SolCoSi: A new online software for evaluate the thermal performance of flat plate solar collectors

Rodolfo Pérez-Espinosa[1], Octavio García-Valladares[2]

[1] Posgrado en Ingeniería (Energía), Unviersidad Nacional Autónoma de México, Privada Xochicalco S/N, Centro, C.P. 62580 Temixco, Morelos, México.
jrpee@ier.unam.mx

[2] Instituto de Energías Renovables, Universidad Nacional Autónoma de México, Privada Xochicalco S/N, Centro, C.P. 62580 Temixco, Morelos, México.
ogv@ier.unam.mx

Abstract

SolCoSi (SOLar COllector Simulator) is a software program developed in order to determine the thermal performance of flat plate solar collectors used in solar water heating systems. SolCoSi can be used as a tool for design and optimize flat plate solar collectors, it enables an analysis of different materials and dimensions of the absorber, transparent covers, number of tubes, types and dimensions of insulation, selective surface, and different working conditions (mass flow rate, wind speed, solar radiation, etc.). The mathematic model consist in a two-dimensional arrange of nodes disposed in longitudinal and axial direction; in order to determine the temperature in each node, an energy balance was solved. As a result, SolCoSi predicts the thermal efficiency curves (lineal or quadratic), the incident angle modifier factor, the stagnation temperature (calculated for the particular case when the mass flow rate is near zero) and the temperature distribution in fluids and solids. The model developed is available as free online software in English and Spanish on the following website: http://solcosi.ier.unam.mx/

Keywords: Numerical model, flat plate solar collector, water heating, free software

1. Introduction

SolCoSi (SOLar COllector Simulator) is a software program developed by the Instituto de Energías Renovables – UNAM. This software can be used to predict the thermal efficiency curves (lineal or quadratic), the incident angle modifier factor, the stagnation temperature (considering as the outlet water temperature in the solar collector when the water mass flow rate is near zero) and the temperature distribution in fluids and solids of flat plate solar collectors used in water heating systems. In order to design new prototypes of solar collectors, it is necessary to modify the principal parameters of these equipment such as: materials and dimensions of the absorber, transparent cover, number of tubes, types and

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dimensions of insulation, selective surface, and its working conditions (mass flow rate, wind speed, solar radiation, etc.).

2. Mathematical model

2.1 Equation of energy balance

The model combines the multilayer method proposed by Cadafalch (2009) with a discretization also in the longitudinal axis proposed by García-Valladares and Velázquez (2009) in order to take into account the temperature profile along the risers. The discretization used for SolCoSi is shown in Fig. 1.

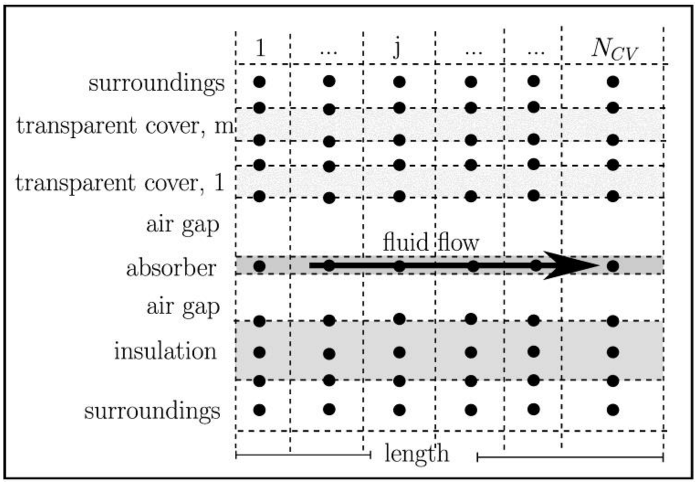

Fig. 1 Internal discretization of flat plate sola collector used for SolCoSi.

The eq. (1) shows the general form of the energy equation applied to each control volume. The model takes into account the following assumptions: steady state conditions, heat transfer in axial and longitudinal directions, the total water mass flow rate is divided into equals parts in each riser.

$$(Z_K + Z_{k-1} + Zs_j + Zs_{j-1})T_{j,k} = Z_k T_{j,k+1} + Z_{k-1} T_{j,k-1} + \\ + Zs_j T_{j+1,k} + Zs_{j-1} T_{j-1,k} + q_{g,k} \qquad \text{(eq. 1)}$$

Where Z and Zs values correspond to heat transfer coefficients (conductive, radiative and convective) in each node in W/m^2K. The conductive and radiative coefficients are calculated with the Fourier and Boltzman's laws respectively using the thermophysical properties of the different materials. The convective coefficient are calculated using empirical correlations for each specific layer: (a) for the environmental heat transfer coefficient, the equations proposed by Duffie and Beckman (Duffie and Beckman, 2013); (b) for the fluid inside the tubes, the equation developed by Gnielinski (Gnielinski, 1979); and (c) for the air gaps between the back insulation and transparent cover the method suggested by Bejan (Bejan, 1993) are used respectively.

The $q_{g,k}$ term is the heat generation in W/m^2, $T_{j,k}$ is the temperature of the node analyzed and $T_{j,k-1}$, $T_{j,k+1}$, $T_{j+1,k}$ and $T_{j-1,k}$ are the temperatures of its neighbor nodes. The set of energy balance equation in each control volume is solved using the Tri-Diagonal Matrix Algorithm (TDMA) according to Patankar (Patankar, 1980). For more details see the following article (Pérez-Espinosa and García-Valladares, 2018).

3. Validation

In order to validate SolCoSi, a comparison with the experimental data of different commercial flat plate solar collectors (evaluated according to the international standard ISO-9806:2013 (2013) in different accredited solar laboratories around the world) has been carried out. A statistical analysis between the thermal efficiency curve predicted by SolCoSi (referred as the y−dependent variable) and the experimental thermal efficiency curve (defined as the x−independent variable) was used according to Verma and Santoyo (1997). In this statistical method, an ideal correlation is obtained when y=x; for this reason a ±3% error band was plotted in Fig. 2, this figure shows that 78.3% of the 23 numerical data points obtained were within and error band of ±3% and 95.7% were within and error band of ±5%. The mean deviation between experimental and numerical results was ±2.55%. With this analysis, a good agreement between numerical and experimental results has been observed. Appendix B shows the thermal efficiency data points of experimental and numerical results used in Fig. 2.

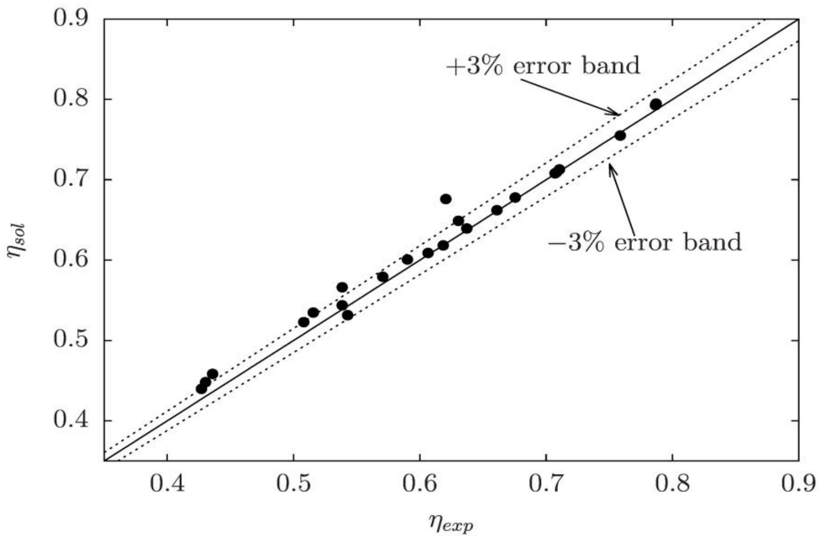

Fig. 2 Comparison of thermal efficiency between numerical and experimental data points.

4. Results

Once the SolCoSi was validated, the software was written in Java code and the program is now available in the website http://solcosi.ier.unam.mx with a visual interface and an English and Spanish versions. The result is a new software program named SolCoSi than can be used to evaluate the thermal performance of a flat plate solar collector: the thermal efficiency curve, the incident angle modifier and the stagnation temperature. These results can be download in a .pdf file as a report, the report includes: in the first section the principal values used in the simulation (values given by the user), after that it shows the linear and quadratic equations of the thermal efficiency (see Fig. 3); in the third section, it is shown the equation to determine the incidence angle modifier factor and the curve obtained with this equation (see Fig. 4); in the fourth section the stagnation temperature obtained by the simulation when the water mass flow rate is close to zero is shown. The main menu of the SolCoSi website is observed in Fig. 5.

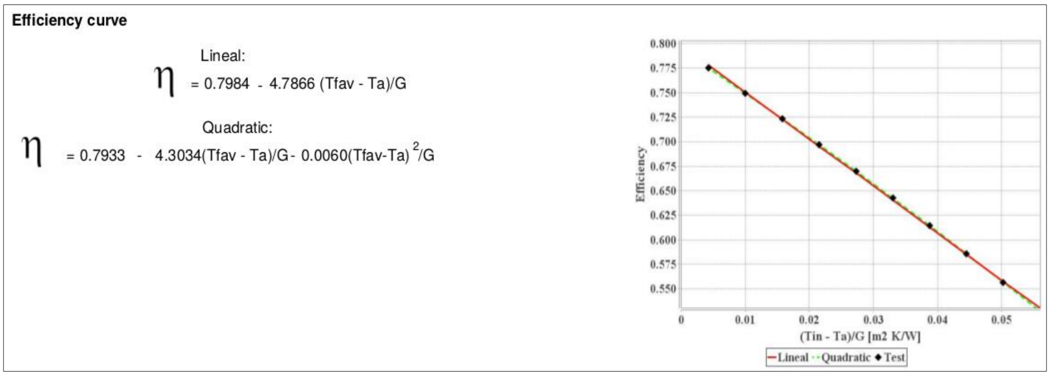

Fig. 3. Thermal efficiency equations and curves obtained by SolCoSi.

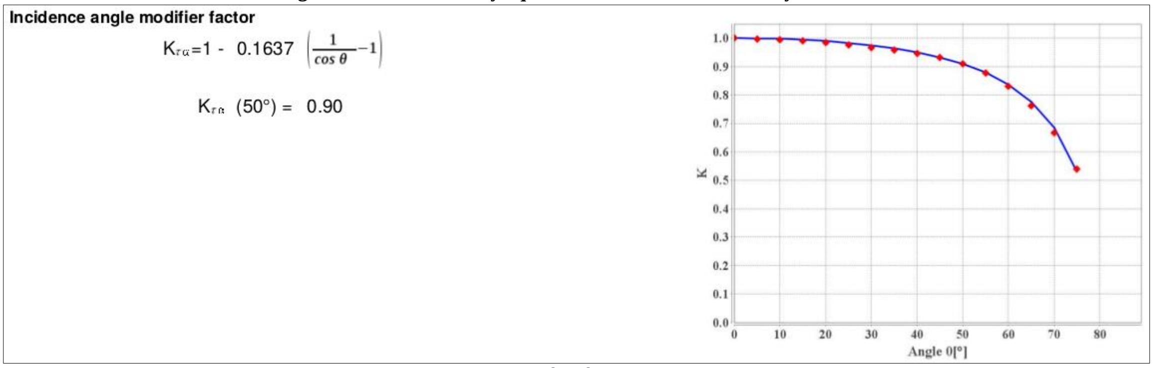

Fig. 4. Incidence angle modifier factor and its respective curve.

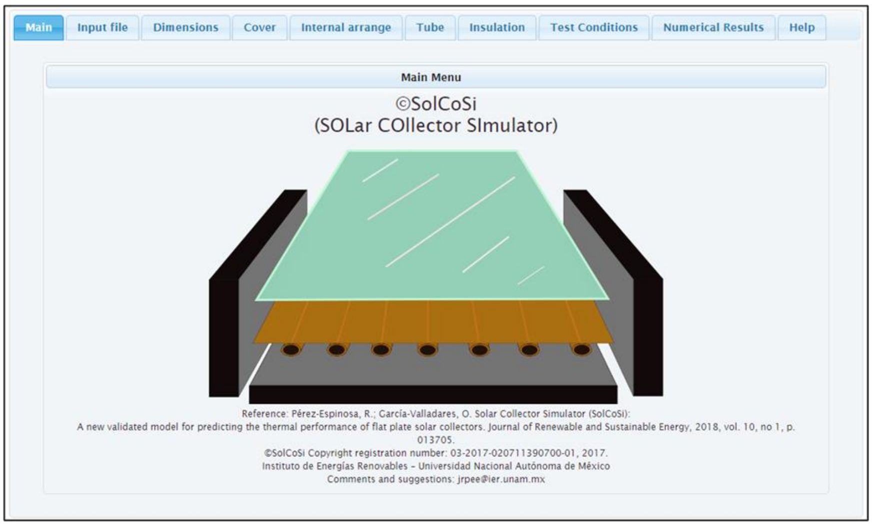

Fig. 5. Main menu of SolCoSi website.

5. Concluding remarks

A Solar Collector Simulator (SolCoSi) has been successfully developed. The model discretize the flat plate solar collector in the axial and longitudinal directions and it can be used to evaluate the thermal efficiency curve, the incident angle modifier factor, the stagnation temperature and the temperature distribution in fluid flow and solids.

SolCoSi was validated against a wide range of experimental data (70 experimental data points grouped in 23 groups) of different commercial flat plate solar collectors fabricated with different geometries, materials and working under different operating conditions; this validation includes a comprehensive statistical analysis based on error bands. A good agreement between numerical and experimental results has been observed with a mean deviation of ±2.55%.

6. Acknowledgements

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7. References

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8. Appendixes

Appendix A: units and symbols

Table 1 shows all the symbols used in to the paper.

Table 1: Symbols used in this paper.

Quantity	Symbol	Unit
Global irradiance	G	W m^{-2}
Incidence angle modifier	$K\tau\alpha$	
Number of the control volumes	Ncv	
Heat generation	q	W m^{-2}
Temperature	T	K
Longitudinal thermal resistance	Zs	W $m^{-2}K^{-1}$
Subscripts		
Ambient	a	
Fluid at average temperature	fav	
j-th longitudinal control volume	j	
k-th axial control volume	k	
Greek letters		
Thermal efficiency (SolCoSi)	η_{sol}	
Thermal efficiency (experimental)	η_{exp}	
Collector incidence angle	θ	°

Appendix B: data of the tests

Table 2 shows the experimental and numerical results used in Fig. 2.

Table 2. Experimental and theoretical thermal efficiency data points

Test group	η_{sol}	η_{exp}
1	0.7105	0.7129
2	0.6305	0.6489
3	0.5385	0.5662
4	0.7080	0.7090
5	0.6065	0.6089
6	0.5080	0.5228
7	0.4270	0.4397
8	0.6205	0.6760
9	0.4358	0.4583
10	0.7865	0.7928
11	0.6610	0.6621
12	0.5706	0.5793
13	0.4303	0.4481
14	0.7870	0.7947
15	0.7070	0.7080
16	0.6185	0.6183
17	0.5385	0.5438
18	0.6372	0.6394
19	0.5428	0.5315
20	0.7587	0.7550
21	0.6755	0.6779
22	0.5901	0.6007
23	0.5156	0.5347