Effect of Inclination Angle on Temperature Characteristics of Water in-Glass Evacuated Tubes

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ABSTRACT

The water-in-glass evacuated tube is an integral part of evacuated tube solar water heater. Solar water heaters with evacuated tube collectors perform better than that of flat plate collector. The usage of evacuated tube collectors is increasing day by day. For flat plate collectors it is essential that the inclination of the collectors should be based on the latitude of that place for better performance. This paper discusses the experimental study conducted on the evacuated tube collectors mounted at different angles of inclinations i.e 15, 30 ,45 degrees. The temperature characteristics obtained as a result of the experiment show that the performance varies with respect to angle of inclination. A salient feature of this study is the employment of twelve temperature sensors located inside of three tubes and three tanks. A data logger was used to collect data during the experiment on daily basis for seven hours. The data collected during the experiment shows the highest values of water temperatures for lesser inclination angles (15 degree) at earlier stages of the experiment.

Keywords***: Evacuated tube collector, Solar water heater, Collector tilt angle, Thermosyphon, Thermal Performanceetc.***

1.INTRODUCTION

Solar energy, being abundant and widespread in its availability, makes it one of the most attractive sources of energies. Tapping this energy will not only help in bridging the gap between demand and supply of electricity but shall also save money in the long run. A Solar Water Heating System (SWHS) is a device that makes available the thermal energy of the incident solar radiation for use in various applications by heating the water [5]. The SWHS consists of solar thermal collectors, water tanks, interconnecting pipelines, and the water, which gets circulated in the system. Solar radiation incident on the collector heats up the tubes, thereby transferring the heat energy to water flowing through it. The performance of the SWHS largely depends on the collector's efficiency at capturing the incident solar radiation and transferring it to the water. With today's SWHS, water can be heated up to temperatures of 60 °C to 80 °C. Heated water is collected in a tank insulated to prevent heat loss. Circulation of water from the tank through the collectors and back to the tank continues automatically due to the thermosyphon principle [6]. The hot water generated finds many end-use applications in domestic, commercial, and industrial sectors. The evacuated tube solar collectors perform better in comparison to flat plate solar collectors, in particular for high temperature operations.One of the most significant developments is the use of double-glass evacuated tubular solar water heaters. The mechanism of this type of solar water heater is driven bynatural circulation of the fluid in the collector and the storage tank. It consists of all-glass vacuum tubes, inserted directly into a storage tank, with water in direct contact with the absorber surface. Morrison et al has mentioned that evacuated tube solar collectors perform better than flat plate collectors during high temperature operations [1]. Evacuated tube solar collector system is better option for domestic utilization because of its simplicity and low cost.

2. WORKING PRINCIPLE

Solar Water Heater (ETC System) works on a simple principle 'Black body heat absorption principle'. The principle says, 'black colour absorbs maximum heat, more than any other colour' Solar water heating systems using vacuum tubes made of borosilicate glass with special coating to absorb the solar energy are called as Evacuated Tube Collector system (ETC Systems).Air between the gap of two glass tubes is evacuated. It results in high level of vacuum, which acts as the best insulation to minimize the heat loss from inner tube. The black coating on the inner tube absorbs the solar energy and transfers it to the water. The water on upper side of Vacuum Tube becomes hot and thus lighter, so it starts moving upwards in the tank. At the same time cold water, which is heavy, comes downward from the tank and is stored at the bottom. The phenomenon is called as natural Thermosyphon circulation, which occurs in every tube.Thermosyphon Systems: In this type water flows through the system and when water gets warm it rises as cooler water sinks. The collector is installed below the storage tank so that warm water will rise into the tank. These systems do not involve any pump and are more reliable.

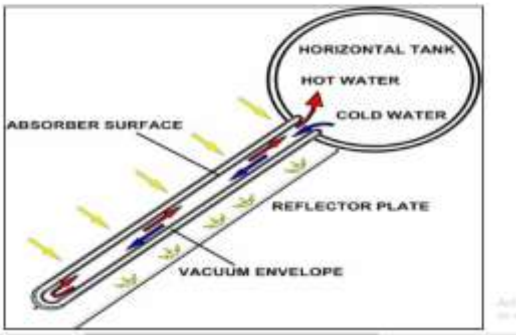


Fig-1: Working of Evacuated Tube Collector.

2.CONTRUCTIONAL FEATURES

Main components of evacuated tube solar water heater:Evacuated glass tubes and Barium Getter, Storage tank, Mounting Frame

2.1Evacuated Tubes

The evacuated tube is made of borosilicate glass. The diameter of the tube is 47mm and the length is 1500mm. Figure 2 shows the detail parts of the evacuated tube.The vacuum tubes consist of a double wall glass tube with a space in the centre which contains the heat pipe. The presence of the vacuum wall prevents any losses by conduction or convection - just like a thermos flask. Because of this, the system will work even in very low temperatures, unlike traditional flat plate collectors. In order to maintain the vacuum between the two glass layers, a barium getter is used. During manufacture this getter is exposed to high temperatures which cause the bottom of the evacuated tube to be coated with a pure layer of barium. This barium layer actively absorbs any CO, CO2, N2, O2, H2O and H2 out gassed from the tube during storage and operation, thus helping to maintaining the vacuum. The barium layer also provides a clear visual indicator of the vacuum status. The silver coloured barium layer will turn white if ever the vacuum is lost.

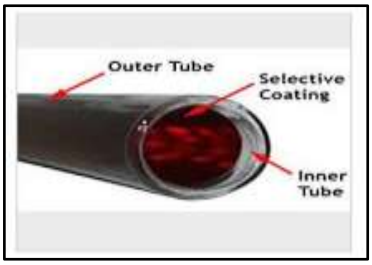


Fig-2: Details of Evacuated Tube Collector.

2.2 Storage Tank

It is a tank which stores the water and come from external water source like water tank. Outer cylindrical surface is covered by high tech insulating material (Rock Wool or mineral wool) in order to reduce the heat losses from the heated water exist inside the inner tank heated by the evacuated tube solar water heater. Rock wool is a man madefiber and has many excellent characters like non-combustible, non-toxic, low thermal conductivity, long service life and so on. Storage tank is placed at the top of frame and tubes. The top open end of the tubes is connected to the storage tank. The bottom end of tubes is placed in a holder provided at bottom of the frame. Figure 3 shows storage tank of 7 Litrecapacity.

Fig-3: Storage Tank

2.3 Mounting Frame

The whole system required a structure strong enough to hold up all the tubes at various angles at the same time.It is structure made of no. of metallic angle or plate, on which no. of units like storage tank tubes etc. are mounted.Figure 6 shows a frame assembly for evacuated glass tube solar water heating system upto7 Litre Capacity.

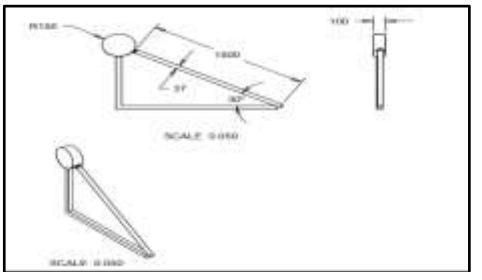


Fig-4:Mounting frame (creo model).

3.INSTRUMENTATION.

Temperatures are to be measured in two places of the tube, viz., top and bottom. The type of thermocouple used in the experiment is a PT100 thermocouple with the maximum measuring capacity of 300°C. The thermocouple is calibrated with a series of minor experiments and checked for errors. Data logger used was Series DL-35W 16 channel. It supports various thermocouples including K-type, R-type and PT-100. We used PT-100 thermocouples for the experimentation. It is developed by Microcubs Systems Pvt. Ltd.

Fig-5: Sensor PT(100)

Fig-6: DAQ (Data logger).

4.EXPERIMENTAL DESCRIPTION

The basic experimentation is to record the temperature readings of the water in the evacuated tubes at particular time intervals. The time intervals were chosen from a frequency of about once in every 15 minutes. Initially the experiment is conducted with tubes facing the south direction. Figure-5 gives the view of experimental set-up. The experiment is conducted on clear sun-shine day with global radiation of 820 W/m2. The solar radiation is measured with the help of pyranometer available in the solar radiation monitoring station. The readings are taken continuously for every one hour from 10.00 a.m. to 5.00 p.m.

Fig-7: Experimental Setup.

4.1 Stagnation Test

To find out the maximum temperature achieved inside the empty tube with air only, we conducted a test known as stagnation test. It gives temperature rise over the period of the day. If the temperature achieved is of around 200 ^{0}C then tube is healthy and working properly. The observation table no. 1 gives the results of the stagnation test 1. With this check we assure manufacturing uniformity among all the tube. When these tubes are subjected to radiations they absorb same amount of radiations when kept at equal inclinations. The test setup was inclined at angle of 25^0 to the horizontal. The test was conducted for 2hours and results obtained were plotted against the time to verify the variation of the temperature along with radiation variation with respect to time. T1 stands for thermocouple reading of tube 1, T2 for thermocouple reading of tube 2 and T3 for thermocouple reading of tube 3. T4 is ambient air temperature during the test. Solar radiation intensity is also plotted into the graph to understand variation of the behaviour of the tubes.

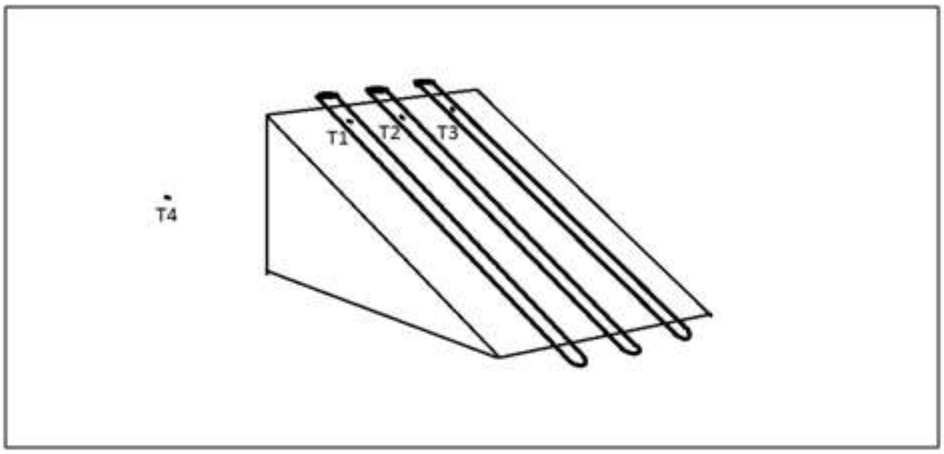
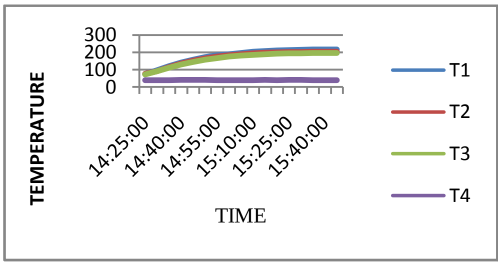


Fig-8: Stagnation test thermocouple location.

Table-1:Stagnation test 1.Table-2:Stagnation test 2.

Date	Time	T1	T2	T3	T4
18/02/2017	11:15:00	69.4	74.6	72.8	36.5
18/02/2017	11:20:00	94.5	101.0	93.8	38.9
18/02/2017	11:00:10	35.2	35.5	36.0	35.5
18/02/2017	11:25:00	116.8	119.9	116.2	37.3
18/02/2017	11:30:00	136.7	135.6	134.5	36.8
18/02/2017	11:35:00	153.8	150.7	149.5	38.5
18/02/2017	11:40:00	168.2	163.7	161.8	37.4
18/02/2017	11:45:00	179.7	173.7	171.0	38.6
18/02/2017	11:50:00	189.1	181.8	178.5	38.7
18/02/2017	11:55:00	197.1	188.2	184.2	38.6
18/02/2017	12:00:00	202.0	193.3	188.4	39.2
18/02/2017	12:05:00	205.7	196.2	191.3	39.1

Date	Time	T1	T2	T3	T4
18/02/2017	14:25:00	74.2	75.4	73.4	39.7
18/02/2017	14:30:00	95.7	90.8	91.4	40.4
18/02/2017	14:35:00	119.5	114.4	112.2	39.3
18/02/2017	14:40:00	140.1	134.4	130.0	41.0
18/02/2017	14:45:00	157.2	150.8	145.5	40.6
18/02/2017	14:50:00	171.1	164.0	158.4	41.5
18/02/2017	14:55:00	182.3	174.5	168.2	39.6
18/02/2017	15:00:00	189.4	182.5	176.3	39.6
18/02/2017	15:05:00	196.8	188.7	182.4	39.6
18/02/2017	15:10:00	202.6	193.5	186.7	39.6
18/02/2017	15:15:00	207.4	196.8	190.2	40.7
18/02/2017	15:20:00	210.8	199.3	192.5	40.0



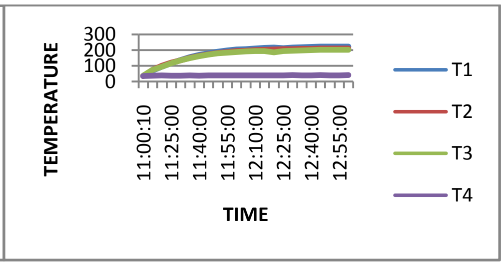


Fig-9: stagnation test(1). **Fig-10: stagnation test(2).**

4.2 System Heat loss Test

All the assembly was preheated in the solar radiations for 4 to 5 hours for to get heated. Then evacuated tubes were covered to prevent heat gain from sun in the time of the day. Two hours temperature readings were taken. Temperature profiles were plotted for heating as well as cooling for finding out heat loss coefficient. If density of the liquid is ρ, Volume of the tank is V_T, T_f is final average temperature of the system. T_i is final average temperature of the system. T_0 is ambient air temperature. Time span is represented by (t2-t1) which in our case was two hours

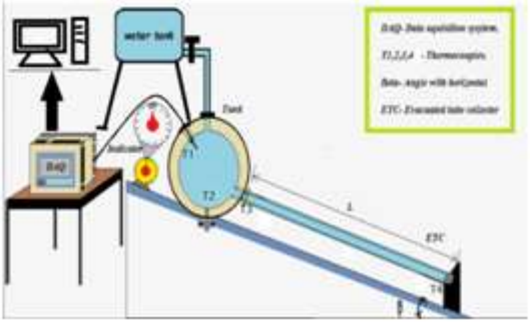


Fig-11:System Heat Loss.

$$U_{loss} = \frac{\rho V_T C_f \ (T_f - T_i) \ln\left\{\frac{T_i - T_0}{T_f - T_0}\right\}}{(t2 - t1)} \ldots (1)$$

. The formula used for calculations requires following properties to be known of the liquid.

1. Density of the liquid water. Assumed to be constant 1000 kg/m3
2. Volume of the liquid bulk
3. Specific heat of water also constant for given temperature range
4. Initial and final temperatures of the bulk and ambient average temp.

Various temperatures at instances are averaged throughout the setup. Ambient temperature was averaged over given span of time of conduction of the test. There are two ways to find out the heat loss coefficient viz. either we can apply transient analysis or can use standard formula for calculation of heat loss coefficient as proposed in standard procedure of ISO9459-2, 1995. Second way is to find useful heat gain rate during day from reference [1] et. al. Morrison and then subtracting it from irradiation to get heat lost during heating. First procedure seems to be easier from experimentation point of view hence first procedure was adopted in order to calculate heat loss coefficient.

Table-3:Heat loss coefficient for 45 degree. Fig-12: Heat loss test graph 45 degree.

Date	Time	T1	T2	T3	T4
22/03/2017	17:05	62.5	61.1	58.4	53.5
22/03/2017	17:10	61.7	60.8	58.4	53.4
22/03/2017	17:15	61.4	60.5	58.4	53.4
22/03/2017	17:20	60.8	60.2	58.4	53.4
22/03/2017	17:25	60.4	60.1	57.6	53.3
22/03/2017	17:30	60.0	59.7	57.5	53.1
22/03/2017	17:35	59.9	59.4	57.2	53.1
22/03/2017	17:40	59.6	59.5	57.1	53.0
22/03/2017	17:45	59.3	60.0	57.0	52.7
22/03/2017	17:50	59.1	59.0	56.9	52.6

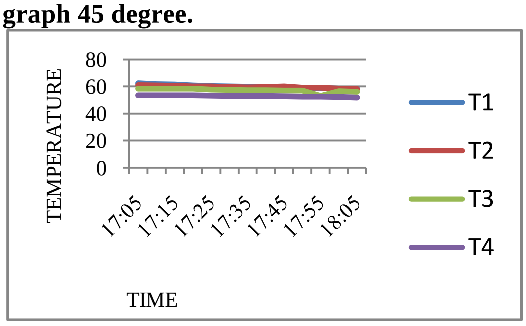


Table-4:Heat loss coefficient for 30 degree. Fig-13: Heat loss test graph 30 degree.

Date	Time	T5	T6	T7	T8
22/03/2017	17:05	63.2	62.2	62.8	57.3
22/03/2017	17:10	62.5	61.8	62.7	57.5
22/03/2017	17:15	62.3	61.6	62.6	57.6
22/03/2017	17:20	62.0	61.4	62.3	57.6
22/03/2017	17:25	61.6	61.6	62.1	57.5
22/03/2017	17:30	61.5	60.9	62.1	57.4
22/03/2017	17:35	61.2	60.8	61.7	57.3
22/03/2017	17:40	61.0	60.4	61.6	57.3
22/03/2017	17:45	60.7	60.2	61.4	57.0
22/03/2017	17:50	60.5	60.0	61.3	56.9

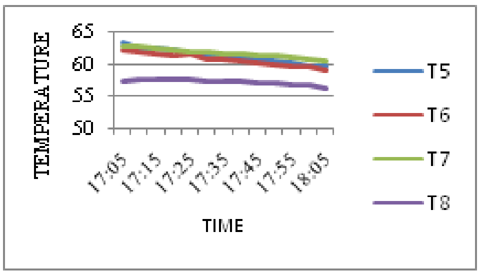


Table-5:Heat loss coefficient for 15 degree. Fig-14: Heat loss test graph 15 degree.

Date	Time	T9	T10	T11	T12
22/03/2017	17:05	63.7	63.8	64.8	57.8
22/03/2017	17:10	63.8	63.8	64.6	58.1
22/03/2017	17:15	63.4	63.4	64.3	58.1
22/03/2017	17:20	63.5	63.5	64.2	58.1
22/03/2017	17:25	63.0	63.1	64.0	58.0
22/03/2017	17:30	62.8	63.0	63.9	57.9
22/03/2017	17:35	62.5	62.6	63.5	57.9
22/03/2017	17:40	62.3	62.3	63.4	57.7
22/03/2017	17:45	62.1	62.3	63.1	57.7
22/03/2017	17:50	61.8	61.9	62.9	57.4

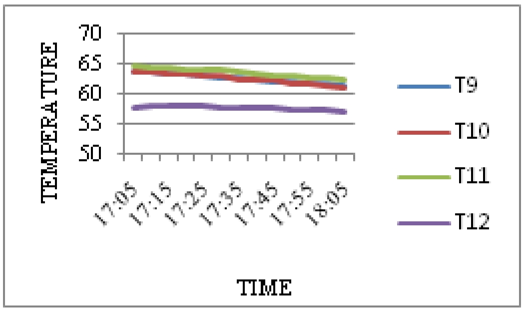


Table-6: Heat Loss Coefficient Of System.

Test no	Duration (hrs)	T_{iavg} (^{0}c)	T_{favg} (^{0}c)	U_{loss} (W/K)
1	1	56.69	54.41	2.263
2	1	60.37	58.52	1.286
3	1	61.60	59.78	1.186

5.RESULTS OF THE EXPERIMENT

The temperature characteristics are plotted based on the observed readings from experimental set-up facing southdirection**.**

DAY 1:On 29 Mar 2017

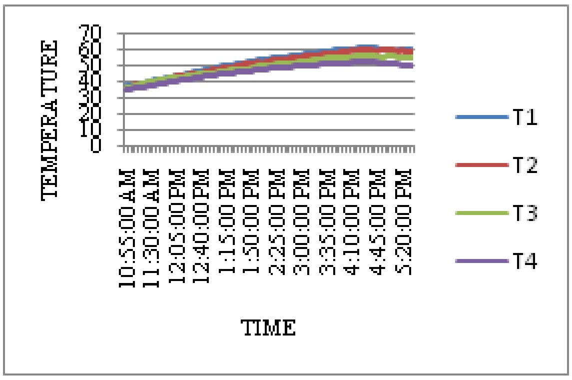


Fig-15:Temperature characteristic at 45 degree.

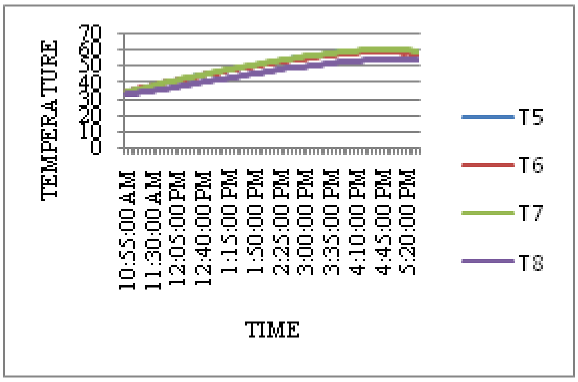


Fig-16:Temperature characteristic at 30 degree.

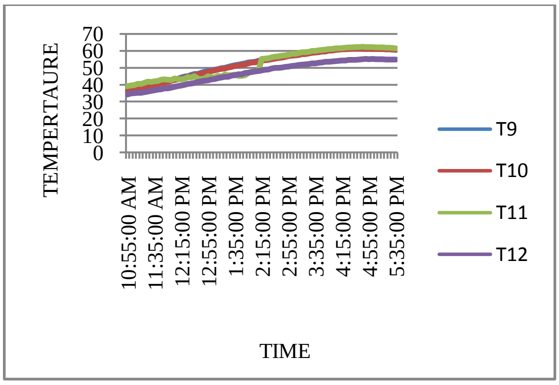


Fig-17:Temperature characteristic at 15degree.

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DAY 2:On 1st april 2017

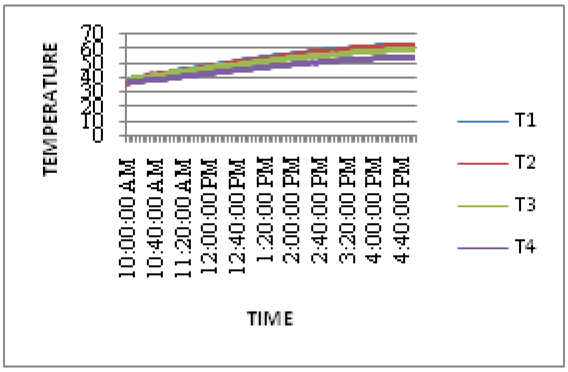
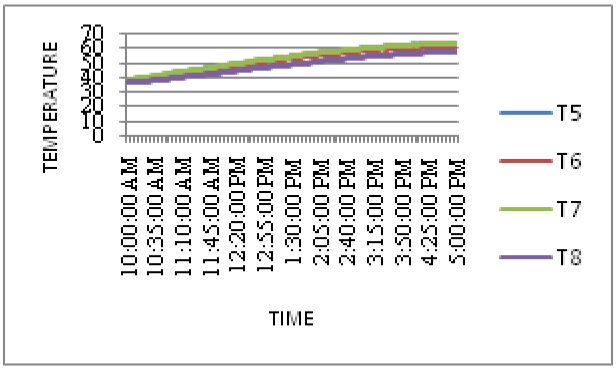


Fig-18:Temperature characteristic at 45 degree



.Fig-19:Temperature characteristic at 30degree.

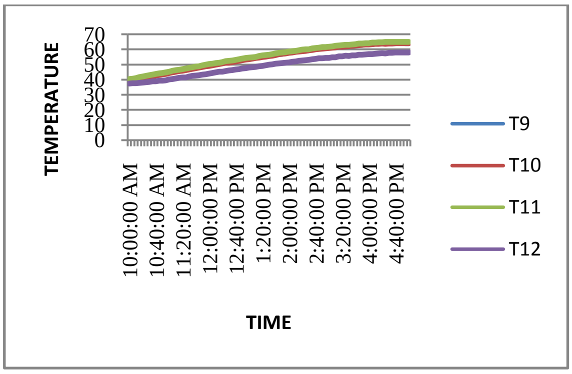


Fig-20:Temperaturecharacteristic at 15 degree.

6. CONCLUSION

The temperature characteristics obtained as a result of the experiment show that the performance varies with respect to angle of inclination. The data collected during the experiment shows the highest values of water temperatures for lesser inclination angles (15 degree) at earlier stages of the experiment.The Heat loss coefficient is constant for all the three tubes, as shown from the graph (Fig no 12,13,14) hence all systems of tubes are uniform. For 15 degree system it is seen that temperature at the open end of the tube is maximum as compared to other loactions. Hence for smaller angles stagnation zone inside the tank is more dominant. On the other hand, for 45 degree system the initial variation shows higher departure of temperature for closed end of tube as compared to other locations. Hence stagnation zone is more dominant inside the tubes at higher angles.

FUTURE SCOPE

Further performance can be enhanced by using Owen illuinios tube inside the evacuated tube collector, which will eliminate stagnation zone fromthe system. Simulation of the Test Setup can be carried out to validate the results by using CFD software.

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