Advance Physics Letter

Experimental Analysis of Thermal Performance of Evacuated U-Tube Solar Collector

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Abstract— Energy is one of the essential requirements of livinghood. In present scenario conventional energy resources for producing energy to sustain our lives has become a necessity. Since these sources are depleting at faster rate and cost of energy is increasing simultaneously, so conversion of renewable form of energy is much desired and solar energy is a good resource.

The present work is based on the solar radiation received in Raipur region and the city Raipur is located in the sunny belt of the country and receives a good amount of solar radiation over the year. Research reveals that the daily average solar energy incident over India varies from 4 to 7 kWh/m^2 having approximately 2,300–3,200 sunny hours per year. In the Raipur region the daily global solar radiation in this region is 4.58 kWh/m^2, while the daily diffuse radiation is 1.72 kWh/m^2. The present work is based on the experimental analysis using evacuated U-Tube collector. Also a system is always successful when its efficiency level increases, hence efficiency analysis under different radiation parameters has also been performed.

Depending on the temperature change of atmosphere, variation in solar irradiation the thermal performance of evacuated U-tube solar collector has analysed. The analysis utilizes the set of observed data for different operating conditions. In the present study it is found that the concept of inserting copper fin in to it, has increased the thermal performance of evacuated tube collector by 10% -15% from water-in-glass evacuated collector.

Index Terms— Non-conventional Energy Sources, Performance Analysis, Solar Energy, U-tube.

I. INTRODUCTION

Due to the nature of solar energy, two important parts are required to have a functional solar generator of energy. These two components are a collector and a storage unit. The collector collects the radiation that falls on it and converts a fraction of it to other forms of energy either electricity and heat or heat alone. The storage unit required because of non-constant nature of solar energy at certain times i.e. when sunshine blocked by clouds [1].

With the technological advancement, more efficient thermal collectors are introduced for water heating purposes. The conventional solar flat plate collectors are not much efficient in cloudy and rainy days [2]. Also the response time of flat plate solar collectors for water heating is around 30 minutes when exposed to sun light. To overcome such deficiency a new type of solar thermal collector has been introduced which differs in design from conventional flat plate collector. Basically solar thermal collectors exhibits three distinct energy flows. Incident energy from solar radiation is absorbed by the collector. As the temperature of collector increases, energy is lost back to the surrounding either by conduction, convection, and radiation. The difference between these two energy flows is the useful energy delivered by the collector.

Radiative energy losses can be reduced by decreasing the emittance of the solar absorbing surface. The surface with low emittance for thermal radiation and to maintain a high absorptance for solar radiation due to spectral separation of the solar radiation and thermal radiation at typical operating temperatures. Such a surface is termed as “selective” [2]. A good quality selective surface has a solar absorptance above 90 percent with an infrared emittance of few percent.

Previous Research work shows that further reductions in energy losses from solar collectors can be achieved by reducing conduction and convection losses. Maximum reduction of these losses will achieved if the space surrounding the selective surface is vacuumed. In a practical device it is only realistic to achieve this with a vacuum envelope of tubular geometry. Such a device is called as Evacuated Tubular Solar Collector. It has been also studied that with the introduction of U-tube in copper fin, heat retaining capacity increases [22,23].

The vacuum acts as perfect insulator and does not allow short wave radiations to escape through the glass tubes. Due to this important property of vacuum trapping of solar radiation is much more effectively and hence an appreciable efficiency can be achieved [7]. Creating vacuum helps to keep the tubes from cooling down in colder weather conditions heat supply can therefore continue even there is no sunlight striking the collector, due to trapped heat in the evacuated glass tube. Thus the advantage of the sealed glass evacuated tube is that is acts as heat storage and provides a stable supply of heat to the manifold even during intermittently overcast weather and provides heat energy even after the sun has set.

The present work is confined to the thermal performance analysis of Evacuated U-Tube Solar Collector. Although there have been many researches on evacuated tube solar thermal collector. In the present work the analysis of thermal performance of evacuated U-tube solar collector has been done, according to the Raipur City climatic conditions and the comparision of its result with water-in-glass collector results. This project consist of fabrication of evacuated U-tube solar thermal collector and to analyze its thermal performance. Also the variation of thermal performance of evacuated U-tube solar collector with atmospheric temperature and solar irradiation has been reported.

II. EXPERIMENTAL PROCEDURE AND OBSERVATIONS

A. Experimental Procedure

The experiment conducted from January 2014 to February 2014 at Raipur Institute of Technology, Raipur, CG (longitude=81° 41' E, latitude=21° 15' N), which had Sunny day, partially cloudy and scattered cloud day some times. Throughout the testing period, the collector faced south at a tilt angle equal to latitude of Raipur. The following measurement have been acquired; global irradiation on collector plane, inlet fluid temperature, outlet fluid temperature, surrounding air temperature and fluid flow rate but in the experiment no draw-off condition used.

The surrounding air has been measured on the side of the test rig. The values are almost stable between 0.7 m/s and 1.3 m/s. A collector is considered to operate in steady state conditions. The test period excludes the pre conditioning period of 15 minutes. The devices used here for data recording and experimental work, are pre calibrated. The apparatus is filled with water well before placing in sunshine and testing of any leakage is done properly. No leakages found in the apparatus. The test set up taken into sunshine and arrange in proper condition. The note down the initial reading of water temperature inside the experimental set up and the ambient temperature outside the tube. The solar radiation is measured at starting time of experiment i.e. 09:00 AM. Then after ten minutes note down the readings of water temperature inside evacuated tube, ambient temperature and irradiation. Similarly for next 20 minutes, 30 minutes till 03:10 PM note down the readings. Total 10 readings taken in a day.

Figure 1 : Experimental Set-up for thermal performance analysis of evacuated U-tube solar collector-

B. Observations

Clear Sky Day Observation-

The observed data have been presented here. Also they have been analyzed through their graphical representations as follows.

TIME	**ETSC (Water-in-glass)**	**Atm. Temp**	**ETSC (U-tube with fin)**	**Radiation**
	Temp. °C	°C	Temp. °C	W/m^2
9:00 AM	24	24	24	324
9:10 AM	29	24.3	36.6	461
9:30 AM	33.4	24.8	48.3	498
10:00 AM	38	25	59.1	540
10:40 AM	45	25.3	67	555
11:30 AM	53.8	25.1	78	601
12:10 PM	59.1	25.3	81	680
1:00 PM	59.8	26	90.1	784
2:00 PM	60	25.5	92	796
3:10 PM	60.1	24.9	94.2	657

Table 1

Observations for temperature and time for 13-Jan-14

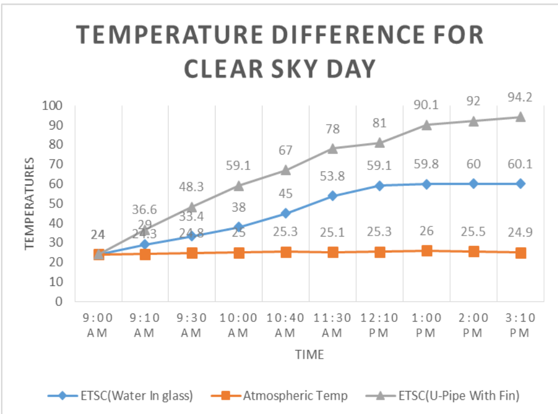

Figure 2 : Graph for temperature V/s time for 13-Jan-14

Partial Cloudy Day Observations-

In the presence of partially sunshine the data recorded for solar radiation, atmospheric temperature and water output temperature from both water-in-glass and evacuated U-tube collector. The analysis of data gives that the maximum temperature that is attained by water in tube is lower than clear sky day. But the difference in output water temperature is maintained as the analysis of curve represents.

TIME	ETSC (Water In glass)	Atm. Temp	ETSC (U-tube with fin)	Radiation
	Temp. °C	°C	Temp. °C	W/m^2
9:00 AM	20	19	20	232
9:10 AM	28.1	19.3	35.5	242
9:30 AM	36.7	21.1	45.2	298
10:00 AM	45	22.6	52.2	357
10:40 AM	51.3	22.9	61.7	478
11:30 AM	55	24	69.4	582
12:10 PM	57.2	24.5	72.4	651
1:00 PM	60	26	79.9	765
2:00 PM	61.2	24	82.2	699
3:10 PM	59.7	19.8	81.4	573

Table 2 : Table for temperature and time for 27-Jan-14

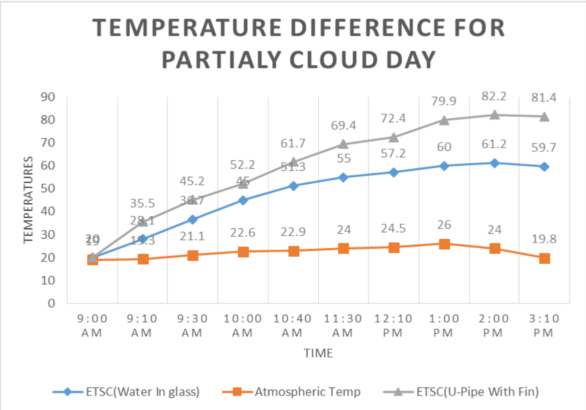

Figure 3 : Graph for temperature V/s time for 27-Jan-14

Scattered Cloud Day Observations-

The data recorded for the day when sun was not present completely but it continued to appear intermittently. Yet the data analysis gives the temperature of water output from evacuated U-tube is higher.

TIME	ETSC (Water-in-glass)	Atm. Temp	ETSC (U-tube with fin)	Radiation
	Temp. °C	°C	Temp. °C	W/m^2
9:00 AM	16	16	16	201
9:10 AM	24.4	17.3	27.1	223
9:30 AM	29	18	38	277
10:00 AM	39	21.8	58.3	350
10:40 AM	47	22.1	66.4	450
11:30 AM	52	24	72.2	672
12:10 PM	56	24.4	76	701
1:00 PM	58.6	24.9	79	723
2:00 PM	60	24	82	687
3:10 PM	59.8	20.3	80.6	500

Table 3 : Table for temperature and time for 11-Fab-14

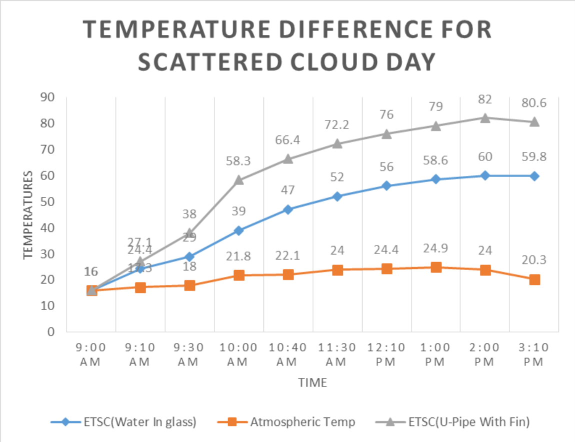

Figure 4 : Graph for temperature V/s time for 11-Fab-14

The conclusion may draw from above recorded data that the atmospheric temperature varies with solar radiation. Thus when there is fair sunshine then evacuated U-tube collector has given a very high temperature water output and it is quite suitable for steam generation. Water output is depending on atmospheric temperature and solar radiation. Comparison of these curves gives the performance of the evacuated U-tube solar collector is higher than water-in-glass solar collector. This is because of copper circular fin fitting to it. In the absence of copper fin the performance is penalized by the reducing output temperature.

The efficiency of collectors have been investigated using empirical relations suitable to assumptions and collectors selection for recorded set of data and plotted as a function of temperature difference of output water and atmosphere to insolation. [Duffie and Beckmen [1980].

C. Computational Performance Analysis

To simplify the analysis following assumptions [10, 23] were made:

- The heat transfer process is assumed to be steady [2, 10].
- The averaged heat flux along the circumferential direction is assumed [2, 22].
- The header covers a small area of collector and hence a small amount of conduction from glass tube walls. Hence this effect is assumed to be neglected.

The length and out diameters of the outer glass tube and absorber tube are taken as 1200 mm, 47 mm and 37 mm, respectively. The U-tube is fitted inside a circular fin. And the solar energy absorbed by the selective absorbing coating is equal to the incident solar radiation, reduced by conduction, convection and radiation losses.

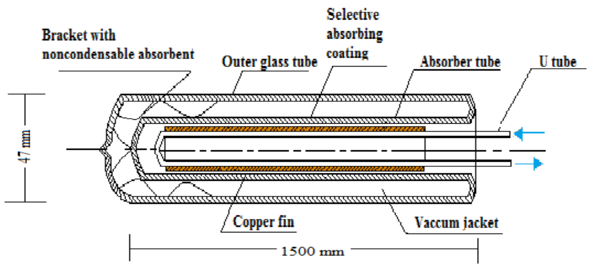

Figure 3 : Axial structure of evacuated U-tube solar collector tube with copper fin

The cross sectional view of evacuated U-tube collector is shown below with the elements –

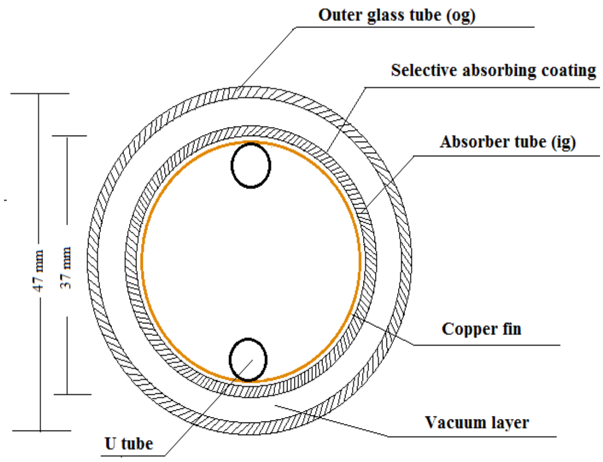

Figure 4 : Cross section configuration of evacuated U-tube solar collector

To present the thermal processes, a thermal circuit has been drawn to analyze the thermal performance of evacuated tube solar collector in simple way.

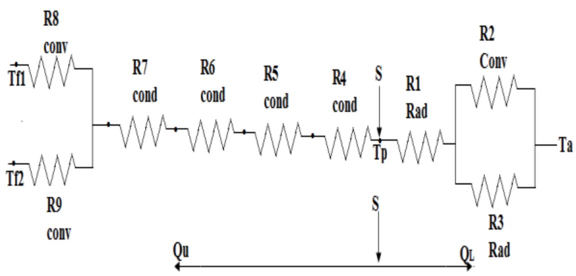

Figure 5 - Thermal Circuit

The heat loss coefficient U_L is calculated from thermal resistance between the absorber tube and the outer glass tube and between the outer glass tube and the surrounding and other parameters using aforementioned relations by Dilip Mishra et. al. [2].

D. Simulation

Simulation has been done to see the velocity variation, pressure variation, temperature variation and water flow with in the collector.

In this section the simulation has been done by using ANSYS software for pressure variation, velocity variation, temperature distribution and fluid flow in U-tube solar collector.

Pressure Variation in U-tube Solar Collector

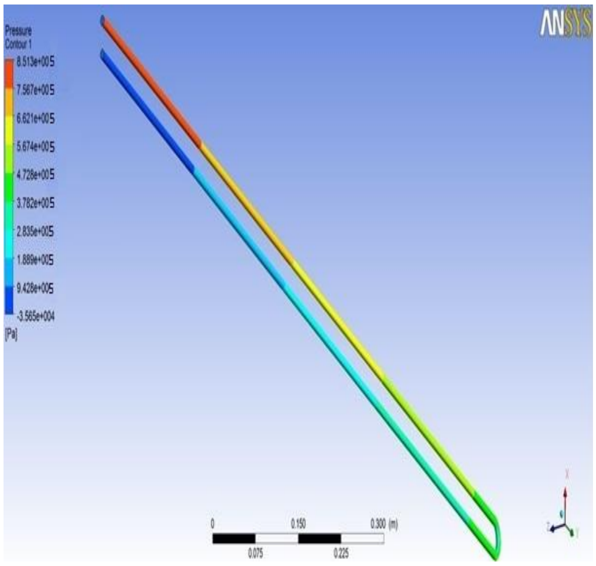

Figure 6 : Pressure Variation in U-tube

From the figure 6 (Pressure Distribution In U-tube) it is clear that as water enters into the U-tube, it absorbs heat and its pressure increases. The pressure increase is found at the end of tube i.e. fluid outlet end.

Velocity Variation in U-Tube Solar Collector

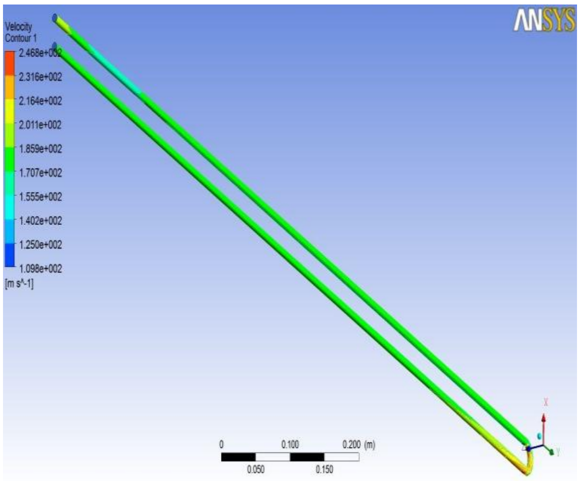

Figure 7 : Velocity Variation in U-Tube

Above figure describes the velocity distribution in the U-tube solar collector. The simulation depicts as the water starts heating its velocity increases, as low density water (hot water) rises in up direction.

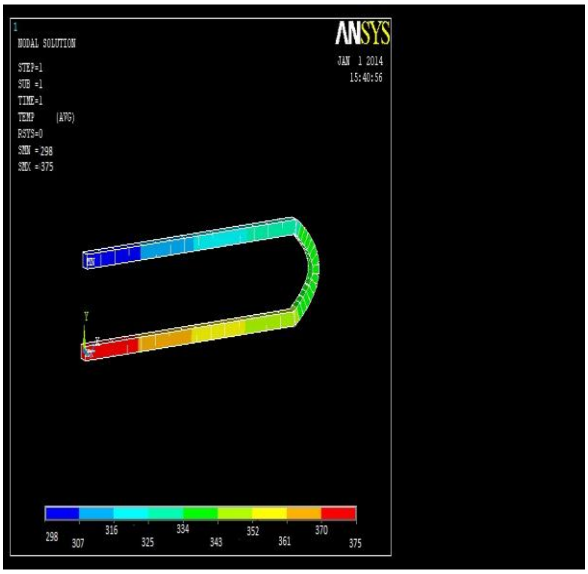

Figure 8 : Temperature Distribution in U-tube Solar Collector

The simulated result describes that as the water flows from inlet to out-let, its temperature gradually increasing from inlet to outlet. Simulated result is evidencing the thermos-syphon principle.

This is because, as the colder water comes through inlet section water absorbs heat energy at inlet section results in lowering the temperature at inlet section and higher at outlet section. Also when the colder fluid enters through the inlet the hot water get displaced through outlet.

E. Outcomes of the Work

III. RESULT AND DISCUSSION

The radiation heat transfer coefficient between the absorber tube and outer lass tube, $h_{rad,ig-og}$ is 0.898 W/m^2 K and is related to the temperature of ambient and absorbing coating. It means that the radiation heat transfer coefficient will increase with the increment of ambient temperature. For the heat losses to the ambient the heat transfer coefficient from inner glass tube to outer glass tube is very small compared with the radiation heat transfer coefficient from outer glass tube to ambient and convection heat transfer coefficient from outer glass to ambient and energy can be easily transferred to the working fluid. The results obtained are in good agreement with the Jili [10] and evidencing that vacuum acts as good thermal insulator. It has been observed that the maximum solar irradiation observed value during the experimentation was 932w/m^2. The efficiency of evacuated U-tube solar collector is calculated and graph representing the variation in efficiency with respect to atmospheric temperature plotted. It is observed that the result are in accordance with Hayak and Jili [13, 22]. The efficiency calculated is higher than that of water-in-glass evacuated tube collector. In following figure series 1 and series 2 represents efficiency profile for water-in-glass and evacuated U-tube collector respectively.

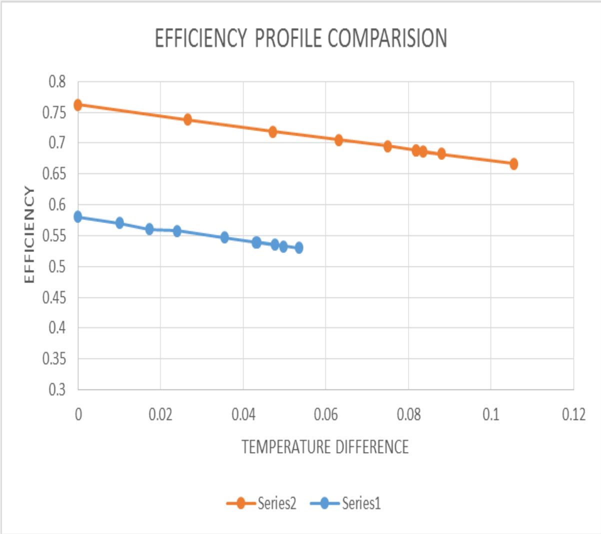

Figure 9 : Efficiency Profile Comparison with Temperature Difference

It is observed that the concept of inserting copper fin in to vacuum glass tube resulted in increased thermal performance. Further analysis of graph reports that the efficiency decreases with increase of the inlet fluid temperature in the solar collector, indicating the thermal loss of the solar collector increase with increase of the working fluid temperature. As the copper fin is inserted in to tube, the proper contact must be maintained else there will air layer present. And Zhao Dan [22] reported that with air layer between fin and inner glass tube the thermal efficiency falls by 9% due to increased radiation heat loss from absorber surface

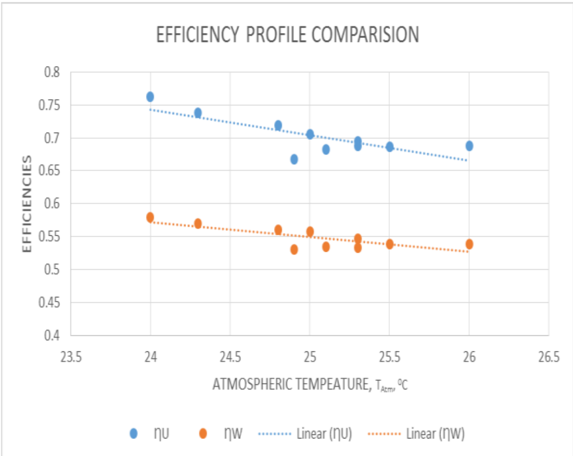

Figure 10 : Efficiency Profile Comparison with Atmospheric Temperature

The present study of evacuated tube solar water heating system report that the trend of using power efficient device will be rapidly growing in coming decades. This analysis of energy consumption by mean of water heating is estimated also Evacuated tube water heater. Comparison of analysis data and experimentally reported that Evacuated U-tube water heating system is much efficient around 10% to 15% than the water-in-glass evacuated tube collector for above mentioned climatic condition. The result of efficiency difference shows that the circular copper fin's heat capacity in evacuated U-tube collector leaded the efficiency up to 74% where as in water-in-glass evacuated tube collector up to 66%. We can use aluminium fin also in place copper fin but copper has better heat retaining properties. The payback period is calculated and found that after 567 days all investment comes back and it becomes free and saving of around 9000/- Rs per year can achieve. The evacuated U-tube collector's output temperature can use for Raipur (C.G.) climatic condition for house hold uses. Thus it can be used also in industrial application to generate steam for rice mill, power plants etc.

It has been seen experimentally that evacuated U – tube solar collector has high heating capacity as compared to simple evacuated tube collector or any other collector but even there are some limitations observed in Evacuated U-tube Collector that is-

I. Initial cost is high as compared to other collectors.

II. Construction of Evacuated U-tube Collector is little bite complicated as compared to other collectors and thus proper handling required.

III. Some-times due to improper handling and maintenance temperature becomes very high due to lack of water in the tube and hence it causes a thermal shock so tube may crack and resulting vacuum to loose.

IV. CONCLUSIONS

In the present work, the thermal performance of the evacuated U-tube solar collector is investigated. Further from study it is found that vacuumed tube prevents the leakage of heat from collector and traps heat for useful heating purpose of water. Thus helps in increasing collector thermal performance. The influences of atmospheric temperature and the solar radiation intensity on the collector efficiency are studied. Effect of copper fin and U-tube in terms of its heat retaining capacity has been observed and it is found that the thermal efficiency of Evacuated U-Tube Collector has been increased by 10-15% then water-in-glass evacuated tube solar ware heater.

All the results have been taken from natural convection flow of water inside the tube. The further augmentation of heat transfer from vacuum tube can be made by creating turbulence in the fluid flowing inside the tubes. The turbulence can be set-up by following three methods-

I. By vibrations.

II. By forcing the fluid or water by means of some external power, used safely to avoid breakage.

III. By cross movement of experimental set-up with changes in angles as per the position of sun in the sky.

V. FUTURE SCOPE OF THE WORK

In the present study it is seen that instead of one copper U-pipe for letting water in and out two copper U- pipes can be inserted with in a vacuum glass tube to increase the heat retaining capacity of evacuated tube collector. The observation can be made to see the effect of two copper U-tube insertion within a vacuum glass tube over the efficiency of the Evacuated U-tube Solar Collector and also on the response time of collector. The research can be further extended for other parameters which are considered here. These parameters may be the other shapes of the tube, material of the tube, different climatic conditions, etc. The work can also be extend in the other regions of the country.

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