, reserves of fossil fuels are limited and their large-scale use is associated with environmental deterioration [2]. These facts

*Abbreviations:* CFD, computational fluid dynamics; FEM, finite element method; IHTP, inverse heat transfer problem; RMSE, root mean square error.

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**Nomenclature**

| | |
|---|---|
| $a_l$ | constant factor of the regression function 'l' |
| $b_{ul}$ | exponent (constant value) of the regression function 'l' |
| $Bi$ | Biot number |
| $c_f$ | fluid specific heat (J/(kg K)) |
| $c_p$ | specific heat of the absorber plate (J/(kg K)) |
| $D_i$ | inner diameter of the risers (m) |
| $e$ | plate thickness (m) |
| $e_q$ | 2D equivalent thickness of the pipe-weld-plate (m) |
| $e_r$ | pipe thickness (m) |
| $f_l$ | exponential regression function 'l' |
| $Gr$ | Grashof number |
| $h$ | final estimated film coefficient of the inner wall water (W/(m$^2$ K)) |
| $h_o$ | initial film coefficient of the inner wall-water (W/(m$^2$ K)) |
| $I_T$ | global incident radiation over tilted surface (W/m$^2$) |
| $k_e$ | extinction coefficient of the covering glass (m$^{-1}$) |
| $k_f$ | pipe conductance (W/(m K)) |
| $k_p$ | conductance of the absorber material (W/(m K)) |
| $k_h$ | proportionality factor applied to $h$ |
| $k_q$ | proportionality parameter associated to the volumetric equivalent heat transfer coefficient $U_c$ |
| $k_{uc}$ | proportionality factor applied to $U_c$ |
| $k_{iT}$ | conduction heat transfer coefficient of the insulation material (W/(m K)) |
| $K_c$ | global heat transmission coefficient plate-fluid (W/(m$^2$ K)) |
| $\dot{m}_f$ | fluid flow rate into the risers (kg/s) |
| $\dot{m}'_f$ | fluid flow rate in lower and upper pipes (kg/s) |
| $n_2$ | refraction index of the covering glass |
| $Nu$ | Nusselt number |
| $Pr$ | Prandtl number |
| $q''_1$ | unitary surface heat radiation on the absorber (W/m$^2$) |
| $\dot{q}_1$, $S$ | internal heat generation in the absorber due to solar radiation (W/m$^3$) |
| $q''_2$ | unitary surface heat loss in the absorber plate (W/m$^2$) |
| $\dot{q}_2$ | loss of the internal heat generation in the absorber (W/m$^3$) |
| $q''_3$ | unitary surface heat transferred to the working fluid (W/m$^2$) |
| $\dot{q}_3$ | loss of the internal heat generation in the absorber due to heat transmission to water (W/m$^3$) |
| $\dot{q}_v$ | internal heat generation in the absorber (W/m$^3$) |
| $q'_u$ | net heat released in the refrigerant water per length unit (W/m) |
| $r_i$ | inner radius of the riser (m) |
| $r_e$ | outer radius of the riser (m) |
| $r'_i$ | inner radius of lower and upper pipe (m) |
| $Re$ | Reynolds number |
| $s$ | collector tilt (rad) |
| $\overline{SP}^n$ | known conditions vector at time '$n$' |
| $t$ | time (s) |
| $T$ | temperature (K) |
| $T_a$ | cuidado si es $T_o$ (Eq. (2.b)) |
| $T_o$ | room temperature (K) |
| $T_b$ | plate temperature in the bulb thermometer (K) |
| $T_{fi}$ | refrigerant fluid inlet temperature (K) |
| $T_{fo}$ | refrigerant fluid outlet temperature (K) |
| $T_f$ | fluid mean temperature in a differential element (K) |
| $T_{f,p}$ | fluid temperature into the upper and lower horizontal pipes(K) |
| $T_p$ | material temperature of the upper and lower horizontal pipes (K) |
| $T_m$ | mean top surface temperature (K) |
| $T_w$ | mean temperature in the inner side of the pipe in a differential element (K) |
| $\overline{UP}^n$ | Unknown parameters vector at a stationary state at time '$n$' |
| $U_L$ | volumetric heat transfer loss coefficient of the collector (W/(m$^3$ K)) |
| $U_l$ | global heat loss coefficient of the collector (W/(m$^2$ K)) |
| $U_b$ | heat loss behind the collector (W/(m$^2$ K)) |
| $U_t$ | top heat loss (W/(m$^2$ K)) |
| $U_C$ | volumetric equivalent heat transfer coefficient of the control volume pipe-weld-plate (W/(m$^3$ K)) |
| $X_{ul}$ | standardized input parameter '$u$' of a regression function for output parameter '$l$' |
| $x$ | transversal direction distance in the collector (m) |
| $y$ | longitudinal direction distance in the collector (m) |
| $\alpha$ | thermal diffusivity of the absorber plate material (copper) (m$^2$/s) |
| $\alpha_\theta$ | directional absorbance of the cooper black plate |
| $\Delta$ | increment |
| $\varepsilon_g$ | glass emmitance |
| $\varepsilon_p$ | plate emmitance |
| $\rho$ | absorber density (kg/m$^3$) |
| $\rho_f$ | refrigerant density (kg/m$^3$) |
| $\varphi$ | latitude (rad) |
| $\omega$ | timing angle (rad) |
| $\delta$ | declination (rad) |
| $\gamma$ | azimutal angle (rad) |
| $\theta$ | incident angle of beam irradiance over the tilted surface (rad) |
| $\Psi$ | objective function to minimize by the identification process |
| $\Gamma$ | auxiliary expressions for Eqs. (7.a), (7.b), (9.a) and (9.b) |

*Sub-index*

| | |
|---|---|
| $i$ | $x$ direction |
| $j$ | $y$ direction |
| $m$ | number of nodes in $x$ direction |
| $w$ | number of input parameters in a regression function |
| $p$ | number of riser |
| $r$ | node number |

*Super-index*

| | |
|---|---|
| $k$ | time in transient regime analysis |
| $n$ | interval of time |

have encouraged growth in the use of renewable energy resources worldwide [3]. Solar energy is considered one of the main promising alternative sources of energy to replace the dependency on other fossil energy resources [4,5]. Solar water heating systems are very common systems, extensively used in many countries with high solar radiation potential, such as Mediterranean countries [6]. They are often viable to replace fossil fuels used for many home applications [7]. Conventional flat plate solar collectors with a metal absorber plate and covers are used to transform solar energy into heat [8]. Optimization of solar heating systems provides both running and design parameters that ensure maximal collected heat.