Analysis of Solar Steam Generation Device and Effect of Black Coating for Receiver

Mr.Shashikant G. Mane [1] Prof. P.R. Sawant [2],Prof.N.N.Shinde[3]

[1]Reaserch student Energy Technology, Department of Technology, Shivaji University, Kolhapur, Maharashtra, India
[2] Rajarambapu Institute of Technology, Sakharale, Islampur, Maharashtra, India
[3] Energy Technology, Department of Technology, Shivaji University, Kolhapur, Maharashtra, India

---***---

Abstract - This paper presents the present scenario of solar water heating system and Solar Concentrated Power. From study it is observed that there is no any device which can be used for the generation of high temperature water or low temperature steam. At present flat plate collectors are used to heat the water. Flat plate collectors cannot achieve high temperature which is sufficient for steam generation. As present system unable to provide the steam the steam generation device will play a role to increase percent of solar energy in industrial process heat. If CSP is used for water heating the boiling temperature and the steam generation can be achieved with the help of solar energy. This steam can be directly used for various low pressure applications. Also in the Solar Steam generating device if Black Coating is done for receiver it improves the efficiency of system and output energy of the steam. Black epoxy coating improves the absorptance of the receiver surface and thus increase the amount of energy absorbed which reflects on it by collecting surface. Simultaneously temperature of the system improves which causes to increase the convective losses from the system. But due to improved energy absorptance this increment doesn't affect the efficiency worst. This type of coating can improve the efficiency of the system. Thus one can achieve improved quality of output steam. Paper presents the actual development of device, testing and analysis of the test results. Paper also explains the experimental results which show the effect of black coating for receiver on the efficiency and energy collected by the system.

Key Words: *Concentrated Solar Power (CSP), Solar Water Heating, Steam generation, Black epoxy coating to improve efficiency of system .*

1. INTRODUCTION

Concentrated solar is type of solar system which allows the effective collecting and concentrating of the incoming solar irradiation. The concentrator receives approximately 1.064 kW/m2 of solar insolation (dependent upon time of year), which is concentrated and reflected to the receiver with less area. By concentrating the incoming radiation, the operating temperature of the system is increased significantly, and subsequently increases the efficiency of the conversion from sunlight to thermal energy.

At present, there are four main CSP technology families, which can be categorized by the way they focus the sun‟s rays and the technology used to receive the sun's energy:

1. Parabolic Troughs (Line Focus, Mobile Receiver)
2. Linear Fresnel Reflectors (Line Focus, Fixed Receiver)
3. Solar Towers (Point Focus, Fixed Receiver)
4. Parabolic Dishes (Point Focus, Mobile Receiver)

The basic principle of solar thermal collection is that when solar radiation is incident on a surface (such as that of a black-body), part of this radiation is absorbed, thus increasing the temperature of the surface. As the temperature of the body increases, the surface loses heat at an increasing rate to the surroundings. Steady-state is reached when the rate of the solar heat gain is balanced by the rate of heat loss to the ambient surroundings.

Two types of systems are used to utilize this solar thermal conversion.

1) Passive systems

Passive system is considered, in which an external solar collector with a heat transfer fluid is used to convey the collected heat.

2) Active systems

Active system doesn't need any additional working fluid or the system required to circulate it.

As present system unable to provide the steam the steam generation device will play a role to increase percent of solar energy in industrial process heat. Concentrated solar system is not used in the domestic sector. With application of proposed system solar concentrator can applicable with the domestic use. It is also found that, parabolic dish collectors installed in various locations in India are used for solar steam cooking applications. When this two system are combined they can be useful for various industrial sector where low pressure steam is used for various processes. These applications are briefly shortlisted below.

Table 1 Industrial Applications of Low pressure Steam

Industry	Pressure (bar)	Flow Rate (kg/hr)
Bakeries	1	10
Restaurants	1	100
Hospitals	3	150
Paper Production	1	7
Creameries and Dairies	0.3 – 3	200

It can overcome the drowback of traditional solar water heater. It can supply steam at required pressure for end use.However the efficncy of convertion for economical industrial application is needed .

2. Design and Development of the system

Methodology for system design

1. Material selection consideration for various system components
2. Material selection based on the availability and working conditions
3. Detailed theoretical design for of the each components
4. Specification finalization for the system with modification from practical constraints
5. Proposed system details
6. System after manufacturing

Material Selection

Materials for all components are selected as per the standard guidelines for the material selection for solar concentrating and stem generation devices. Important selection is for black coating to improve the efficiency of the system.

Black epoxy paint used for the receiver coating. Black coating improves the radiation absorbance of the receiver plate. Thus experiments are carried out for receiver with black coating and receiver without black epoxy coating.

a. Absorbance-Transmittance factor for black pint
b. Optical and thermal properties of the paint

Design details and proposed system:

Load on the system to be designed is finalized based on the system output requirement and depending steam quality required.

Final Specification of the System parameters
Amount of water to be converted into steam = 1.5 kg/hr
Minimum pressure at which steam is extracted from the absorber = 1.5 bar
Maximum pressure at which steam is allowed to heat = 3.0bar
1. Finalize the Specification for the Concentrator dish
Surface area of the Concentrator dish = 1.54 m2
Focal length of the concentrator dish = 0.3223 m
2. Finalize the specifications for the absorber cylinder
Minimum internal diameter of the absorber cylinder = 190mm
Minimum Height of the absorber cylinder = 130mm
Minimum thickness of the absorber cylinder = 2.235mm

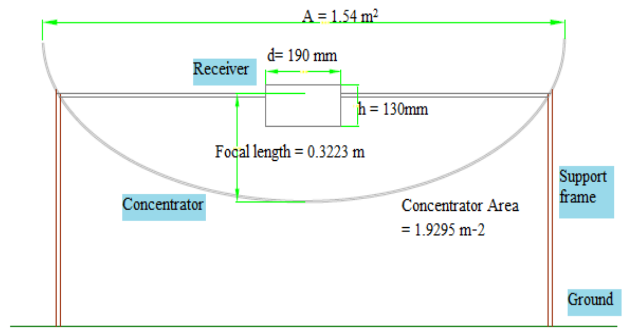


Figure 1: Design details and proposed system

Figure 2: System Details for Steam generation device

3. Use of Black Epoxy coating

Selection of the coating for the receiver surface is based on the following conditions. The selected coating surface should consider the following properties.

a) eceiver should be good absorber of heat energy
b) Receiver should have high thermal conductivity
c) eceiver should have low thermal resistance
d) eceiver should not be corrosive
e) eceiver should withstand high temperature

Black epoxy paint used for the receiver coating. Black coating improves the radiation absorbance of the receiver plate. Thus experiments are carried out for receiver with black coating and receiver without black epoxy coating.

a. Absorbance-Transmittance factor for black pint
b. Optical and thermal properties of the paint

Value of Absorbance-Transmittance factor for the receiver surface without black coating is

$\rho_{AL} \times \alpha_{AL} = 0.7$.

Simultaneously this value for Black Coating is

$\rho_{BC} \times \alpha_{BC} = 0.94$.

From this values the difference between collected energy can be find out which will be higher for the receiver with black coating. So the receiver temperature and usefull energy gain will increase for black coating.

4. Testing and Performance Evaluation

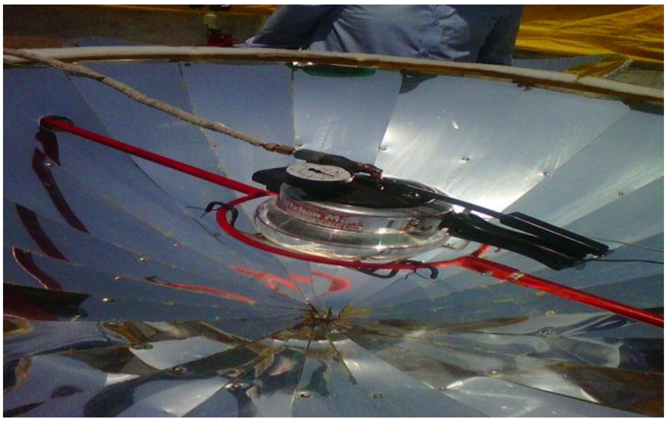


Figure 3: Experimental Setup for Testing of system without black coating

Testing Methedology

The system specifications are finalized for 1.5 liter of water heating with aluminum absorber, vertical cylinder type. A cooker made of Aluminum with the given dimensions is fitted at the focal point of reflector which will fall below the top horizontal surface, so as to enable to fix the top glass cover during the experimentation. The schematic is shown in figure 2.

1. Concentrating solar collector -with Aluminimium-without coating absorber CSC-A with 1.5 liter water capacity
2. Concentrating solar collector -with Aluminimium-with absorber Coating CSC-A with 1.5 liter water capacity

Figure 4: Receiver surface with black coating

Performance Evaluation of the Proposed System

Theoretical performance analysis of the system can done one basis of the theory developed as follows. One has to calculate total available energy and total losses in the system to calculate the performance of the system. Methodology for the performance evaluation can explained as follows

1. Calculate the Total solar radiations available at the plane of the system.
2. Find out the total energy collected by the concentrator
3. Calculate total amount of heat loss at receiver
4. Calculate total amount of heat loss in steam piping
5. Evaluate the performance of the system in the form of collector efficiency and system efficiency.
6. Proposed parameters that have to be recorded for performance evaluation in experimental method.

Formulas for performance evaluation

1. $Q_{OPTAINED} = \Gamma \times (\rho_{AL} \times \alpha_{AL}) \times E_{INC}$

Γ =capture fraction for receiver

$\rho_{AL} \times \alpha_{AL} = 0.7$ = reflectance absorptance product for receiver material.

2. $Qloss = Ar \times Ul \times (Tr - Ta)$

Ar = Area of receiver

U_l = Overall Heat loss coefficient

T_r = Receiver temperature

T_a = Temperature of air surrounding a receiver

3. $U_l = h_{conv} + h_{rad}$

h_{conv} = Convective heat loss coefficient

h_{rad} = Radiative heat loss coeffiecient

4. Collector efficiency $\eta_{collector} = \frac{QOPTAINED - QRECEIVER\ LOSS}{Ibc}$

5.Collector efficiency

$\eta_{collector} = \frac{Qoptained - (Qreceiver\ loss + Qpipe\ loss)}{Ibc}$

Data is collected for both of the test setups and above specified calculations are carried out. From this calculations and detailed data analysis following reading is found.

Table 2 results for Experiments on system efficiency

Case	Average Solar Radiation	Temperature		Steam Pressure		Time to achieve 1.5 bar (min)	System efficiency (%)
		Receiver surface	Steam inside receiver pot	Maximum Achieved	Average		
Case 1A	1100	155	140	1.92	1.7	30	51.00
Case 1B	975	125	120	1.68	1.5	30	52.00
Case 2A	950	160	135	3.1	3.0	20	72.00
Case 2B	900	150	110	2.0	1.8	15	72.00

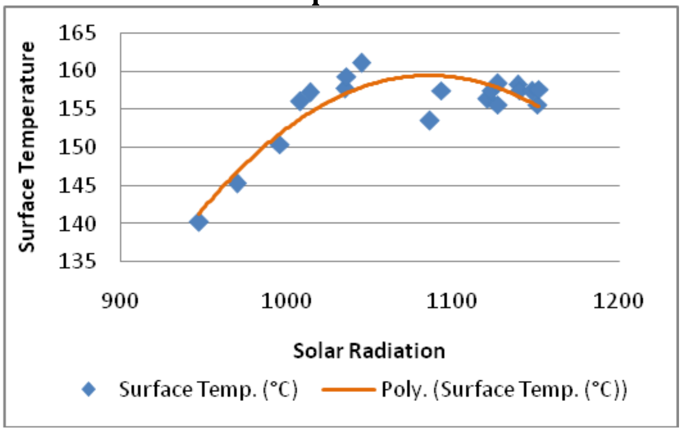
5. Effect of Black Epoxy coating

Black coating on receiver increases the energy absorbed by the receiver. Receiver without coating has the reflectance absorptance product of 0.7. Same value for the receiver with black coating is equal to 0.94. This increase in absorptance- reflectance factor causes nearly 30 % increase in absorbed energy for the same amount of solar radiation.

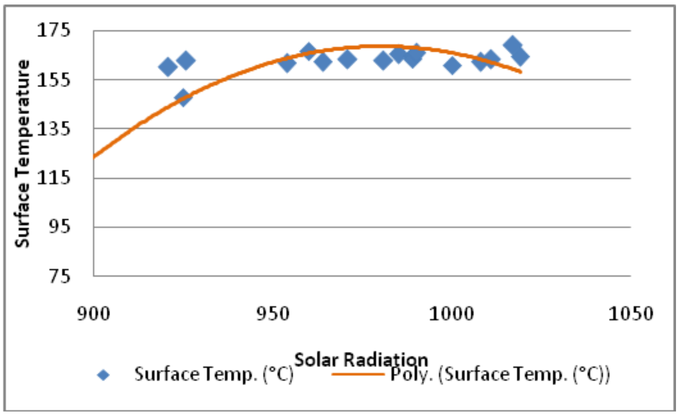
This effect can studied on the three basic criteria

1. Effect on temperature
2. Effect on Useful Heat Gain
3. Effect on System efficiency

Effect on Receiver Temperature



Graph 1: Temperature Vs Solar radiation for receiver without black coating.

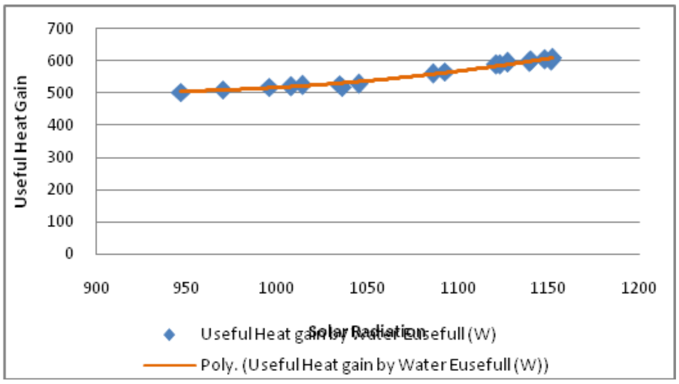


Graph 2: Temperature Vs Solar radiation for receiver with black coating.

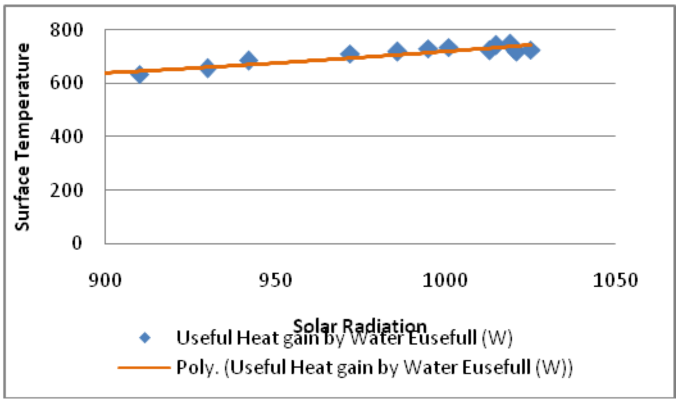
From the above graphs it can be seen that as one use the black coating for the receiver the surface temperature for the receiver increases.

1. Maximum and average surface temperature will be increased by 15°C -20°C.
2. Nearly 15% rise in surface temperature is observed.

Effect on Useful Heat Gain



Graph 3: Useful Heat Gain Vs Solar radiation for receiver without black coating.

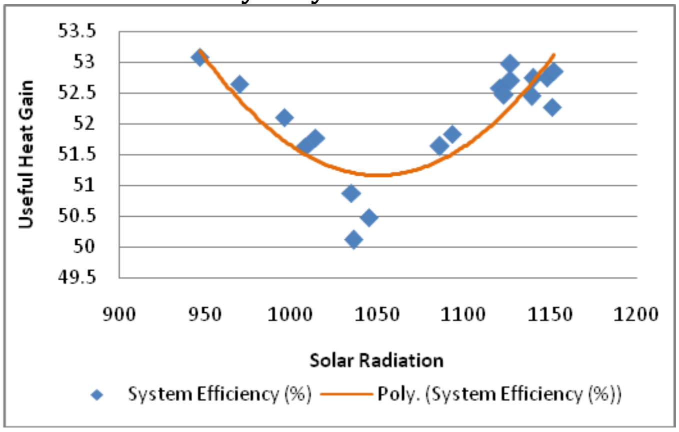


Graph 4: Useful Heat Gain Vs Solar radiation for receiver with black coating.

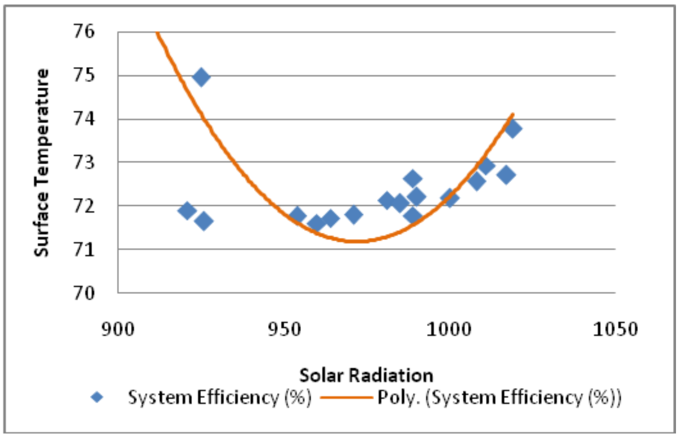
From the graph it is seen that as the radiation increases total heat gain also increases. The effect of glass cover total useful heat gain increases for same amount of solar radiation. If we consider the values of total useful heat gain for 1000 watt of solar radiation results are:

1. Without glass cover total heat gain for 1000watt solar radiation is nearly 550 watt.
2. With glass cover same value will be nearly about 700 watt.
3. Thus one can conclude that total heat gain will increase by 25%-30% at the 1000 watt solar radiation.

Effect on Efficiency of System



Graph 5: Useful Heat Gain Vs Solar radiation for receiver without black coating.



Graph 6: Useful Heat Gain Vs Solar radiation for receiver with black coating.

Effect of black coating on the system efficiency for receiver without glass cover is shown in the graphs.

1. Average efficiency for receiver without black coating is nearly 51-54%
2. Average efficiency for receiver with black coating is nearly 71-74%
3. Average increase in efficiency is 20%, efficiency becomes 1.4 of actual value due to black coating.

6. Results and Conclusion

It is observed that a system producing steam for solar heating of water will be very useful in the industrial and commercial sectors. This system can help to reduce the load on the electrical and Fossil fuel energy used to steam generation. Also with the help of black coating it is easy to achieve boiling temperature as well as to improve the efficiency of the system. . Receiver surface temperature increases by 27 % as compared non coated receiver, it increases thermal conductivity of air surrounding the receiver, and hence therefore a increases convective & radiative heat losses from receiver by 36 %. Thus overall heat loss from receiver increases by 36 %. With black coated receiver useful heat gain is increased by 10 % As compared to non coated receiver collector efficiency is increased by 17.5%For 36 % rise in total heat losses, collector efficiency is increases by 17.5 % & overall heat loss coefficient increases by 7.35 % as compared non coated receiver. Time taken to produce steam is also reduced with use of black coating. Black coating applied reduce time to produce steam is reduced from 30 min to 17min.

7. Recommendations

System described above can be optimized for following reasons System can be converted into continuous steam generation system with use of water pumping system and valves. It can be used to supply steam for instantaneous steam generation requirement. Performance improvement is possible with the experimental evaluation. Automatic tracking system either mechanical or hydraulic can be used. By variation of coating materials, performance of system can be evaluated. Heat losses in the steam pipe and steam generator can reduced with proper coating material. Commercial models can be designed. System is best suitable for various industrial and commercial applications along with domestic application.

8. References:

1. Atul A. Sagade (2012),"Experimental Investigation of Variation of Mass Flow Rate on the Performance of Parabolic Dish Collector with Nickel Chrome Coated Receiver".
2. Mr. Atul A. Sagade,(2013), "Effect of receiver temperature on performance evaluation of silver coated selective surface compound parabolic reflector with top glass cover", Energy Procedia 48 (2014) 212 – 222.
3. Sethuraman Ramasamy and Pakkirisamy Balashanmugam,(2015), IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 2, Issue 1, January 2015, ISSN 2348 – 7968.
4. Lacour Ayompe ET.AL. Thermal Performance Analysis of a Solar Water Heating System With Heat Pipe Evacuated TubeCollector Using Data From a Field Trial, 2013-04-01, School of Civil and Building Services Engineering.
5. P.Balashanmugam, G.Balasubramanian, K.Balasubramaniyan, Fabrication And Testing Of An Integral Compact Solar Water Heater, International Journal of Advanced Scientific and Technical Research Issue 3 volume 5, Sep.-Oct. 2013.
6. Mathew Job, The future water heating technologies, The Mechanist apr-jun 2013.

7. Shahidul Islam Khan, Asif Islam, Performance Analysis of Solar Water Heater, Smart Grid and Renewable Energy, 2011, 2, 396-398.
8. Sara Al-Beaini, Merwan Benhabib, Samantha Engelage, Adam Langton, Domestic Solar Water Heater for Developing Countries, Final Report,May 16, 2007.
9. Wolfgang Scheffler, Solare Bruecke, Graf Von Werdenbergst, Introduction To The Revolutionary Design Of Scheffler Reflectors, Www.Solare-Bruecke.Org.
10. Matthew Damon Mercer, Design, fabrication and analysis of thermal storage solar cooker prototype for use in Rajasthan, India, Theses and Dissertations, University of Iowa Iowa Research Online.
11. Fareed . M. Mohamed, Auatf.S.Jassim, Yaseen. H. Mahmood, Mohamad A.K.Ahmed, Design and Study of Portable Solar Dish Concentrator, International Journal of Recent Research and Review, Vol. III, September 2012, ISSN 2277 – 8322.
12. Gang Xiao, Manual making of a parabolic solar collector, 2011.
13. Charles Christopher Newton, Electronic Theses, Treatises and Dissertations, The Florida State University, DigiNole Commons.
14. Dr. Shireesh B. Kedare, ARUN Solar Concentrator for Industrial Process Heat Applications, 2010.