

Computer Simulation Of A Flat Plate Collector For Solar Water Heater System

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ABSTRACT:

As the globe seeks low-carbon energy, solar electricity is the most plentiful resource. This century's problem is harnessing energy. Photovoltaics, solar heating and cooling, and CSP are common solar energy uses. Different technologies, proportions of the solar resource, site requirements, and production capacities distinguish these solar energy systems. Every solar energy application needs accurate solar resource data. Small rooftop installations and huge solar power plants are affected. Because huge installations might cost over \$1 billion, solar resource knowledge is very important. The best fuel supply quality and dependability information must be accessible before such a project. To predict the daily and annual performance of a proposed solar heating and cooling system or power plant, this project needs reliable data about the solar resource available at specific locations, including historic trends with seasonal, daily, hourly, and (preferably) subhourly variability. Without this data, manufacturers and dealers cannot provide reliable financial analysis. sun energy system performance assessments need sun radiation data. The National Solar Radiation data source in India includes stored hourly, daily, and monthly data for various capital cities and districts for 60 years. Since simulating systems for 60 years is computationally intensive, it is easier to use typical data in performance analyses by simulating a computer program for as many years to any location, any time, any day, and any month and year of the country only by knowing its latitude and longitude.

Flat Plate Collectors are the easiest and most common way to convert solar energy into heat. Solar radiation hits the darkened collector absorber surface via clear cover plates and is absorbed as thermal energy. Air or liquid movement removes thermal energy from the absorber, delivering heat for use or storage. A C-language computer program has been developed to predict the performance of a flat plate collector that stores heat in water called a Solar Water Heater. The program takes into account beam radiation, diffuse radiation, global radiation, total solar flux, declination, incident angle, outlet fluid temperature, and instantaneous efficiency.

Simulation of flat plate collector for solar water heaters produces rapid results and optimizes cost and efficiency. This research simulates a flat plate collector for a solar water heater using a C-language software designed to forecast solar collector system performance based on location and time of day. Program calculates instantaneous beam and diffuse radiations for the collector's location, number of days (n value) for any date in the year, angle of incidence of beam radiation on the collector, total solar flux incident on the collector, transmissivity – absorptivity product, incident flux absorbed by the absorber plate, collector heat removal factor,

overall loss coefficient, water outlet temperature, and instantaneous. The modeling tool estimates solar collector system performance and can size solar hot water systems for varied applications.

The study includes parametric investigation of the effect of selective surfaces, number of covers, spacing, collector tilt, fluid inlet temperature, incident solar flux, and dust on top covers on solar water heater performance and validation of computational results with experimental results from literature and Chickballapur. The customized comparison approach may correlate the generalized program with solar collector performance for solar water heaters at any location without tests, ensuring precision and correctness.

Key Words: Flat plate Collector, Solar water Heater, Computer program in C-language.

1. INTRODUCTION:

Although solar energy research, development, and systems experiments were conducted in the late 1800s and early 1900s, it was the sharp increase in the price of oil in 1974 precipitated by the Middle-Eastern oil embargo the previous year that escalated national and international investment in solar energy. In the United States and other industrial countries, the technological tools and advancements produced during World War II, the post-war rebuilding and prosperity, the U.S. nuclear power and space programs, and other technological achievements were applied to solar energy research and development. The result was that research, which had been limited to backyard tinkerers and small specialized companies, was spread to universities, national laboratories, and industry.

The federal solar budget rose from less than \$1 million in early 1970s to over \$1 billion in the early 1980s; the budget is now about \$200 million, with about \$50 million for solar thermal technology. Solar thermal technology is concerned principally with the utilization of solar energy by converting it to heat. In the concentrating type of solar collector, solar energy is collected and concentrated so that higher temperatures can be obtained; the limit is the surface temperature of the sun.

However, construction materials impose a lower, more practical limit for temperature capability. Similarly, overall efficiency of energy collection, concentration, and retention, as it relates to energy cost, imposes a practical limit on temperature capability. If solar energy were very highly concentrated into a tiny volume, the result would approach a miniature sun. If the same energy were distributed along a thin line, the line would be cooler than the miniature sun, but still hot. If distributed on a large surface, the surface would be less hot than the line. There are solar concentrators that focus sunlight into a point or a line. There are also non-focusing concentrators. Each type has preferred temperature-dependent applications.

Renewable energy utilization is synonymous with solar energy utilization, as Sun is the source of all renewable energy. The transition to a solar energy economy has begun all over the world and the renewable energy sector has moved progressively to the center stage of the energy mix and energy policy of the developed and developing nations of the world. Direct solar energy means the radiation intercepted by collectors and indirect solar energy includes Wind, Ocean and Biomass energy. Mankind has enjoyed the heat from the sun

during all his existence. It is, however, a periodic and in most places a fickle source of energy; so much that our most significant single technical accomplishment has been the development of fire, the first auxiliary energy source. The most convenient fossil fuels – oil and gas – are now in short supply, and within a few decades even the remaining oil-rich areas will be exhausted. The present rate of consumption is so enormous that no discoveries conceivable can change this conclusion – they could only push the date a few more decades into the future. Energy efficiency improvements beyond the substantial energy conservation can further reduce the energy demand and narrow the prospective gaps between energy demand and supply.

Solar water systems can heat the water from ambient temperature to over 90°C. Using solar collector to heat the water can very easily attain required temperatures. Solar hot water systems are normally designed for a definite temperature at the outlet of the collector bank or in the storage tank. The potential for the solar water heater should be analyzed carefully. Hot water consumption, consumption pattern, social habits, commercial and non-commercial energy spent on hot water, standard requirements affordability, and use of various conventional heating systems are some of the important aspects to be considered, besides local conditions like availability of solar radiation, daily and seasonal variations, temperatures and other climatic conditions.

Designing a solar water heating system is always as easy from the efficiency point of view as it may appear. It is merely a matter of Optimization and Cost effectiveness rather than simply maximizing efficiency.

The work describe on analytical method for predicting the daily performance of thermostatically controlled solar hot water system. The program has been developed in C-language to get the analytical solutions easily. The program developed for this purpose is however general and can be used to predict the performance of solar system using a variety of data inputs as different options.

A need for detailed analytical prediction method for solar hot water system was felt for the following reasons.

- It was difficult to determine experimentally, the effect of various parameters such as thermostat setting, the flow rate, the insulation levels and ambient temperature.
- It is difficult to manually calculate by iterations to get the performance values with an assumption that consumes more time.
- By developing the generalized C-program the results can be obtained with much ease and less elapsed time. The different data types and options cited in reference [1] require more number of iterations to produce the optimized results.

A solar water heater is a cost effective means of obtaining hot water supply utilizing the freely available sunlight, with sufficient portability. Conventional solar water heaters though simple in design gives lesser output, so many attempts have been made to develop innovative designs to give higher yield. Such designs need to be tested before actual implementations because it may prove to be poor in performance. Computer

simulation is an efficient method to certify the suitability of such innovative designs by making a choice of optimal parameters.

2. DEVELOPMENT OF COMPUTER PROGRAM FOR PERFORMANCE ANALYSIS OF FLAT PLATE COLLECTOR FOR SOLAR WATER HEATING SYSTEMS.

2.1 INTRODUCTION:

The present work describes an analytical method of predicting the daily Performance of thermostatically controlled Solar Water Heater with a fixed flat plate collector for Chickballapur location at BGS R&D centre, Department of Mechanical Engineering, Chickballapur. The Program has been developed in C-Language to get the analytical solutions easily. The program developed for the purpose is however general and can be used to predict the performance of a solar water heater with a fixed flat plate collector for a domestic application with 100 litres capacity, using a variety of data inputs at different options. A need for detailed analytical prediction method for solar water heater with a flat plate collector was felt for the following reasons.

1. It was difficult to determine experimentally the effect of various parameters such as thermostat setting, the flow rate, the insulation levels and ambient temperature.
2. It was difficult to calculate manually the iterations to get the performance values with assumptions and consumes more time.
3. By developing the generalized C-program, the results easily obtained and quickly for different data types with different options.

Solar water heater used for domestic application can heat the water from ambient temperature to over 90° C. Required temperatures can very easily be attained by using solar collector to heat the water. These solar water heaters can help to a large extent in saving other sources of energy. It may be remembered that solar energy cannot replace the existing sources; it can only supplement it, as it is available only during the day time. Solar water heaters are normally designed for a definite temperature at the outlet of the collector bank or in the storage tank.

In actual practice, it is not possible to maintain the same temperatures during the different seasons of the year since total solar radiation, ambient temperature and the atmospheric conditions do not remain the same. However, the quantity of the heat that can be extracted from the system during all the seasons can be maintained constant, provided constant hot water temperature at the output is not the essential requirement. The energy required to raise the temperature of one litre by 1° C is 4.19×10^3 Watt/sec that is,

$$E = 4.19 \times 10^3 \times C \times T \text{ Watts/sec}$$

$$= 1.6 \times 10^3 \times C \times T \text{ kWh}$$

Where C = mass rate of water, T = Rise in temperature

The energy required to heat 500 litres of water at 60°C

$$E = 1.6 \times 10^3 \times 500 \times 60 \text{ kWh}$$

$$= 34800000 \text{ kWh.}$$

Energy savings from solar water heater look quite attractive. But the potential for the solar water heater should be analysed carefully, hot water consumption, consumption pattern, social habits, commercial and non-commercial energy spent on hot water, standard requirements, affordability, and use of various conventional heating systems are some of the important aspects to be considered. Besides, local conditions like availability of solar radiation, daily and seasonal variations, temperatures and other climatic conditions should also be considered. Large systems should be installed after careful study. Possibility of energy conservation in an existing hot water system should be studied before introducing a solar system. Designing solar water heaters is always as easy from the efficiency point of view as it may appear. It is merely a matter of optimization and cost effectiveness rather than simply maximizing efficiency

2.2 SCOPE OF DEVELOPING COMPUTER PROGRAM:

Scope of the present work includes the study of effect of the following variable on Efficiency. Incident flux, Inlet fluid Temperature, Time over a day, Spacing, Water flow rate, ambient temperature, Latitude angle, Area of absorber plate

The detailed analysis is carried out only for the location of Flat Plate Collector at Chickballapur location in SJCIT, BGS R&D centre, Department of mechanical engineering.

2.3 STATEMENT OF THE COMPUTER SOFTWARE DEVELOPED:

The present work deals with the development of a computer program to study the thermal performance analysis of a Solar Water Heater with a fixed Flat plate collector. It includes calculation of the following for any given location.

I_b - Instantaneous/hourly beam radiation on a horizontal surface, W/m^2 or kJ/m^2-h

I_{bn} - Instantaneous/hourly beam radiation on a surface normal to the direction of the rays, W/m^2 or kJ/m^2-h

I_d - Instantaneous/hourly diffuse radiation on a horizontal surface, W/m^2 or kJ/m^2-h

I_g - Instantaneous/hourly global radiation on a horizontal Surface, W/m^2 or kJ/m^2-h

n - Number of days for the given date.

θ - Angle of incidence of beam radiation on the collector

I_T - The total solar flux incident on the collector

$(\tau\alpha)_b$ - transmissivity-absorptivity product for beam radiation

$(\tau\alpha)_d$ - transmissivity-absorptivity product for diffuse radiation

S - The incident flux absorbed by the absorber plate

F_R - Collector heat-removal factor

U_l - Overall loss coefficient, W/m^2-K

T_{fo} - Temperature of fluid at outlet, K

η - Instantaneous collection efficiency based on beam radiation

3. DEVELOPMENT OF THE COMPUTER PROGRAM:

3.1 Input Data For The Computer Program Developed:

1. A flat plate collector is made up of a copper absorber plate, copper tubes fixed on the underside and one glass cover consisting the following data:

- Length of the collector = 2.03m
- Width of the collector = 1.03m
- Length of the absorber plate = 2.01m
- Width of the absorber plate = 1.01m
- Material of the absorber plate = copper
- Plate to cover spacing = 35 mm
- Thermal conductivity of the plate material = 401 $W/m^{\circ}K$
- Plate absorptivity for solar radiation = 0.93
- Plate emissivity for re-radiation = 0.18
- Plate thickness = 0.00112m

- Wall Thickness of the tube = 0.6 mm
- Diameter of the tube = 12.5 mm
- Outer diameter of the tube = 13.1 mm
- Inner diameter of the tube = 12.5 mm
- Tube center to center distance = 119 mm
- Number of tubes used = 09
- Extinction co-efficient of glass = 19 m^{-1}
- Thickness of the glass cover = 04 mm
- Glass cover emissivity / absorptivity = 0.85
- Refractive index of glass relative to air = 1.526
- Diameter of header pipes = 25.5 mm
- Insulating material used = Resin bonded Rock-wool
- Thermal conductivity of insulating material = $0.045 \text{ W/m}^{\circ}\text{K}$
- Density of insulating material = 48 kg/m^3
- Back Insulation thickness = 50 mm
- Location of collector = Chickballapur
- Latitude and Longitude for Chickballapur = $(13^{\circ}24'9'', 77^{\circ}43'49'')$
- Wind speed = 3.5 m/s
- Reflectivity of the surrounding surfaces = 0.2
- Ambient temperature = 28°C
- Date = May 15th
- Collector tilt = latitude angle
- Surface azimuth angle = 0°
- Adhesive resistance = Negligible
- Fluid to tube heat transfer coefficient = $205 \text{ W/m}^2\text{-K}$
- Water Flow rate = 70 kg/h
- Water inlet temperature = 60°C
- Assuming that the side loss coefficient is 10% of the bottom loss coefficient.

3.2 Flow Chart Of The Computer Program:

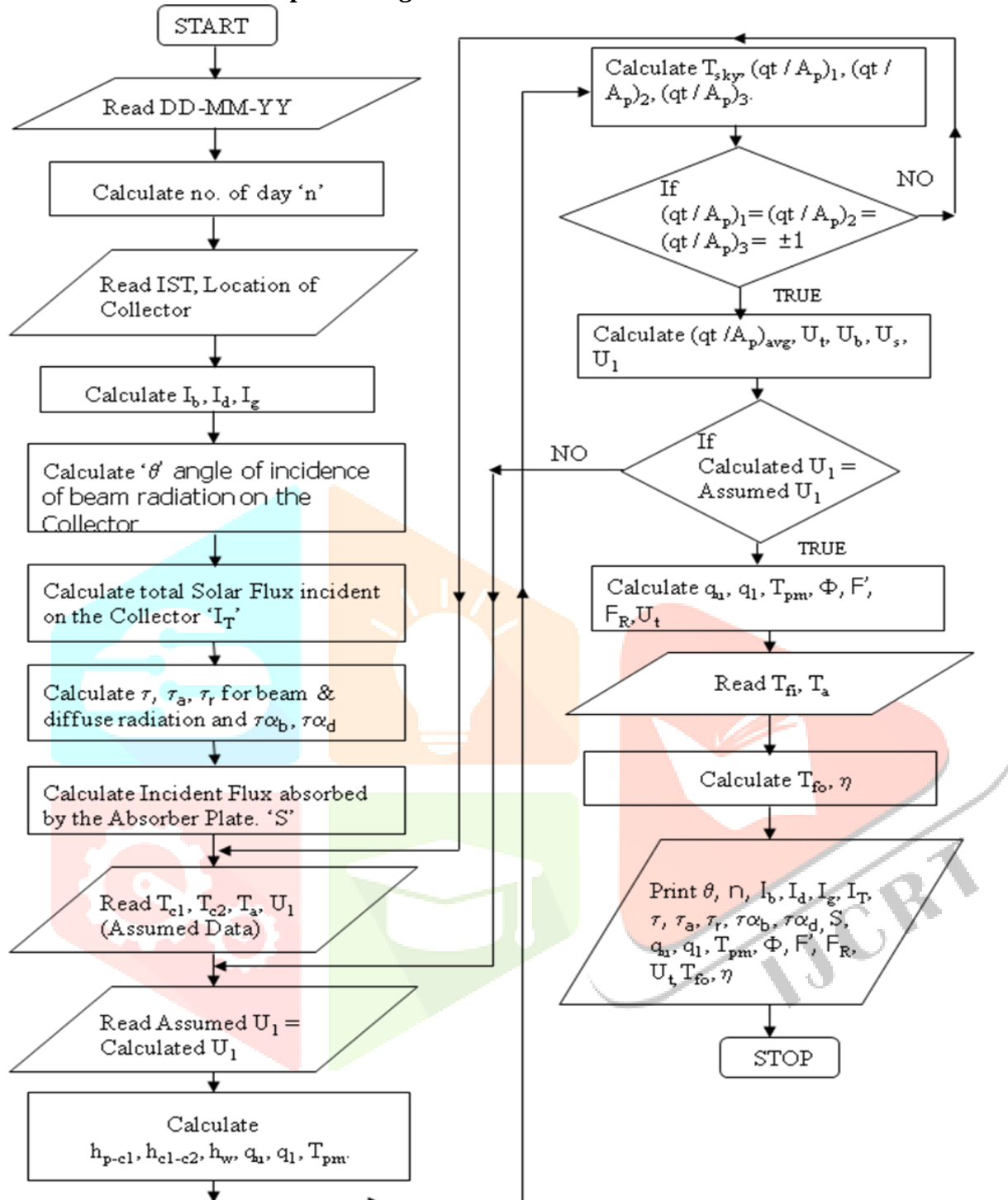


Fig. 2.1: Flow Chart of the Computer Program

3. 3 Predicted values of the performance of the working model fixed flat plate collector over a Whole day at Chickballapur location is presented in the below table 2.1:

Table 2.1: Performance of a fixed flat plate collector over a whole day at Chickballapur location.

Location: Chickballapur (13°24'9", 77°43'49"); Clear day on May 15 th .										
IST Hours	8.00 Am	9.00 Am	10.00 Am	11.00 Am	12.00 Noon	1.00 Pm	2.00 Pm	3.00 Pm	4.00 Pm	5.00 Pm
Parameter										
I_b W/m ²	879	1098	1273	1391	1444	1429	1345	1200	1004	769
I_d W/m ²	119	123	126	127	128	127	127	125	122	117
I_g W/m ²	998	1221	1399	1518	1572	1556	1472	1325	1126	886
I_T W/m ²	882	1129	1319	1446	1503	1486	1397	1241	1025	752
S W/m ²	487	722	878	976	1019	1006	938	816	627	350
T_{pm} °K	342	348	352	354	355	355	350	350	346	339
U_t W/m ² °K	3.04	3.31	3.47	3.57	3.61	3.60	3.4	3.4	3.2	2.87
q_u Watts	651	1055	1323	1489	1561	1541	1273	1216	893	414
T_{fo} °C	68	73	76	78	79	79	74	74	71	65
η %	36	46	49	51	51	51	49	48	43	27
θ °	66	52	39	27	19	22	32	44	58	72

Table 2.2: Calculation of Instantaneous efficiency when the area of absorber plate varied.

Location: Chickballapur (13°24'9", 77°43'49"); Clear day on May 15 th ; IST :11.00 Am										
Area of plate, m ²	1.0	1.1	1.5	2.0	2.03	2.5	2.75	3.0	3.1	3.2
η %	53.00	52.00	51.70	51.00	51.00	49.86	49.41	48.96	48.33	48.00

Table 2.3: Calculation of Instantaneous efficiency when inlet fluid temperature is varied.

Location: Chickballapur (13°24'9", 77°43'49"); Clear day on May 15 th ; IST :11.00 Am										
Inlet fluid temp. °C	25	30	35	40	45	50	55	60	65	70
η %	63.00	62.00	59.00	58.00	56.00	54.50	52.66	50.72	48.74	46.71

Table 2.5: Calculation of Instantaneous efficiency when ambient temperature is varied.

Location: Chickballapur (13°24'9", 77°43'49"); Clear day on May 15 th ; IST :11.00 Am										
Ambient temp. °K	288	293	298	303	313	318	323	328	333	335
η %	45.31	47.36	49.45	51.59	56.00	58.30	60.68	63.15	65.77	66.87

Table 2.4: Calculation of Instantaneous efficiency when the water flow rate is varied.

Location: Chickballapur (13°24'9", 77°43'49"); Clear day on May 15 th ; IST :11.00 Am										
Water flow rate kg/h	50	55	60	65	70	75	80	85	90	95
η %	49.24	49.71	50.11	50.44	50.72	50.98	51.20	51.39	51.56	51.72

Table 2.5: Calculation of Instantaneous efficiency when the IST is varied.

Location: Chickballapur (13°24'9", 77°43'49"); Clear day on May 15 th ; IST :11.00 Am										
IST hours	8.00 Am	9.00 Am	10.00 Am	11.00 Am	12.00 Noon	1.00 Pm	2.00 Pm	3.00 Pm	4.00 Pm	5.00 Pm
η %	36	46	49	51	51	51	49	48	43	27

4. RESULTS AND DISCUSSIONS

4.1 Effect of Various Parameters over Efficiency of a Flat Plate Collector:

Performance of flat plate collector is mainly influenced by a large number of parameters. These parameters could be classified as design parameters, operational parameters, meteorological parameters and environmental parameters. In this work the effects of some of these will be considered. The parameters discussed are area of the absorber plate, inlet fluid temperature, ambient temperature, water flow rate and dust on the top cover.

4.1.1 Performance of Flat plate collector over a day at Chickballapur location:

It is of interest to study the performance of a flat plate collector over a whole day. This is done for the same collector by using radiation data measured over a whole day. For the sake of simplicity, the water flow rate, water inlet temperature, ambient temperature and wind speed are all assumed to be constant at the values for prediction of computer results based on the experiments conducted. The radiation data used and the results obtained are given in the table.

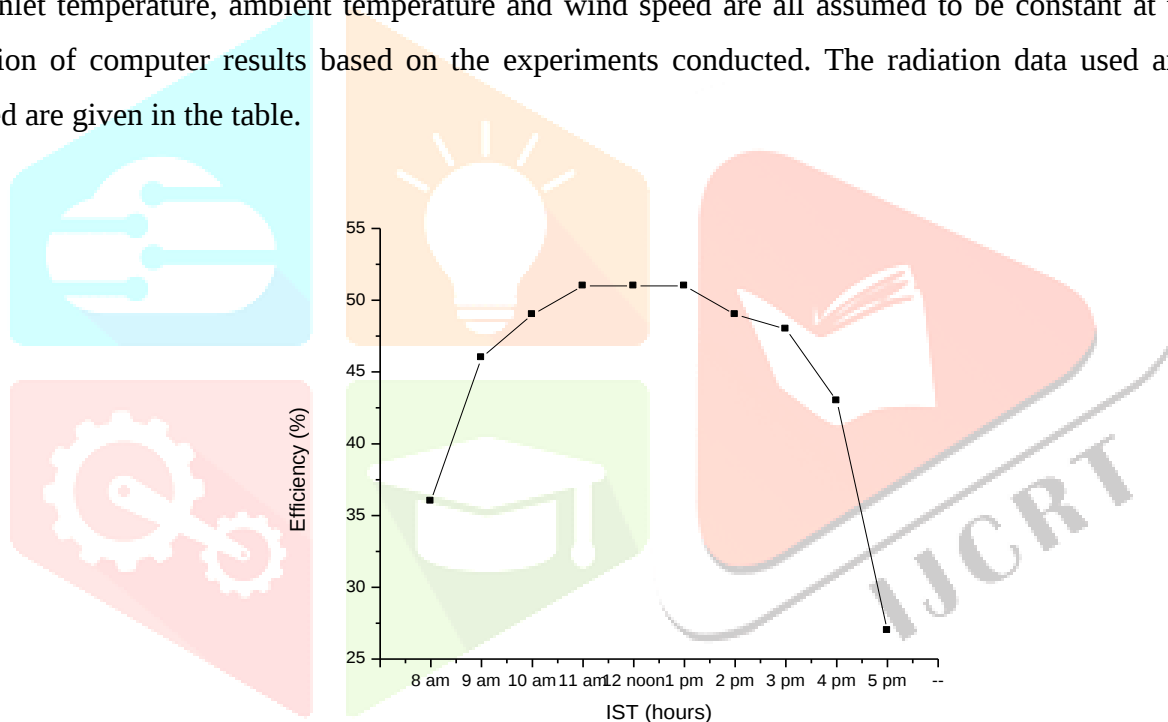


Fig. 1: Variation of Instantaneous efficiency of a FPC Over a clear day at Chickballapur

It is seen that the values of the useful heat gain and the efficiency (Fig.1) increase sharply from 09.00 to 11.00 h, touch a peak around noon and then drop sharply after 15.00h. The variation obtained is typical for a flat plate collector and indicates the strong dependence of these factors on the radiation incident on the collector. It is also seen that the value of the overall loss coefficient does not vary much. The average efficiency over the whole period, during which useful energy is collected, can be approximately calculated if it is assumed that the values of instantaneous efficiency and solar radiation are valid for half an hour on either side of the instant considered. Making this approximation, the efficiency averaged over 10 hours from 08.00 to 17.00 h works out to be 40 per cent.

4.1.2 Effect of area of absorber plate on the performance of a flat plate collector:

Table 2.2 shows the effect of variation of efficiency with area of absorber plate. Here it is observed that as the area of plate increases the efficiency decreases due to more losses occurred when the area of absorber plate increased and if the area of the plate is decreased the efficiency increases. This effect is shown by the Fig.2 varying area of absorber plate with efficiency.

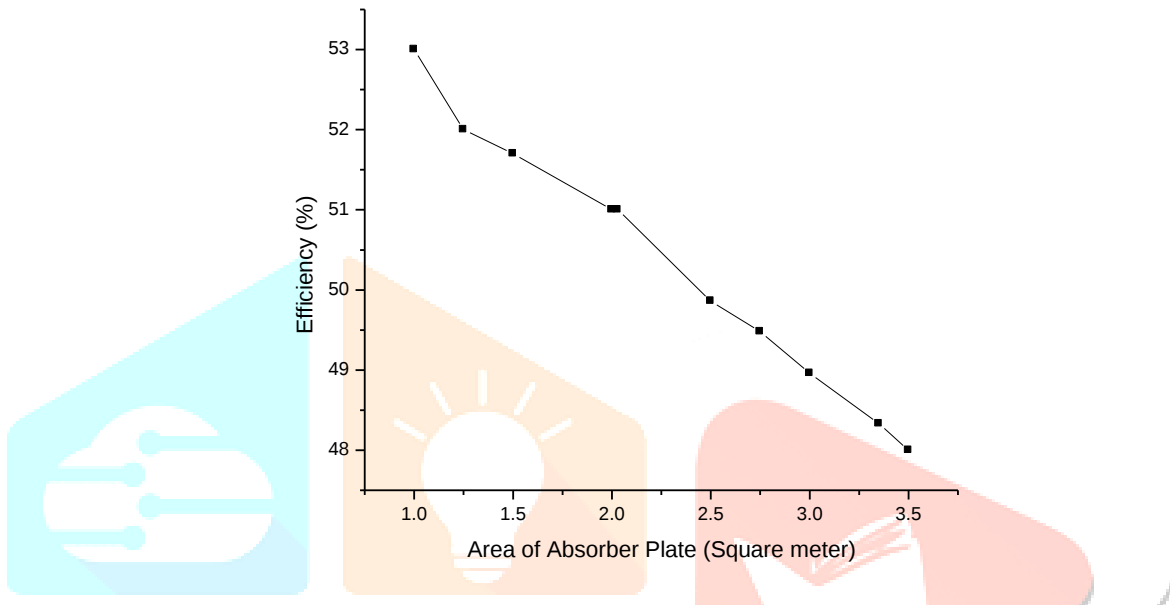


Fig. 2: Variation of Instantaneous efficiency with area of absorber plate of FPC

4.1.3 Effect of dust on the top cover on the performance of a flat plate collector:

The preceding calculations of the flux transmitted through the covers of the collector have been done under the assumption that the top cover is clean and has no dust accumulated on it. This assumption is acceptable only if the cover is continuously cleaned. However, in any practical situation, this is not possible. Cleaning is generally done once every few days. For this reason, it is recommended that the incident flux be multiplied by a correction factor which counts for the reduction in intensity because of the accumulation of dust. The correction factor is the ratio of the normal transmissivity of a dust-laden cover to the normal transmissivity of a clean cover. There is, however, considerable difficulty in assigning a value to the correction factor in a specific situation because of its dependence on a number of parameters. The value depends obviously on the location of the collector and the time of the year. It also depends upon the material of the cover (glass or plastic), the tilt of the collector and the frequency of cleaning. The results of some studies are as follows. For collectors inclined at 30° in Boston, USA, Hottel and Woertz found a reduction of less than 1 per cent in the transmitted radiation and accordingly recommended a correction factor of 0.99. However this recommendation seems to be on the higher side. Garg conducted studies at Roorkee on glass covers inclined at various angles. The experiments were performed during May and June, which are relatively dusty months. For a collector inclined at 45°, Garg

obtained a correction factor of 0.92 for a cleaning frequency of 20 days. More recently, Hegazy measured the dust accumulation on glass plates with different tilt angles ranging from 0° to 90° in Minia, Egypt (28°N , 30.5°E). The location was surrounded by agricultural fields but was not far from the eastern and western deserts of Egypt. Data were collected over a period of one year so that different weather conditions prevailing in the Minia region were considered. The measurements show that for tilt angles from 20° to 40° , a correction factor of about 0.95 was obtained after 4 days of exposure and that a value of about 0.92 was obtained after 7 days. Based on his data, Hegazy recommends that in a moderately dusty place, the transparent covers of a collector system should be definitely cleaned at least once a week as part of the maintenance routine. He also recommends that the covers be cleaned immediately after a dust storm. These suggestions were followed to my research work for conducting of my experiments and it was found correct to follow and get good results. For most parts of India, the dust accumulation would be less than the values measured in Minia by Hegazy.

5. CONCLUSION:

The development of computer program in C-language to predict the performance analysis of a working model flat plate collector without tracking used in the houses for domestic purpose have the salient features as follows:

1. The developed program is user friendly and the predicted values matches well with the experimental results.
2. The results predicted for Chickballapur location show similar to that of the experimental results conducted at BGS R&D centre; in turn the values vary marginally.
3. After predicting the performance, the Instantaneous/hourly beam radiation and diffuse radiation for Chickballapur location over a whole day for the data taken in program, it is seen that the efficiency goes on increasing from 8.00 am to 12.00 noon and after 12.00 noon goes on decreases. The efficiency observed for the location and output temperatures are same with the experimental results but with a little difference of values.
4. With the increase in Inlet fluid temperature above the ambient temperature, the efficiency of collector was observed to decrease gradually, this is because of radiation losses from the collector due to higher temperature distribution.
5. As Incident flux I_T increases, the collector efficiency also increases due to more absorption of global radiation by the collector.
6. With the increase in ambient temperature it was observed that the collector efficiency increases gradually
7. Collector efficiency increases with the increase in water-flow rate due to absorption of heat energy with high velocity flow rate and less radiation losses.
8. Collector efficiency decreases with the increase in area of the absorber plate due to increased due to increased surface area leading higher rate of heat losses.

9. With the variation of angle of incidence corresponding to 8.00 am to 5.00 pm it was observed that Transmissivity (τ), calculated based on the beam radiation decreases gradually.
10. The overall research work is satisfactory by predicting the performance of flat plate collectors used for solar water heaters for domestic purpose with the developed program and comparing these results with experiments conducted at BGS R&D centre are satisfactory.

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