CODEPRO (Flat-Plate Solar Collector Design Program)

There are two important aspects of solar collector test : determination of instantaneous efficiency with beam radiation nearly normal to the absorber surface and effects of angle of incidence of the incident radiation. CODEPRO (COllector DEsign PROgram) has an ability to determine them by numerical simulation. It is related to the test of optically isotropic flat-plate solar collector whose construction is of sheet and parallel tube type. Its methodology is based on the ASHRAE STANDARD 93-1986 and SRCC DOCUMENT RM-1.

EES

CODEPRO was developed using EES (Engineering Equation Solver). To see more features of EES, please refer to EES help files or manuals.

I. Calculations

In this section the calculations of the thermal performance of a solar collector are explained briefly. Major assumptions are as follows:

Assumptions

1. In calculating the instantaneous efficiency, the radiation is incident on the solar collector with the fixed incident angle.
2. The optical properties of the cover and absorber plate are independent of the temperature.
3. The headers cover a small area of collector and can be neglected.
4. The header provides uniform flow to tubes and the flow is one-dimensional.
5. The collector is a flush-mounted collector (FM).
6. There is no ground reflection.
7. The sky temperature is assumed to be the same as the ambient temperature (temporarily).

Instantaneous Collector Efficiency

The employed thermal performance models are linear and 2nd-order polynomial equations. Once the program calculates the collector efficiency for different values of (Ti-Ta)/GT, the coefficients of these equations can be determined by curve fitting using linear regression.

incidence angle modifier

The dependence of performance on the incident angle can be represented by the relation between incidence angle modifier and incidence angle. Relation of Souka and Safwat (1966) is used for the general relation between them

Some **features** of the program are as follows:

- In this program, working fluid can be chosen among water, ethylene glycol/water and propylene glycol/water.
- In calculating the useful gain, the effect of aperture area is considered to get more reasonable results.
- To get the various values of (Ti-Ta)/GT, the inlet temperature is changed from the ambient temperature to the saturation temperature.
- The heat transfer coefficient between the collector fluid and the tube is calculated using Petukhov equation for turbulent flow and the constant wall temperature relation for laminar flow. Relations for constant wall temperature usually yield the value of heat transfer coefficient less than the actual case. Thus the calculated performance can be less than the experimental results.
- To get an overall loss coefficient, not empirical relations but exact equations are used.
- To compare the performance from one collector design to others, the configuration and results can be stored up to 5 sets.
- To determine the Incidence angle modifier coefficient, the incident angle is changed from 0 to 60 degrees.
- The ranges of variables are confined to get reasonable values as inputs and to make the calculation converge.
- This version includes only SI units.

In the program, many functions were developed by Solar Energy Laboratory, University of Wisconsin – Madison. It takes about 2 seconds to evaluate the solar collector performance in Pentium II 350 MHz personal computers.

II. Diagram Windows

Main Window

Main window consists of two boxes. The upper one (Input Box) is to input collector and test conditions (5 buttons), to save the configuration and calculation results (Save Calculation as : Pull down menu), and to perform calculation (calculate button). Each variable has a preset value that was used in test in development level. After setting all the variables and calculation conditions, just click the [Calculate] button to start calculation.

The lower box (Output Box) shows the calculation results, Collector Efficiency Equations and Incident Angle Modifier Equation. Efficiency Equations are shown in 3 ways i.e. one linear equation and two 2nd order polynomials. You can see plot for that equations just by hitting the plot button.

Child Window 1 - Test Conditions

In this window, it is expected to enter the test conditions to obtain collector performance.

Input variables
- Incident Solar Radiation
- Diffuse Radiation Proportion

- Incident Angle of Beam Radiation
- Collector Slope
- Ambient Temperature
- Wind Speed

Child Window 2 – Collector Dimensions

The overall and aperture collector dimensions are to be entered through this window. Here, it is assumed that the area of absorber is the same as the aperture area.

Input variables
- Overall Dimensions
    - Length : *L*
    - Width
    - Thickness
- Absorber Dimensions
    - Length
    - Width

Output variables
- Gross Area
- Aperture Area

Child Window 3 – Cover and Plate

This window needs the values of optical and thermal properties of glass cover and absorber plate. The collector can have two covers with different material. If there is only one cover, its properties should be entered through Cover 1 section. In case of plastic cover system, cover 1 and cover 2 should be made of the same materials in this version (6/4/99).

Input Variables
- Cover
    - Number of Covers : 0,1,2
    - Cover material (it will determine the refractive index)
    - Transmittance (solar spectrum)
    - Emittance (long-wave spectrum)
    - Transmittance (long-wave spectrum)
- Cover-Plate Air Spacing
- Cover1-Cover2 Air Spacing
- Plate
    - Thickness
    - Solar absorptance
    - Long- wave emittance
    - Conductivity

* Transmittance for long-wave spectrum is only for the non-glass covers.

Child Window 4 – Edge and Insulation
To calculate the heat loss coefficient, it is necessary to input the data about the edge and back insulation through this window.

Input Variables
- Thickness of Back Insulation
- Conductivity of Back Insulation
- Thickness of Edge Insulation
- Conductivity of Edge Insulation

Child Window 5 – Tube and Fluid
Through this window, the values for the tube and fluid can be entered. The working fluid are to be chosen among water, ethylene glycol/water and propylene glycol/water. The tube space (dt) will be calculated using the width (W) and number of tubes (Nt) by dt =W/Nt. The bond conductivity represents the contact resistance between the tube and absorber plate. If the connection between them is pretty good, its value should be larger than 1000 W/mC.

Input Variables
- Tube
  - Number of Tubes
  - Inner Diameter
- Fluid
  - Kind of Fluid
  - Percent Composition (in case of ethylene glycol/water and propylene glycol/water)
  - Mass flow rate
  - Inlet Pressure
- Plate-Tube Bond Conductivity

Output Variables
- Tube Spacing

Plot Windows
Plot windows display collector performance and incident angle modifier in graphic form. The graph for each data set is distinguished by line colors. Plot windows also have fitting equations whose coefficients are given in Output Box of Main Window.

III. Save Calculation as

You can store up to 5 solar collector configurations and calculation results to see the effect of design change by comparing results. All the data are stored in LOOKUP table which you can approach using windows/lookup table menu. The stored data can be copied to spread sheet program like Excel or can be saved as a text file through Tables/Save Lookup Table menu.

Please do not anything but Save Lookup Table in Tables menu, or you cannot save your calculation.

Options

[Do Not Save] : Do not save calculation just for trial calculation.
Set 1 : Save collector configuration and calculation results as Set 1
Set 2
Set 3
Set 4
Set 5
[Erase All Data] : Erase all data stored before.

III. Stagnation Temperature

Stagnation temperature is the highest temperature of the collector. It occurs when the collector is not working, that is, there is no flow. In this case, the useful gain is zero and the energy equation becomes this equation. By solving this equation, we can get the stagnation temperature.
Stagnation temperature window shows the condition that affects the temperatures, stagnation cover temperatures, and stagnation plate temperatures.

Things to be added in near future
- etched glass
- English unit version