PERFORMANCE EVALUATION & ANALYSIS OF LOW COST PARABOLIC DISH TYPE SOLAR COLLECTOR FOR DOMESTIC & INDUSTRIAL HEATING APPLICATION

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ABSTRACT

From Indian perspective there is a large potential available for low cost solar water heating systems. With above system we can instantly fulfil needs of hot water in industrial sector. Concentrated solar collectors have high efficiency. Therefore for water heating application, we can achieve high efficiency. We used parabolic dish collector for instant water heating that can be used as a boiler feed water. Also this type of system is used for instant water heating in domestic applications. System consist of parabolic dish of 1.4 m diameter .It is made of anodised aluminium mirrors & supported with locally manufactured steel stand. This paper revels prototype design of solar parabolic dish collector with truncated cone shaped helical coiled receiver made up of copper & coated with nickel chrome at focal point. The concentrator receives approximately 1.064 kW/m^2 of solar insolation with geometrical ratio of 21 (dependent upon time of year), which is concentrated and reflected to the receiver. Instantaneous collector efficiency of 68% was achieved with above described system.

This prototype was evaluated for its performance during month of April & May 2010.

KEY WORDS: *Solar energy, instant water heating, truncated cone shaped helical coiled receiver, concentration ratio, standard test conditions, high efficiency,*

INTRODUCTION

The concentrated solar thermal energy system is designed and constructed with the conventional parabolic concentrator with the receiver placed along the line between the center of the concentrator and the sun. The receiver used was coiled helically with specific design so that all the solar rays concentrated at center were received without shadow. Manual tracking was used during evaluation stage. This allows for effective collecting and concentrating of the incoming solar irradiation. The concentrator receives approximately 1.064 kW/m^2 of solar insolation (dependent upon time of year), which is concentrated and reflected to the receiver. By concentrating the incoming radiation, the operating temperature of the system increases significantly and subsequently increases the efficiency of the conversion.

NEED OF RESEARCH IN LOW COST PARABOLIC DISH SOLAR WATER HEATER:

1. Hot water can be made instantly available within short period of time
2. Reduction in the quantity of material & material cost required for the collector

3. Increasing the rate of water heating

4. Reduction in heat losses & to increase efficiency of total system.

5. Production of significant amounts of high-temperature heat for industrial processes.

DESCRIPTION OF SYSTEM USED:

System consist of parabolic dish of 1.4 m diameter .It is made of anodised aluminium mirrors & supported with locally manufactured steel stand. At focus truncated cone shaped helical coil, made up of copper is fitted & it is coated with nickel chrome. Inner & outer diameters of hollow receiver coils are 5.0 mm & 5.1mm respectively. The spacing between two coils is 5 mm & angle of helix is 5°. Inlet & outlet pipes made of high temperature & pressure PVC are attached to coil. Inlet water flow is controlled by using inlet valve & hot water at outlet is collected in insulated tank. Flow rate of water is 0.5 litres per min. Thermocouples are used to measure the temperatures of inlet & outlet water, receiver surface temperature. Wind speed is measured using anemometer & solar radiation is measured by using Pyranometer. This prototype was evaluated for its performance during month of April & May 2010 under standard test conditions.

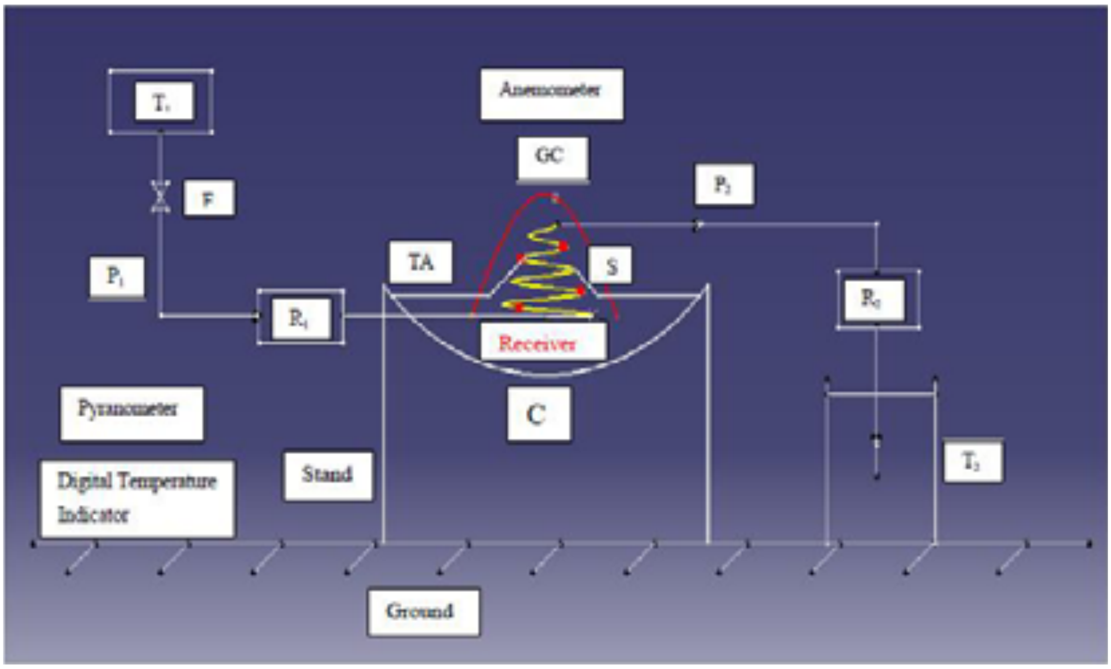

Figure 1 Schematic Diagram of Test Set up and Instrumentation

T_1 –Cold water supply tank at inlet
T_2 - Hot water storage tank at outlet
P_1- High temperature & pressure flexible pipe at inlet
P_2- High temperature & pressure flexible pipe at inlet
R_1-Rotameter for measurement of inlet flow
R_2- Rotameter for measurement of outlet flow
F-flow control valve at inlet

TA –Tracking axis of collector
C –Parabolic dish collector
GC-Cylindrical shaped Glass cover on receiver
S- Wooden supports for receiver
-Thermocouple for measuring receiver surface temperature

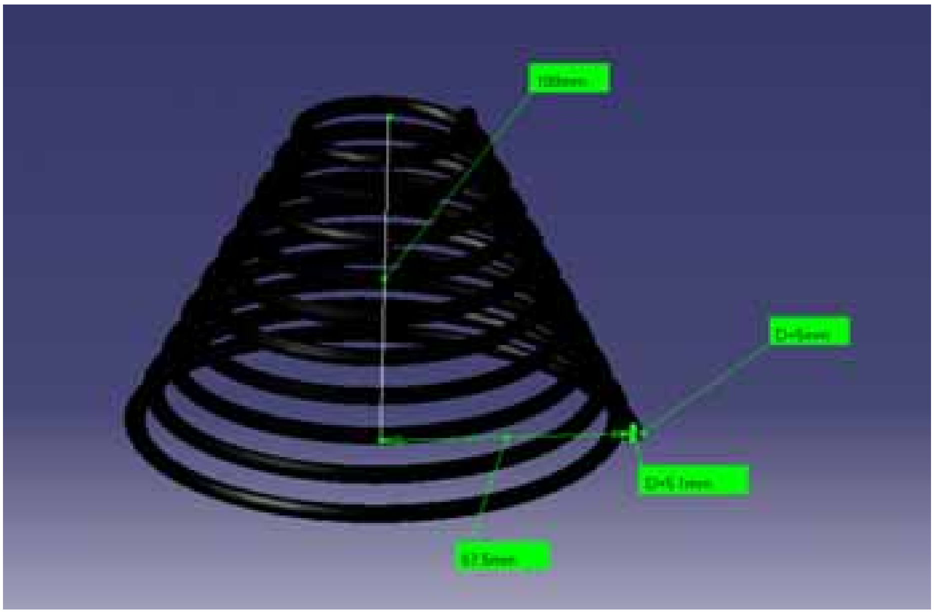

Figure 2 Receiver (with black Nickel chrome paint coating)

Sr. no	Name of component	Dimension
1	Diameter of Parabolic dish	1.4 m
2	Thickness of mirror of Parabolic dish	2mm
3	Reflectivity of Parabolic dish	0.86
4	Depth of Dish	0.38 m
5	Focal length of dish	0.3223 m
6	Surface area of parabolic dish collector	1.9295 m^2
7	Aperture area of parabolic dish collector	1.54 m^2
8	Diameter of receiver at bottom	0.135 m
9	Diameter of receiver at top	0.095 m
10	Mean Diameter of receiver	0.115 m^2
11	Surface area of receiver	0.2357 m^2
12	Effective length of receiver coil	3.96 m
13	Thermal conductivity of copper (W/m k)	384
14	Density of copper (gm/cm^3)	8.9
15	Melting point of copper (°C)	1083
16	Specific gravity of copper	8.9
17	Absorptivity-transmitivity product of copper	0.7
18	Emissivity of copper	0.725
19	Absorptivity-transmitivity product of coating	0.94
20	Emissivity of coating	0.10 - 0.14

Table 1.Parameters of system used for experimentation

EXPERIMENTAL PROCEDURE

The schematic of the experimental set-up is shown in Figure.1. It consists of a cavity receiver supported by support. The receiver is kept vertically upright with respect to the horizontal. The cold water circulated in the receiver is supplied from a water tank of 100 litre capacity. The working fluid is circulated through the receiver tubes by gravity. A rotameter at inlet measures the mass flow rate of cold water entering the receiver. The cold water is circulated at constant inlet temperature through the receiver. The temperatures of the fluid in the tube at four locations (including the outlet) are measured using K-type thermocouples. The flow is kept constant for the complete period of an experimental run on a given day. The system is operated under open loop condition as the water exiting from the receiver is not circulated back to the inlet cold water supply tank. The hot water is stored in an insulated tank at the near the outlet. The wind speed measurements are taken at a fixed location near the parabolic dish collector plane. The wind blows in the direction normal to the receiver & also the direction of the wind is parallel to the receiver.

All the measuring instruments used in the experiments are calibrated. The working fluid is cold water and on experiment days inlet temperatures varies between 23°C and 27°C. For each test, the inlet fluid temperature is measured using thermocouple. The working fluid enters and exits the receiver as shown in Fig.1. The working fluid inlet is at the bottom portion of the receiver and flows through the helically coiled receiver & leaves receiver at the uppermost portion. This is to ensure that the highest temperatures are at the top of the cavity receiver and lower temperatures near the concentrator. The flow rate of water is kept constant at on given day of experiment.

The solar radiations, tube temperatures and the fluid temperatures are measured at intervals of half hour and the experiment is continued till the solar radiation is available at sufficient intensity. The thermal losses are estimated at steady state. Helical coil as shown in Figure.2 representing the receiver with coating of black nickel chrome paint. For the experiments with black coated receiver, the region outside the cavity is surrounded by a downward facing cylindrical glass enclosure. The fluid inlet and the outlet tubes of the receiver are extended to the enclosure walls and are assumed to be adiabatic so that they do not affect the temperature and flow profile in the region external to the cavity. The material properties of air, working fluid used for the calculation are taken from S.P.Sukhatme (2009). The boundary conditions used for the numerical analysis are as follows:

(1) The fluid inlet temperature (at the receiver outlet) and the fluid velocity as specified.

(2) Enclosure walls are maintained at ambient temperature.

EXPERIMENTAL MEASUREMENTS

Table 2 below shows measurements for May 2010 at Shivaji University, Kolhapur, (Maharashtra, India)

Table 2 Experimental data

Time	wind speed (m/s)	T_{in} (ºC)	T_{out} (ºC)	ΔT (ºC)	T_{amb} (ºC)	Tr_{-avg} (ºC)	Beam radiation on collector (W/m²)	Optical Energy Captured by Receiver (W)	Overall heat loss coefficient (W/m²ºC)	Total heat Loss (W)	Useful heat gain by Water (W)	Collector Efficiency (%)
9:00	2.725	26	42	16	31	56	616.055	475.35324	6.2270801	36.6930	438.66017	71.20471
9:30	3.7	27	51	24	31	76	873.889	674.30009	7.4745583	79.2789	595.02119	68.08888
10:00	4.25	28	54	26	32	80.75	940.1357	725.41664	8.2408162	94.6900	630.72658	67.08889
10:30	5.175	29	50	21	32	65.75	765.1522	590.39791	9.3341971	74.2523	516.14555	67.45658
11:00	5.525	30	56	26	32	104	1061.868	819.34665	10.643559	180.625	638.72121	60.15069
11:30	3.8	30	64	34	33	114.25	1239.796	956.63668	7.8932902	151.161	805.47524	64.96839
12:00	4.275	31	60	29	33	107	1069.604	825.31534	8.5707814	149.489	675.82549	63.18466
12:30	4.25	31	48	17	33	63.25	590.5721	455.69038	7.9395254	56.6082	399.08217	67.57552
13:00	5.2	32	50	18	33	60.25	649.2622	500.97622	9.0407042	58.0668	442.90937	68.21733
13:30	3.875	32	51	19	34	62.25	709.2396	547.25528	7.1740289	47.7684	499.48683	70.42568
14:00	6.025	33	61	28	33	67	1053.599	812.96556	9.9416384	79.6703	733.29526	69.59911
14:30	5.2	33	64	31	33	73.25	1117.949	862.61851	8.6332586	81.9030	780.71544	69.83465
15:00	4.275	32	64	32	33	71	1065.195	821.91333	7.2012315	64.4985	757.41479	71.10575
15:30	3.1	32	63	31	32	67.25	957.3196	738.67589	5.4091385	44.9414	693.73447	72.46634
16:00	4.475	31	57	26	32	62	801.261	618.25976	7.5176983	53.1576	565.10212	70.5266

RESULTS & DISCUSSION

Fig.1 below shows variation of useful heat gain by water, overall heat loss & optical energy captured by receiver throughout the day. It is observed that as the beam solar radiation incident on the collector increases, more optical energy is captured by the receiver.

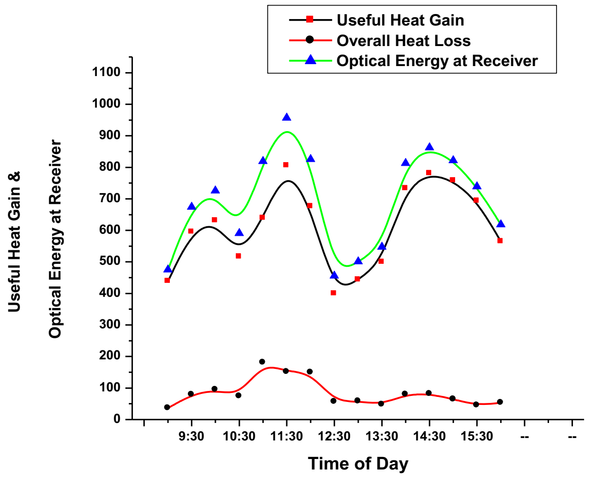

Figure 3 Variation of Useful Heat Gain, Optical Energy at Receiver & overall heat loss throughout the Day

Figures 4 & 5 below shows variation of collector efficiency with convective heat loss & convective heat loss coefficient. Higher the wind speed, higher will be convective heat loss & lower will be the collector efficiency at instant. Radiative heat losses are very small, so their effect on collector efficiency is very less.

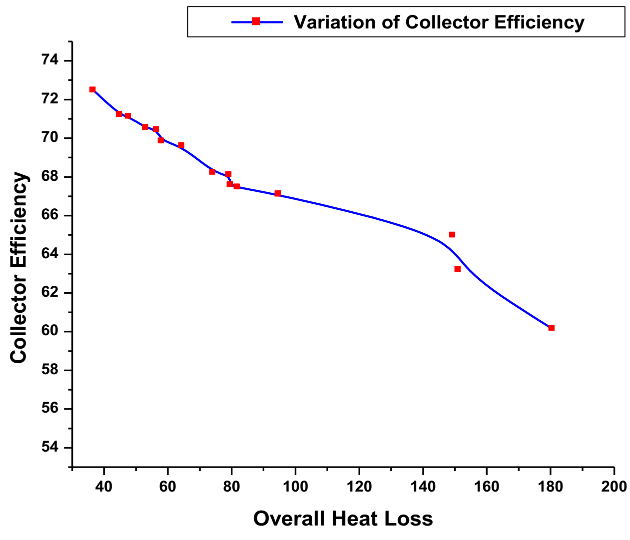

Figure 4 Variation of Collector Efficiency with Overall Heat Loss

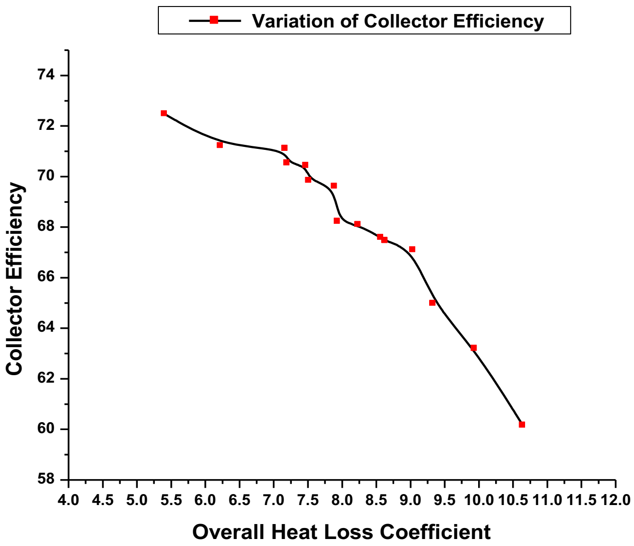

Figure 5Variation of Collector Efficiency with Overall Heat Loss Coefficient

Figures 6 & 7 below shows variation of overall heat loss with average receiver temperature & variation of convective heat loss coefficient with wind velocity .This variation plotted shows that as receiver surface temperature increases , it increases thermal conductivity of air surrounding the receiver, and hence therefore a increases convective & radiative heat losses from receiver. An average receiver temperature was determined to provide accurate receiver loss predictions. Also wind velocity affects the variation of convective heat loss coefficient. From variation plotted, it is clear that as wind velocity increases the convective heat transfer coefficient increases.

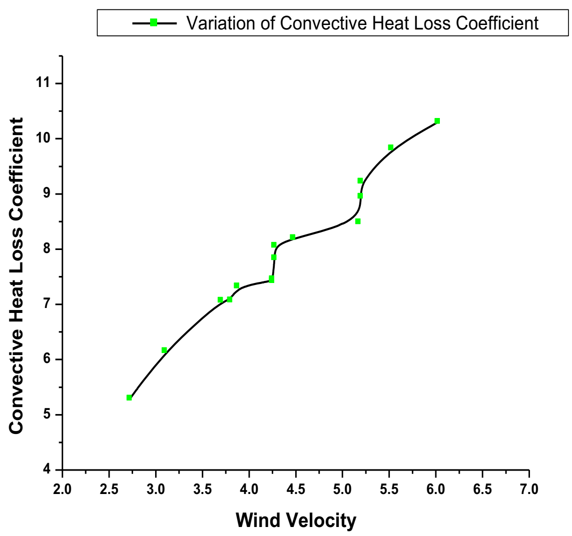

Figure 6 Variation of Convective Heat Loss with Wind Velocity

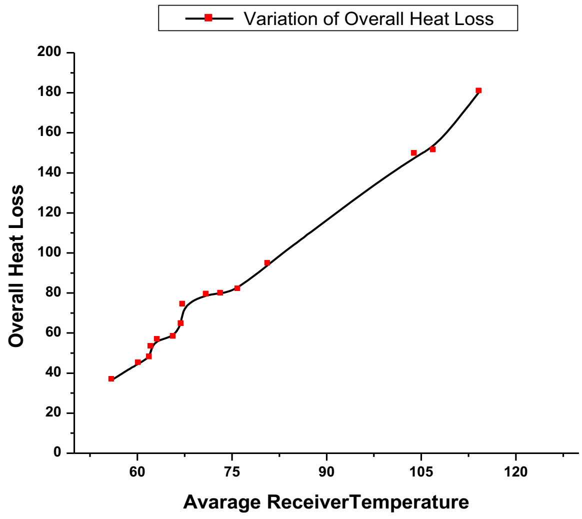

Figure 7Variation of Overall Heat Loss with Average Receiver Temperature

Figures 8 & 9 below shows variation of collector efficiency with wind velocity throughout the day. Wind velocity at instant adversely affects the efficiency of collector. Higher the wind speed, higher will be convective heat loss & lower will be the collector efficiency at instant.

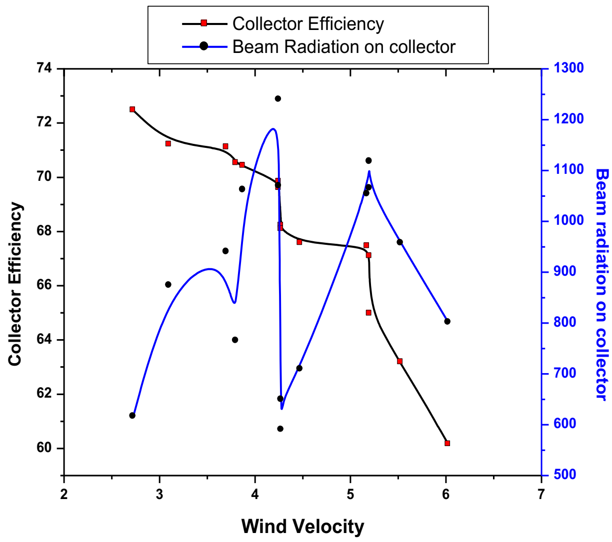

Figure 8 Variation of Collector Efficiency, beam radiation with wind Velocity throughout the Day

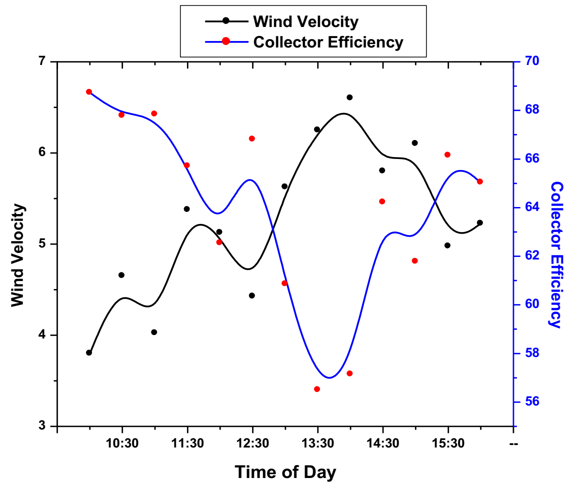

Figure 9 Variation of Collector Efficiency & Wind Velocity throughout the Day

Figure 10 shows variation of direct or beam solar radiation throughout the day with average receiver temperature. An analysis was performed to determine the variation in the average cavity receiver temperature with insolation. It is observed that as the beam solar radiation incident on the collector increases, more optical energy is captured by the receiver.

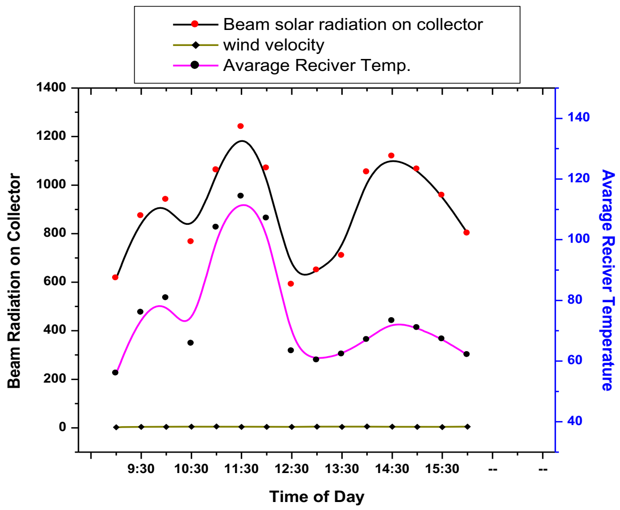

Figure 10 Variation of beam radiation on collector, average receiver temperature & Wind Velocity throughout the Day

CONCLUSION:

From Indian perspective there is a large potential available for low cost solar water heating systems. With above system we can instantly fulfil needs of hot water in domestic as well as industrial sector. Also this type of system helps for reducing deforestation in rural regions for hot water purpose. This system also helps to reduce electricity bills in urban area.

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ABBREVIATIONS & SYMBOLS USED:

$\mathbf{T_{amb}}$ = Ambient temperature

$\mathbf{T_{air}}$ = Temperature of air

$\mathbf{Q_{loss}}$ = Total heat loss from receiver

$\mathbf{Q_{opt}}$ = Optical Energy Captured by Receiver

$\mathbf{Q_{useful}}$ = Useful heat energy available a receiver that is used for water heating

$\boldsymbol{\eta_{Collector}}$ = Instantaneous Efficiency of collector

$\mathbf{T_{in}}$= Temperature water at inlet from storage tank

$\mathbf{T_{out}}$= Temperature of water at outlet

$\mathbf{Tr_{avg.}}$ =Average temperature of receiver

$\Delta T = T_{out} - T_{in}$ = Temperature difference between outlet water temperature & inlet water temperature generated instantly

List of Units:

°C- Celsius degrees (temperature)

°K -Kelvin degrees (temperature)

W –Watt

KW/m^2- Kilowatt per meter square

W/m^2 –Watt per meter square

$W/m^{2o}C$- Watt per meter square per degree centigrade