THERMAL PERFORMANCE OPTIMIZATION OF A FLAT PLATE SOLAR WATER HEATER COLLECTOR USING MATLAB

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Abstract: Solar energy is becoming an alternative for the limited fossil fuel resources. One of the simplest and most direct applications of this energy is the conversion of solar radiation into heat, which can be used in water heating systems. A commonly used solar collector is the flat-plate. A lot of research has been conducted in order to analyze the flat-plate operation and improve its efficiency. This study presents a one-dimensional mathematical model for simulating the transient processes which occur in liquid flat-plate solar collectors. The proposed model simulates the complete solar collector system including the flat-plate and the storage tank. The model considers time-dependent thermo-physical properties and heat transfer coefficients and is based on solving equations which describe the energy conservation for the glass cover, air gap between cover and absorber, absorber, working fluid, insulation, and the storage tank. The differential equations were solved using the implicit finite-difference method in an iterative scheme and executed using the MATLAB. In order to verify the proposed method, an experiment was designed and conducted for several days with variable ambient conditions and flow rates. The comparison between the computed and measured results of the transient fluid temperature at the collector outlet showed a satisfactory convergence. The proposed method is an appropriate for the verification of the absorber and glass cover effectiveness, and to calculate the overall efficiency of the system along with the overall heat loss factor.

Keywords: Transient processes, heat transfer coefficients, overall efficiency, time-dependent thermo-physical properties

I. INTRODUCTION

1.1 The Mathematical Model Development of a Flat – Plate Solar Collector System

This section presents a mathematical model describing the flat-plate solar collector system considering the transient properties of its different zones. In the proposed model, the analyzed control volume of the flat-plate solar collector contains one tube that is divided into five nodes (glass cover, air gap, absorber, fluid and the insulation) perpendicular to the liquid flow direction.

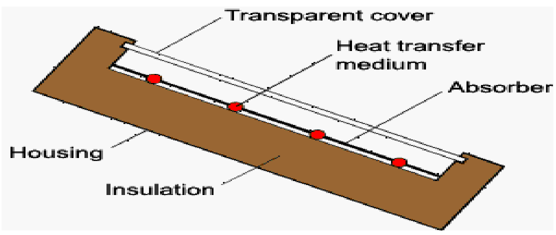


Figure1: Sketch of the five nodes analyzed in the flat-plate solar collector model

The energy balance caused by the mass transfer during the circulating of the fluid within the solar collector is included by the definition that the collector's temperature depends on the coordinate in the direction of the fluid flow. Taking N nodes in the flow direction means that the model describes (5 x N) nodes. The governing equations were derived by applying the general energy balance for each zone in the analyzed control volume of the solar collector.

For one-dimensional heat transfer, the general energy Balance is given by:

$$\frac{dU}{dx} = \dot{Q}_{in} - \dot{Q}_{out} + \dot{Q}_v \qquad (1)$$

$\frac{dU}{dt}$ = Change in the internal energy.

$\dot{Q}_{in}$ = Heat transfer rate into the system.

$\dot{Q}_{out}$ = Heat transfer rate out of the system.

$\dot{Q}_v$ = Heat generation rate into the system.

1.1 To simplify the analysis of the solar collector, the following assumptions were made:

1. Uniform mass flow rate in the collector tubes.

$m_f = m_{t/n}$

n = number of tubes in the solar collector

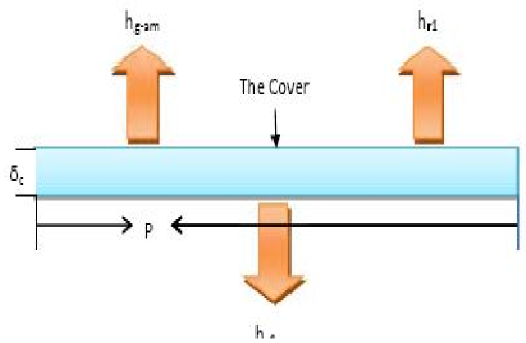
m_f = total the mass flow rate in each tube

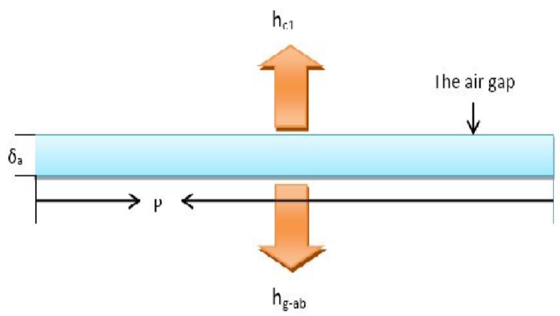
m_t = the total mass flow rate at the solar collector inlet

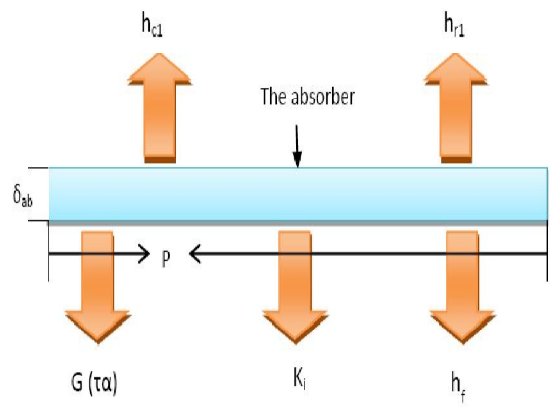
2. One-dimensional heat transfer through the system layers
3. There is no heat transfer in the direction of the flow, the energy transferred in the flow direction by mass transfer
4. The heat transfer from the collector edges is negligible
5. Properties of glass and insulation are independent of temperature (constant)
6. All thermo-physical properties of the fluid, air gap, and absorber are temperature dependent
7. The sky radiation and ambient conditions are time-dependents

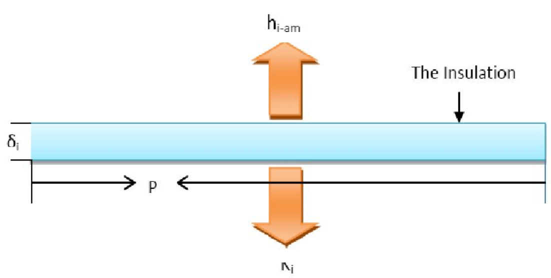
8. Loss through front and back are to the same ambient temperature
9. The sky can be considered as a black body for long-wavelength radiation at an equivalent sky temperature
10. Dust and dirt on the collector are negligible.

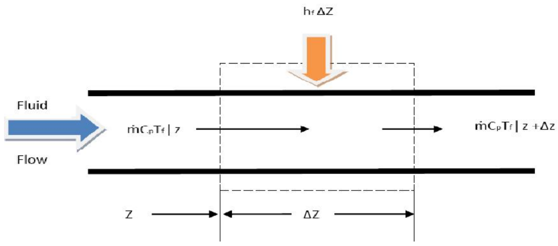
II. MATHEMATICAL MODEL (GLASS COVER, AIR GAP, ABSORBER, INSULATOR, WORKING FLUIDAND STORAGE TANK)

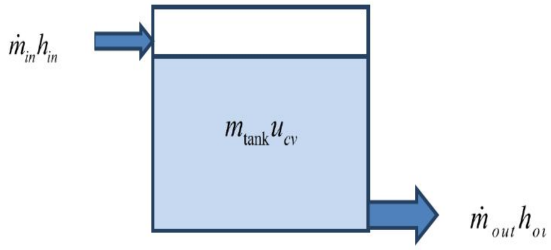












In the tank case there is no work done in the system. Also, by neglecting the Changes in the kinetic and potential energy, we can write approximation

$$\frac{d(mu)_{cv}}{dt} = \dot{Q}_{loss} + \dot{m}_{in}h_{in} - \dot{m}_{out}h_{out}$$

- (2)

3.1 The Numerical Solution for the Solar Collector Mathematical Model

The partial differential equations system has been solved using the implicit finite Difference method. The time and dimensional derivatives were replaced by a forward and
a backward difference scheme, respectively as:

$$\frac{dT_m}{dt} = \frac{T_{m,j}^{t+\Delta t} - T_{m,j}^{t}}{\Delta t}$$

$$\frac{dT_f}{dz} = \frac{T_{f,j}^{t+\Delta t} - T_{f,j-1}^{t+\Delta t}}{\Delta z}$$

- (3)

WHERE,
m = an index of values g, a, a b, f, and I
j = the node number in the flow direction (z)

III. MATHEMATICAL MODEL PROGRAMING

A detailed flowchart entailing the various steps to solve the mathematical model developed in the previous chapter. This model is used for a flat-plate solar collector with single glass cover working in parallel channel arrangement model. All physical dimensions of the collector can be entered as inputs, which make it suitable to any single glass cover flat-plate solar collector without any modifications; however, the use of a second glass cover requires additional formula to be derived in order to determine the temperature histories of the second cover and of the medium between the covers. As all the boundary conditions in the proposed model taken to be time dependent, the inputs data for the numerical code are the following measured data:

- Total fluid mass flow rate.
- Total flux of solar radiation.
- Ambient temperature.
- The initial fluid temperature in tank.

FLOW CHART:

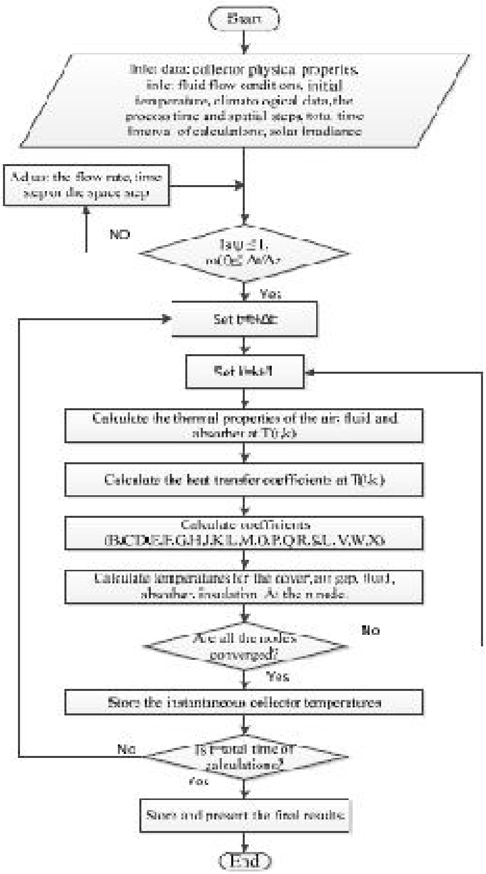


Figure 4: flow chat for matlab

IV. RESULTS AND DISCUSSION

5.1: Convergence Study:

The temperatures distributions obtained by the MATLAB code have been tested for different numbers of nodes (n= 4, 6, 8, 12, 24, 48, and 72) along the flow direction. Figure shows the collector's outlet temperature obtained numerically for each number of nodes at constant flow rate. In order to show the convergence of the proposed method in more details, a selected period of time includes the critical area of the curves (i.e., the solar irradiance step-change) is presented.

As can be clearly seen from the figure, the proposed method converges when the number of nodes is 12 nodes. Table 6.1 present the running time and the range of error in the obtained temperatures compared to the 72 nodes model. However, the results suggest limit the number of nodes to 24 in order to optimize the cost of running time with acceptable differences from the optimum case of 72 nodes. Therefore, the case of 24 nodes represents the minimum bound of number of nodes for the convergence results.

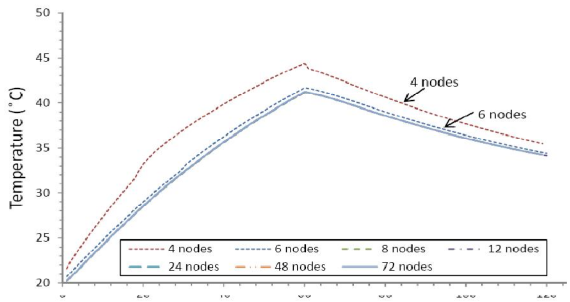


FIGURE 5.1: Outlet temperature histories for different number of nodes at 1.5 GPM

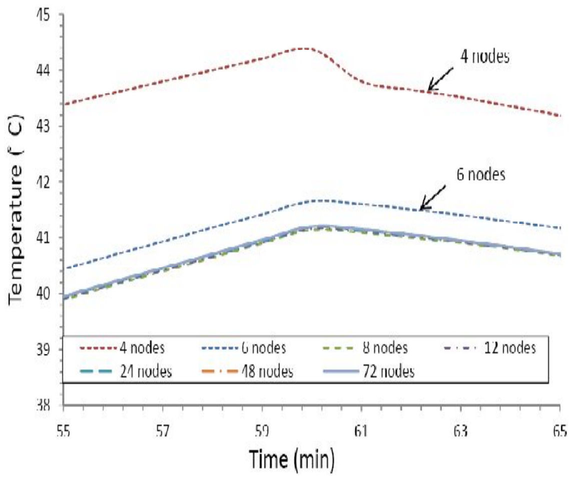


FIGURE 5.2: Selected period for the outlet temperature histories obtained for each number Of nodes

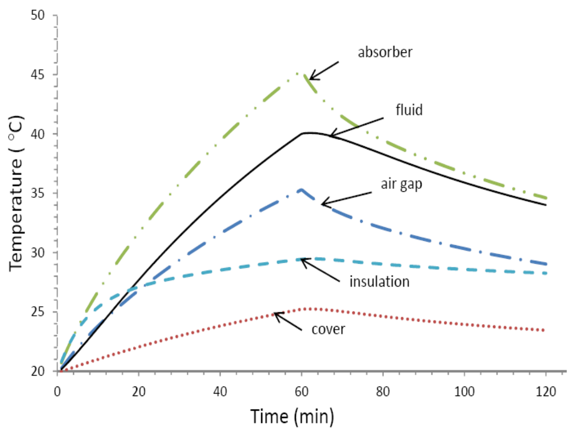


FIGURE 5.3: Temperature histories for all the analyzed cross section (node 12)

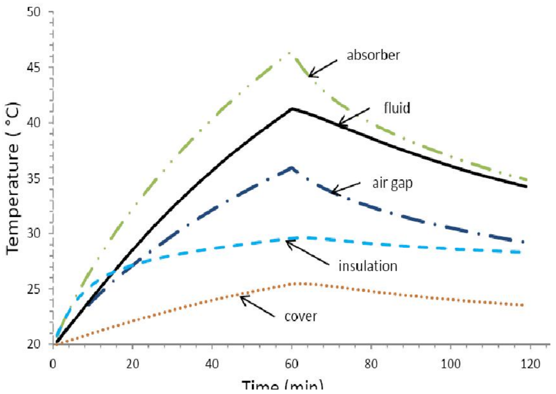


FIGURE 5.4: Temperature histories for all the analyzed cross section (node 24)

As it was expected the temperature of the absorber records the highest value along the running time, since the primary function of the absorber plate is to absorb as much as possible of the radiation reaching through the glazing, to lose as little heat as possible upward to the atmosphere and downward through the back of the container, and to transfer the retained heat to the circulating fluid. The high conductivity of the absorber resulted in the fast response of the working fluid's temperature to the change in the Absorber's temperature. Also it can be seen how the insulation temperature changes very slowly, that is due to the low heat conductivity of the insulation material selected which is required to reduce the heat losses from the system. The purpose of the cover is to admit as much solar radiation as possible and to reduce the upward loss of heat to the lowest attainable value. The glass cover material (patterned low-iron glass) used has a very high transmissivity with a small absorption coefficient. From the cover temperature history presented above the cover has the lowest variation along time, thus it works efficiently for this purpose. The variation of the air gap zone temperature due to the convection and radiation heat transferred from the absorber, this loss can be reduced by evacuating the collector from air.

CONCLUSIONS

On the basis of the results obtained in this study, the following conclusions can be drawn: A detailed mathematical derivation for the flat-plate solar collector cross sections (cover, air gap, absorber, working fluid, and insulation) was presented. A one dimensional mathematical model with distributed parameters that combines the solar collector's tank model and the flat-plat model is derived to simulate the collector process. All the thermo-physical properties of the air gap, the absorber plate, and the working fluid are computed in time dependent mode. The transient heat transfer coefficients are also computed in real time. To solve the derived system of equations, the implicit finite-difference scheme was suggested. The proposed method allows the transient processes occur in the flat-plate solar collector to be simulated. The time dependent flow rate, variable ambient temperature, and variable solar irradiance have been taken in consideration. The proposed solution method was implemented by utilizing the MATLAB software. The code mathematically solves the model and iteratively evaluates the temperature histories for each analyzed cross section of the solar collector at any selected point along the flow direction. The efficiency of the proposed method was confirmed by experimental verification. The analysis shows a very good agreement between the measured and the numerically predicted values for different running conditions and flow rates. The method solved some of the limitations in the existing models with distributed models. It does not require entering the inlet temperature history, it is appropriate for low and high flow rates operations. The code can be applied for verification of the effectiveness of various absorbers materials and their surface coating, as well as the cover materials, without the necessity of carrying out the experimental work.

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8. The efficiency of the proposed method was confirmed by experimental verification. The analysis shows a very good agreement between the measured and the numerically predicted values for different running conditions and flow rates.

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