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Experimental Investigation of Integrated Collector Storage Solar Water Heater

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Abstract

Application of solar energy has tremendously grown in the past due to the depletion of fossil fuels. This direct renewable energy is a in exhaustive source of energy. The power from the sun intercepted by the earth is approximately 1.8×10^{11} MW. The characteristics of sun, solar energy measuring equipments, discussion on the thermal losses, and efficiency of flat plate collector are dealt in this project. The Integrated Collector Storage (ICS) is the type solar water heater that has retained its existence for well over a century. The flat absorber plate ICS collector type is a relatively recent addition. An attempt is being made to increase the efficiency of the integrated collector storage by analyzing the design, material selection. The efficiency has been found for various mass flow rates and different tilt angles and it was found that efficiency is higher for lower mass flow rate of 0.004ml/s.

Keywords: solar energy, Flat plate collector, ICS**,** Solar water heater.

1. **Introduction**

According to the prediction of the scientists, the conventional sources of energy in the global level, particularly, the heat energy will last for eight hundred years. The heat energy is obtained by burning wood, charcoal, coal, straw, plant wastes etc. Also the heat energy is released by disintegration of the atoms which is known as atomic heat energy. The power plants that are using this type of heat energy are known as atomic power stations. Most of the countries have established a number of organizations whose main aim is to study about the non-conventional energy sources. Many researches are going on world - wide, so as to utilize the non-conventional energy in a most economical manner and to get more efficiency in all respects with less expense.

Most of the energy we receive from the sun comes in the form of light, a short wave radiation, not all of which is visible to the human eye. When this radiation strikes a solid or liquid it is absorbed and transformed in to heat energy. It becomes warm and stores the heat, conducts it to surrounding materials (air, water, other solids or liquids) or re radiates it to other materials of lower temperature. The re-radiation is a longer-wave radiation. Glass easily transmits short-wave radiation, which means that it poses little interferences to incoming solar energy, but it is a very poor transmitter of long wave radiation. Once the sun's energy has passed through the glass window and has been absorbed by some material inside, the heat will not be re-radiated back outside. Therefore, glass acts as a heat trap, a phenomenon which has been recognized in the construction of green houses, which can get quite warm on sunny days, even in the middle of winter; this has come to be known, in fact, as the "green house effect". Solar collectors, usually called flat-plate collectors, almost always have one or more glass covers, although various plastic and other transparent materials are often used instead of glass.

Beneath the cover plate, collectors commonly have another plate which absorbs the sun's ray hitting it. This absorber plate is usually made of copper, aluminum, steel or other suitable material and is usually coated with a substance like black paint or one of the more sophisticated selective coating available that will help it to absorb the most heat, rather than reflect or re-radiate it. Once the heat is absorbed, it can be picked up and used. The glass cover help to reduce the loss of heat through the top while insulation reduces heat loss through the back.

From the absorber plate, heat is transferred by conduction to a transfer fluid, usually a liquid or air, which flows over the absorber plate. The ICS is the one of the types of flat plate collector in which the storage tank is directly attached to the absorber plate instead of serpentine tubes or risers. The ICS heaters are popular, inexpensive and a maintenance free means of solar water heating. These heaters have been in use for a relatively longer time compared to the modern day, more sophisticated counter parts because of design simplicity, and lower cost. The cumulative efficiency of the ICS heater is the fraction of heat gained by the water in the tank over the total energy incident upon it. An ICS heater is designed fabricated and tested for its performance. Experiments were carried out for

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different mass flow rate, angle of inclination of collector and the test results were analyzed to optimize its performance.

2. Solar Energy and Its Measuring Instruments

2.1. The characteristics of the sun

The Sun is a sphere of intensely hot gaseous matter, continuously generating heat by thermo-nuclear fusion reactions, which convert hydrogen atoms to helium atoms. This energy is radiated from the Sun in all directions and a very small fraction of it reaches the earth. It is in the utilization of this small fraction of the total solar energy which reaches the earth that we are interested in.

Fusion energy is a form of nuclear energy released by the fusion (or combination) of two light nuclei (i.e. nuclei of low mass number) to produce a heavier nucleus. For two nuclei to fuse, they must come close enough to interact. However, similar electric charges repel one another, and since all nuclei carry a positive charge, an increasing force of repulsion develops as the two nuclei are brought closer together. Consequently, for the nuclei to fuse, they must have enough kinetic (or motion) energy to overcome the force of electrical repulsion that keeps them apart. For the force of the repulsion to be small, and thus make fusion easier to achieve, the interacting nuclei should have small positive charges (i.e. low atomic numbers). The element hydrogen has the lowest atomic number, since the nuclei of its three isotopes all carry a single positive charge. Hence, hydrogen isotopes, which also have the light nuclei, should be particularly suitable for the production of energy by the fusion of two light nuclei to form a heavier nucleus.

The principal characteristics of the sun are,

Mass M $= (1.991 + 0.002) \times 10^{30}$ kg

$R = (6.960 \pm 0.001) \times 10^{8}$ m

Average density $\rho = 1.410 \pm 0.002$ g/cm^3

Temperature (average on the surface) $T = 5762 \pm 50°K$

2.2. Solar energy measuring equipments

Experimental determination of the energy transferred to a surface by solar radiation requires instruments which will measure the heating effect of direct solar radiation and diffuse solar radiation. A total radiation type of instrument may be used for measuring diffuse radiation alone by shading the sensing elements from the sun's direct rays.

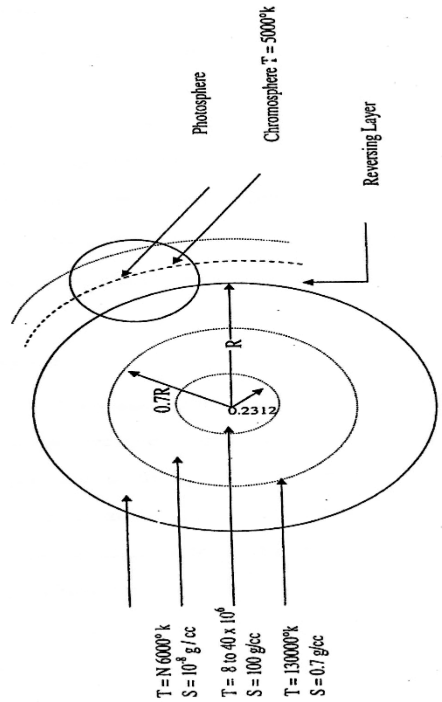

Fig.1 Structure of Sun

2.3 Classification

Pyrheliometer

A pyrheliometer is an instrument for measuring the intensity of direct solar radiation at normal incidence. It can either be a primary standard instrument or a secondary instrument scaled by reference to a primary instrument. The, latter have sometimes been called actinometers. Pyrheliometer is a small telescope like device mounted on a drive mechanism that causes it to follow the sun throughout the day.

Pyranometer

A pyranometer is an instrument for the measurement of solar radiation received from the whole hemisphere. It is suitable for the measurement of the global or sky radiation usually on a horizontal surface. Sometimes the term solar meter is used instead of pyranometer. If shaded from the beam radiation by a shade ring, it measures diffuse radiation. The pyranometer is sensitive to radiation from an entire hemisphere and is usually mounted so that the hemisphere is the sky dome.

Pyrgeometer

A pyrgeometer is an instrument for the measurement of terrestrial radiation only.

Pyradiometer

A pyradiometer is an instrument for the measurement of both solar and terrestrial radiation, i.e. For net atmospheric radiation on a horizontal upward facing black surface at the ambient air temperature.

2.4 Flat plate collector

It basically consists of a flat surface with high absorptivity for solar radiation, called the absorbing surface, Fig.3 (a) is a schematic representation of a typical flat - plate solar collector (plate, and tube type). Typically a metal plate, usually of copper, steel or aluminum material with tubing of copper in thermal contact with the plates are most commonly used materials. The absorber plate is usually made from a metal sheet 1 to 2 mm in thickness, while the tubes, which are also of metal, ranging diameter from 1 to 1.5 cm. They are soldered, brazed or clamped to the bottom (in some eases, to the top) of the absorber plate with the pitch ranging from, 5 to 15 cm. In some designs, the tubes are also in line and integral with the absorber plate. For the absorber plate, corrugated galvanized sheet is a material widely available throughout the world. The methods of bonding and clamping tubes to flat or corrugated sheet are shown in Fig. 3 (b) while 3(c) is the "tube in strip" or roll bond design, in which the tubes are formed in the sheet, ensuring a good thermal bond between the sheet and the tube.

Heat is transferred from the absorber plate to a point of use by circulation of fluid across the solar heater. Thermal insulation of 5 to 10 mm thickness is usually placed behind the absorber plate to prevent the heat losses from the rear surface. Insulation material is generally mineral wool or glass wool or a heat resistant fiber glass. The front covers are generally glass that is transparent to incoming solar radiation and opaque to the infrared re-radiation from the absorber. The glass covers act as convention shield to reduce the losses from the absorber plate beneath. Glass is generally used for the transparent covers but certain plastic films may be satisfactory. Glass is the most favorable material. Thickness of 3 or 4 mm are commonly used. The usual practice is to have 1 or 2 covers with a specific ranging from 1.5 to 3 cm. Advantages of second glass which is added above the first one are,

i. Losses due to air convection are further reduced. This is important in windy areas.
ii. Radiation losses in the infra-red spectrum are reduced by a further 25%, because half of the 50% which is emitted outwards from the first glass plate is the radiated.

It is not worthwhile to use more than two glass plates. This is due to the fact that each plate reflects about 15% of the incoming sunlight.

For water streams the absorber plate can be any metal plastic or rubber sheet that incorporates water channels, while for air systems the space above or below the collector plates serves as the conduit. The surface finish of the absorber plate may be a flat black paint with an appropriate primer. The primer coat should preferably be thin since a thick under coat of paint would increase the resistance to heat transfer. The primer should be of the self-etching type. If the primer is not a self-etching type, the repeated thermal expansion and contraction of the plate may cause the paint to peel after a year or so. Several types of backed on or chemical finishes are also available. Black painted absorbers are preferred because they are considerably cheaper.

The liquid used is generally water. However sometimes mixtures of water and ethylene glycol are used if ambient temperatures below 0°C are likely to be encountered.

2.4.1 General descriptions of flat plate collectors

Flat plate solar collectors may be divided into two main classifications based on the types of heat transfer fluid used.

Liquid heating collectors are used for heating water and nonfreezing aqueous solutions and occasionally for non-aqueous heat transfer fluids. Air or gas heating collectors are employed as solar *air heaters.*The majority of the flat - plate collector have *five* main components as follows,

i. A **transparent cover** which may be one or more sheets of glass or radiation transmitting plastic film or sheet.
ii. **Tubes, fins, passages or channels** are integral with the collector absorber plate or connected to it, which carry the water, air or other fluid,
iii. **The absorber plate,** Normally metallic or with a black surface, although a wide variety of other materials can be used, particularly with air heaters,
iv. **Insulation,** which should be provided at the back and sides to minimize the heat losses,
v. **The casing or container** which encloses the other components and protects them from the weather.

2.5 Integrated Collector Storage Solar Water Heater

Natural convection in inclined cavities or rectangular enclosures has been a topic of wide spread interest. The key application of this study is the built in storage solar water heater known as integrated collector storage heater. The heaters are popular, inexpensive and maintenance free means of solar water heating. These heaters have been in use for a relatively longer time compared to the modern day, sophisticated counter parts because of design simplicity and lower cost.

The earliest evidence of their deployment dated back to the late 19^{th} century when they were being used in forms and ranches in Texas USA have given comprehensive detail on the chronological development of ICS collector type heaters.

Better aesthetical value, easy integration in roof structures and good performance in diffuse radiation are added features of the ICS. The ICS is one of the type of flat-plate solar collector in which the storage tank is directly attached to the absorber plate instead of serpentine tubes or risers. Fig.4. shows the cross sectional view of the ICS heater.

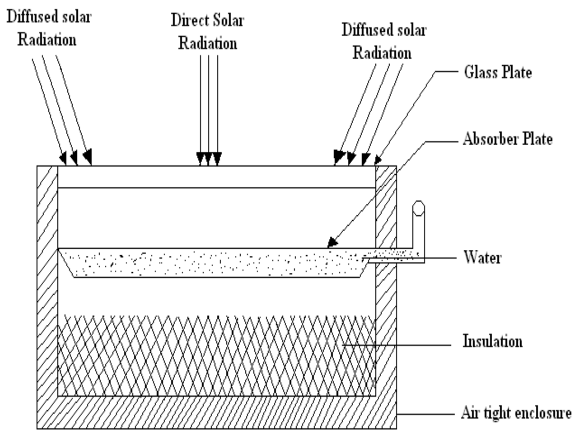

Fig. 2.Integrated Collector Storage Solar Water Heater

2.5.1 Selection Of Materials For Integrated Collector Storage System

(a) Absorber Plate Materials

The collector absorber plate should have high thermal conductivity, adequate tensile and compressive strength, and good corrosion resistance. Copper is generally preferred because of its extremely high conductivity and resistance to corrosion. Collectors are also constructed of aluminum, steel and various thermoplastics.

(b) Cover Plate

The cover plate through which the solar energy must be transmitted is also extremely important to the function of the collector. The purpose of the cover plates are:

i) To transmit as much solar energy as possible to the absorber plate.
ii) To minimize heat loss from the absorber plate to the environment;
iii) To shield the absorber plate from direct exposure to weathering; and
iv) To receive as much of the solar energy as possible for the longest period of time each day.

The most critical factors for the cover plate-materials are strength, durability, non-degradability and solar energy transmission. Tempered glass is the most common cover material for collectors because of its proven durability and because it is not affected by ultraviolet radiation from the sun. Experience has shown that, unless the glass is tempered, the day-to-day thermal cycling of the cover plate tends to cause breakage.

Tempered glass, properly mounted on to a flat-plate collector, is highly resistance to breakage both from thermal cycling and from natural events. Glass is also effective in reducing radiated heat loss because it is opaque to the longer wavelength infra-red (IR) radiation re-emitted by the hot absorber plate. Plastic materials may also be used for cover plates, such as the acrylic poly carbonate plastics, plastic films line Tedlar and Mylar, and commercial plastics such as Lexan.In selecting the glass for cover plates, the mechanical strength must be adequate to resist breakage from the maximum expected wind and snow loads, and normally expected impact. Cover plates for solar collectors normally should be atleast 0.33 cm thick. The rigidity of the cover plate is also important. Rigidity is proportional to the cube of the thickness of the plate. The resistance to fracture under mechanical stress is especially important when the collector is double-glazed. Some flexure may be desirable to accommodate he expansion of air within the gap when this type of collector is heated.

2.5.2 Specification of materials

1) Transparent Cover

- Materials - Glass
- Thickness - 4mm
- Size - 1m^2

2) Absorber Plate

- Material - G.I sheet
- Thickness - 20 SWG
- Size - 100 × 84 cm
- Surface coating - Dull black paint

3) Integrated Water Tank

- Material - G. I sheet
- Length - 1.10 m
- Breadth - 0.90 m
- Height - 0.12m
- Volume - 0.12 m^3

4) Thermal Insulation

- Material - Glass wool
- Thickness - 5 cm

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5) Enclosure

- Material - M.S sheet
- Thickness - 20 SWG

2.5.3 Experimental investigations

A flat-plate built in storage water heater was has to be made for experimental investigation. The water tank has to be made out of galvanized sheet with gauge thickness of 1.5 mm. Wood is used for external casing. The Glass wool insulation is used on the sides and bottom of the water tank. Glass wool covering was 100 mm thick on each side. The gap between the absorber plate and the glass cover was 35 mm. When the ICS heater is inclined because of stratification a variable temperature distribution develops inside the tank. Tests have to be carried out between 10:00 AM and 4:00 PM. The rise in temperature has to be recorded for 15 minutes intervals. The parameters like inlet and outlet temperature of water, solar intensity, mass flow rate, absorber plate temperature, angle of inclination has to be considered while conducting the experiment and hence performance of the collector is to be found.

2.5.4 Thermal losses and efficiency of integrated Collectors

The thermal losses can be separated into three components:

1. Conductive losses

Conductive losses occur through the back and the sides of a collector.

2. Convective losses

Convective losses occur from the absorber plate to the environment through intermediate convection exchanges between the, air enclosed in each insulating zone and the boundaries of each zone the collector covers. In the absence of wind, external convection loss from the outermost cover is by the mechanism of natural convection, but even in low winds, forced convection occurs, and increase the loss substantially.

3. Radiative losses

Radiative losses from the absorber can be reduced by the use of spectrally selective absorber coatings. Selective black coatings are commercially available.

Under steady state conditions, the useful heat delivered by a solar collector is equal to the energy absorbed in the metal surface minus the heat losses from the surface directly and indirectly to tile surroundings.

This principle can be stated in the relationship:

$$Q_u = A_c\,[HR\,(\tau.\alpha)_e - U_L, (T_p - T_a)]$$

Where , T_p -is the average temperature of the upper surface of the absorter plate.

Q_u -is the useful energy delivered by collector,watts.

A_c -is the collector area, m^2

H -is the rate of incident beam or diffuse radiation on a unit area of surface of any orientation; W/m^2

R -is the factor to convert beam or diffuse radiation to that on the plane of collector.

$(\tau.\alpha)_c$ -effective transmittance - absorptance product of cover system for beam and diffuse radiation

U_L -is the overall heat loss co-efficient ; W/m^2 K

T_a -is atmosphere temperature °C

Table 3

Efficiency for Mass flow rate of water= 24Kg/hr
Angle of Inclination = 12°

The energy balance equation on the whole collector can be written as ,

$$A_c\,[\{HR\,(\tau.\alpha)_b + HR\,(\tau.\alpha)_d\}] = Q_u + Q_L + Q_s$$

Where,

Q_u=rate of useful heat transfer to a working fluid in the solar exchanger.

Q_L=rate of energy losses from the collector to the surroundings by re-radiation, convection and by conduction through supports for the absorber plate and so on.

The losses due to, reflection from the useful gain over any time period to the incident solar energy over the same time period.

If the covers are included in the $(\tau.\alpha)$ term;

Q_s=rate of energy storage in the collector.

Time	Atmospric Temp.(Ta) °C	Glass Plate Temp. t_g °C	Absorber Plate Temp. t_p °C	Intensity of Solar Radiation Kj/hr m^2	Water inlet Temp. (t_i)°C	Water Outlet Temp. (t_o)°C	Efficiency ins in %
10	30	36	39	2077.94	31	36	24.41
10.15	30	39	39	2620.1	31	38	27.11
10.30	30	36	36	2710.35	31	39	29.95
10.45	30	39	39	2800.70	31	41	36.23
11.00	31	39	39	2981.39	31	43	40.84
11.30	32	41	39	3162.08	31	47	51.34
11.45	31	40	42	3116.91	32	48	52.10
12.00	31	42	39	3207.25	32	50	56.69

Collector efficiency η_c, is the collector performance and is defined as the ratio of the instantaneous solar collector -efficiency .

3. Tables, Figures and Equations

Experiments were conduct on integrated collector storage of solar water heater using various mass flow rate and different angle of Inclination. While conducting the experiments, Parameters like inlet and outlet temperature of water, solar intensity, and mass flow rate, absorber plate Temperature and glass plate temperature were measured. Instantaneous efficiency of all the observation were calculated on completion of the experiment and after analyzing the results, the following points were inferred.

1) Till the solar intensity reaches its maximum on a day (i.e., in the fore noon). The efficiency was found to be same for collectors.

But in the afternoon hours, as the solar intensity value decreases, it was found that the efficiency of collector is high.

2) When compared to the conventional collector, the temperature rise in the water is high even during the late afternoon hours. (i.e., (from 4.00 pm-5.30pm) When the solar intensity was not significant enough to rise the temperature.

3) The maximum efficiency achieved with the ICSSWH was found to be above 80%.

3.2 Specimen Calculation

Area of collector (A)= L*b

=108*92=0.99m^2

Total heat available in kJ/hr.m^2

$$\frac{pyronometer..reading..in..m.v*60*Cp}{pyronometer..cons\tan.in..m.v/cal.\min^{-1}.cm^{-2}*1000}$$

$$=\frac{6.4*60*4.186*104}{5.56*1000}$$

=2891.05 kJ/hr.m^2

Heat available in the collector in kJ/hr

=total heat available * area of collector

=2891.05*.99

=2862.13 kJ/hr

Total heat gained by the water = m*C_p.Δt

T where m=mass flow rate of water kg/hr

C_p.=sp. Heat of water=4.186kj/kg.k

Δt=Temperature difference=T_{out}-T_{in}

=15*4.186*5

=313.95

Efficiency=

$$\frac{Total..heat..gained..by.the.water}{Heat.available.in.the.collector}$$

$$= \frac{313.95}{2862.13}$$

=45.96%

4. Conclusion

The different types of solar collectors were studied and the advantages of Integrated Collector Storage Solar Water Heater have been identified. Parameters like inlet and outlet temperature of water, solar intensity, mass flow rate, absorber plate temperature, angle of inclination have been considered while conducting the experiment and hence the performance of the collector has been found. From the experimental analysis the efficiency of the ICS has been found to be higher when compared to the conventional collector.

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