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# Design Optimization and Parametric Variation on Receiver of Scheffler Solar Concentrator

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**ABSTRACT**

**Parametric analysis of Scheffler Collector system is performed for improvement in thermal efficiency. Scheffler reflector of size 2.7 m$^2$ has been used for experimentation. In this system receiver was installed at focus point. Thermal efficiency of receiver is calculated on the basis of parameters like shape of receiver, initial heating of inlet water, tilting of receiver, and receiver with glass cover for steam pressure up to 3 bars. Cylindrical and Conical shape receiver of 8 litercapacity has been used for experiment which serves dual purpose of absorber and steam storage device. Cylindrical receiver has maximum efficiency 56.64% in case of initial heating of water (50$^o$C) and conical receiver has maximum efficiency 76.04% in case of tilting of receiver (45$^o$).Response surface method is used to optimize the thermal efficiency of receiver. A general mathematical model for thermal efficiency has been developed for both receivers. There is good agreement found between the experimental and predicted results.**

*Keywords*— **— Scheffler Collector,Thermal Efficiency, Response Surface Method ,Optimization**.

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## I. Introduction

Fixed focus concentrator was introduced in the country by Mr. Wolfgang Scheffler, a German Scientist, in 1990 have proved to be a mile stone in solar thermal energy utilization. The Scheffler dish was initially developed for direct cooking by concentrating solar energy in the kitchen but now the dishes are also used for generating steam and providing process heat. Scheffler collector system is good option for supplying medium (100$^{o}$C-250$^{o}$C) and high temperature (250$^{o}$C – 400$^{o}$C) process heat to industries for various applications such as solar cooling, washing an equipment etc.[11].

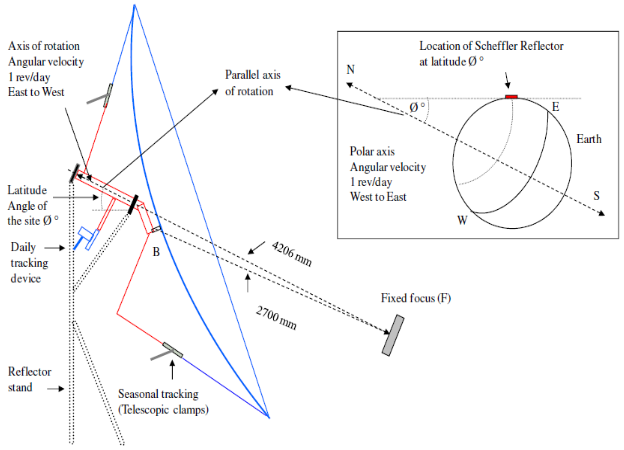


**Fig1: Installation and daily tracking details of Scheffler Reflector[1]**

In fixed focus Elliptical Dish often called as Scheffler Concentrator, the dish comprising of a large number of mirrors moves to reflect the sun rays to a fixed receiver which contains a working fluid to be heated. The working fluid is usually water which can be used as pressurized hot water or converted to steam. A suitable thermic fluid can also be used. Fig.1 shows, tracking mechanism of Scheffler Reflector. The dish can be manually or automatically tracks the sun in E-W direction from morning to evening is single axis tracked system. For seasonal tracking reflector position can be done manually by adjusting telescopic clamps. Scheffler dishes with automatic N-S direction adjustment have also been introduced in India. In a Scheffler collector system, a receiver is a significant component. Receiver is used for heating a water using solar thermal energy conversion and producing a steam for various process heat applications. The performance of Scheffler collector system depends on the thermal efficiency of receiver and thermal efficiency of receiver varies according to parameter like shape of receiver, incident solar radiation, inlet water temperature, wind velocity, tilt angle etc. Many research studies have been carried out for evaluating the performance of solar cavity receiver on the basis of above parameters. RupeshJ.Patil[4] carried out a thermal analysis on storage reservoir having 20 liter water storage capacity. In this case storage reservoir kept at focus point of 8 m$^2$ Scheffler reflector. It is found that average power and efficiency in terms of water boiling test to be 1.30 kW and 21.61% respectively, against an average value of beam radiations of 742 W/m$^2$.Vishal.R.Dafle[5] have done design, fabrication and performance evaluation for 2 bar pressure and 110$^{o}$C temperature cooking application using 16 m$^2$ Scheffler reflector. The Scheffler along with mild steel absorber plate of size, 18 cm diameter and 2.5 cm thick was evaluated for performance in month of February 2012 at composite climate zone. The overall efficiency achieved was 57.41 % which appears on higher side as compared to parabolic trough devices. MangeshPhate[9] studied the performance of portable Scheffler reflector by using response surface methodology. Tilting angle, processing time, water quantity are considered as performance factor. The experiment conducted based on these three factors, three-level, and central composite face centred design with full replications technique, and mathematical model was developed. Sensitivity analysis was carried out to identify critical parameters. The results obtained through response surface methodology were compared with the actual observed performance parameters. Thermal as well as optical loss affects the performance of solar collector system. Convective and radiative losses are the major constituents of the thermal losses. M.Prakash and S.B.Kedare[10] present an experimental and numerical study for investigation of steady state convective losses from downward facing cylindrical cavity receiver. In this case receiver is comprises of helical tube coil of length 0.5 m, internal diameter 0.3 m and wind skirt diameter of 0.5 m . It is found that convective loss increases with mean receiver temperature and decreases with increase in receiver inclination. The numerical study is performed for fluid inlet temperatures between 50$^{o}$C-75$^{o}$C and 100$^{o}$C-300$^{o}$C.Nusselt number correlations are also proposed for these fluid inlet temperatures based on experimental and predicted data. R. D. Jilte[6] performed numerical three-dimensional study of the natural convection and radiative heat loss from cavity receiver of different shapes with and without mouth-blockage have been investigated under isothermal wall condition. Convective heat loss is found to decrease for cavities having mouth blockage created by reducing aperture area (case I) whereas it enhances when mouth blockages are introduced by increasing the cavity dimensions and keeping the same aperture area (case II). Convective loss is characterized by using the convective zone area (Acb). Conical cavity yields the lowest convective loss whereas hetro-conical cavity gives the highest convective loss among different shapes investigated.The literature survey shows that the types of receivers investigated both experimentally and numerically are cavity receiver of cylindrical, conical and hetro-conical in shape. The receivers studied so far do not have plane cylinder and right circular cone shape. In this study Cylindrical and Conical shape receiver are comparatively studied for optimum performance on the basis thermal efficiency. The thermal analysis applied to optimize the Scheffler collector system and a detailed parametric analysis for determining the factors affecting the thermal efficiency. Scheffler solar concentrator of 2.7m$^2$ area has been taken for a study. Cylindrical and Conical shape receiver of 8 liter capacity has been used for experiment which serves dual purpose of absorber and steam storage device. The paper focused on the performance analysis of Scheffler collector system for thermal efficiency in terms of steam generating capacity test at Pune, India.

## I. Experimental Setup

The Scheffler collector system as shown in Fig 2. The system fabricated as per given specification. The main components of Scheffler Collector system is Scheffler Dish consists of reflecting glass plate mounted on the typical elliptical frame and receiver placed at focal point of Scheffler dish which supported by a stand. The technical specification of the Scheffler collector system given in Table 1;

TABLE I
SPECIFICATION OF SCHEFFLER COLLECTOR SYSTEM FOR EXPERIMENTATION

Fig 2 : Scheffler Collector System For Experimentation with (L to R ) Cylindrical and Conical Receiver at MIT,Pune

| Sr.No | Title | Specification | Material Properties |
|---|---|---|---|
| **(1)** | **Scheffler Reflector** | **Model – 2.7 m$^2$ Major Axis – 2200 mm Minor Axis – 830 mm Concentration Ratio-16** | **(1) Glass Reflectivity =0.88** |
| **(2)** | **Receiver** | **a)Cylindrical Receiver Diameter – 450mm Length – 50 mm b)Conical Receiver Diameter – 450 mm Height – 150 mm c) Volume- 8 liter** | **(1)Mild Steel (2)Black Paint Absorptivity:0.91 (3)Insulation-PUF material** |
| **(3)** | **Tracking** | **Manual Tracking** | |

Tilting arrangement is provided for both receiver and measurement of tilting angle have done by using inclinometer. K-type thermocouple is used for measuring the surface temperature of receiver. Direct solar radiation, ambient temperature and wind speed are measured by weather station data logger available at experimental field. Direct solar radiation received by Scheffler reflector which is then reflected onto receiver. As receiver placed at focus of reflector, high temperature point is generated onto surface area of receiver and solar thermal energy conversion take place i.e. Heat transfer take place from outer surface to inner fluid.

## II. METHODOLOGY AND FORMULATION

### A. *Methodology*

Thermal efficiency of receiver is calculated on the basis of parameters like Shape of receiver, Initial Heating of inlet water, Tilting of receiver, Receiver with Glass Cover for steam pressure up to 3 bars. Improvement in thermal efficiency of Scheffler collector system for cylindrical and conical receiver is studied on the basis of following parameters:

*1) General Condition:* In this case, thermal efficiency is calculated at ambient condition. Inlet water temperature is taken 25$^o$C.This inlet water temperature is maintained constant by keeping water under the controlled environment condition. Receiver has no glass cover and tilt angle is 0$^o$.

*2) Initial Heating:*In case of initial heating, inlet water temperature to the receiver is 50$^o$C. Firstly, water is preheated in the same receiver to be tested. Thermal efficiency of receiver is calculated for initial heated water condition. Preheating of water may be done by using flat plate collector system coupled with Scheffler Collector system. Receivers have no glass cover and tilt angle is 0$^o$.

*3) Tilt Angle:* In case of tilt angle, receiver is tilted at 45$^o$ to the horizontal and thermal efficiency is calculated for tilted condition. Many research studies show that as receiver inclination increases, heat loss decreases [6][10]. Heat loss is maximum at 0$^o$ and minimum at 90$^o$.For this 2.7 m$^2$ Scheffler collector system optimum tilt angle of receiver is selected 45$^o$ on basis of focus position onto the receiver surface and ease of experimentation. Inlet water temperature is at ambient condition. There is no glass cover to the receiver surface.

*4) Glass Cover:* In this case toughened glass cover is provided to frontal surface of receiver on which reflector focus is received. It can be used a temperature range up to 300$^o$C .Toughened glass cover has 4 mm thickness and transmissivity is 85%.The clearance between glass cover and receiver surface is 3 mm. The other side of receiver is covered with thin aluminum sheet which is painted white.

### B. *Formulation for Thermal Efficiency*

The thermal efficiency is calculated with equation:

$$\text{Thermal Efficiency } (\eta) = \left[\frac{M_s \times h_{fg}}{Ap \times I_{bn} \times T}\right] \times 100 .......(1)$$

Where, $M_s$-Mass Flow Rate of Steam (kg/hr)
$I_{bn}$- Direct Solar Radiation (W/m$^2$)
T – 3600/1000
The Aperturearea($A_P$) of the Scheffler reflector which is also a variable function whose value can be determined for any day of the year by the formula;[4]

$$A_p = A_{Dish} \times \cos\left[\left(\frac{43.23^0 - \delta}{2}\right)\right] ........(2)$$

And seasonal angle of declination (δ) is given as,

$$\delta = 23.45 \sin\left[\frac{360}{365}(284+n)\right]\text{.........(3)}$$

Where, $A_{Dish}$-Area of Scheffler Dish ($m^2$)

n -Day of the Year

## III. Testing Procedure

Experimentation is done as per British Indian Standard testing procedure. The working thermic fluid is water. Receiver fills with 4 litre water. (Half-Filled for Providing Space for Steam Storage).Focus of Scheffler reflector is adjusted on the receiver according to sun angle. Once desired pressure is reached, receiver drained out and remaining water quantity is measured for calculating the evaporated water quantity. Readings were taken for the focus temperature, surface temperature, air temperature, global radiation, diffuse radiation & wind speed for every 15 minutes. The same procedure is repeated for different parameter.Thermal efficiency is estimated for receiver at different mass flow rate of steam and incident direct solar radiation.

## IV. Results and Discussion

Figure 3 and Figure 4 shows experimental values of thermal efficiency of both receivers at various testing parameter:

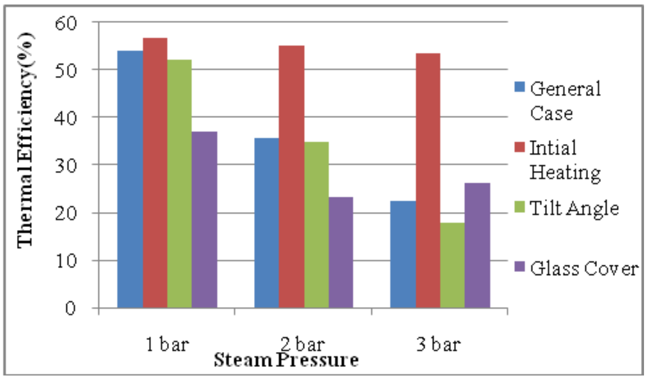


Fig 3 Thermal Efficiency for Cylindrical Receiver

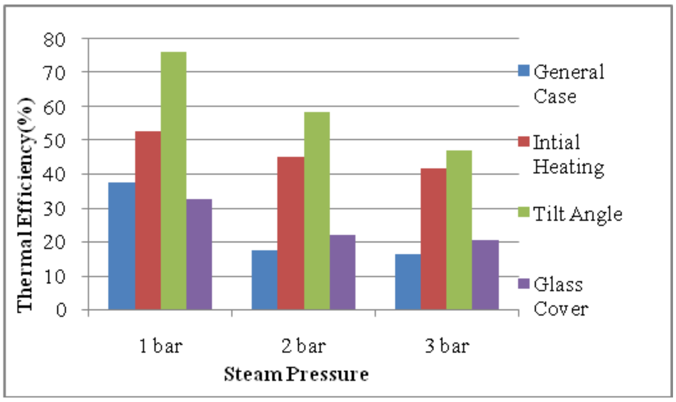


**Fig 4 Thermal Efficiency for Conical Receiver**

For cylindrical receiver maximum thermal efficiency is 56.54% in case of initial heating of inlet water whereas for conical receiver it is 76.07% in case of tilting of receiver at 1 bar steam pressure. Overall performance is better for cylindrical receiver in case of initial heating case, while for conical receiver it is better in case of tilting of receiver. These values of thermal efficiency depend upon the incident solar radiation, mass flow rate of steam, and wind speed [10].

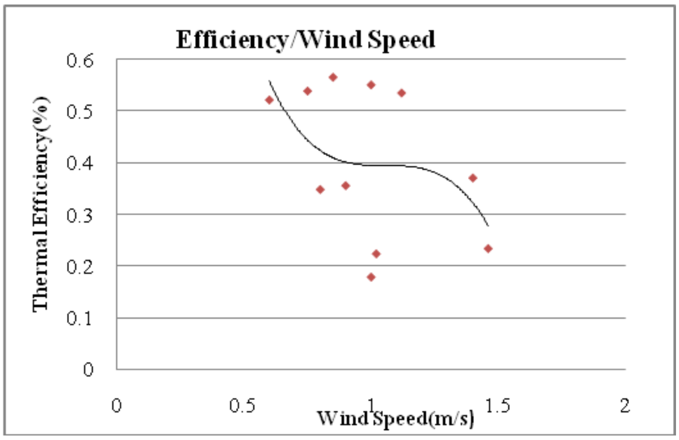


Fig.5.Variation of Efficiency with Wind Speed for Cylindrical Receiver

Fig 5 and Fig 6 shows that variation of thermal efficiency with wind speed which states that the thermal efficiency decreases with increase in wind speed. As wind speed increases convective loss also increases, hence there is significant variation in thermal efficiency.

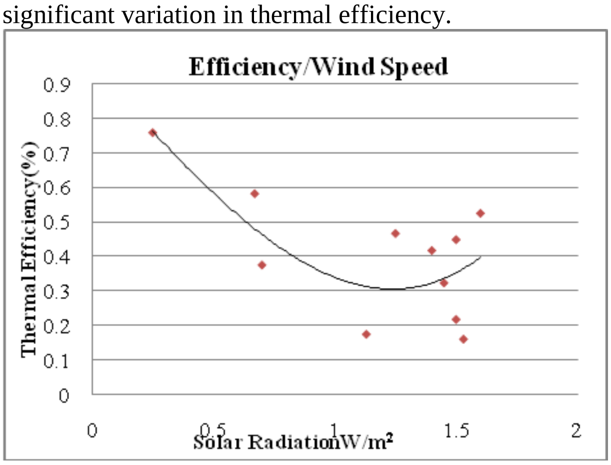


Fig.6.Variation of Efficiency with Wind Speed for Conical Receiver

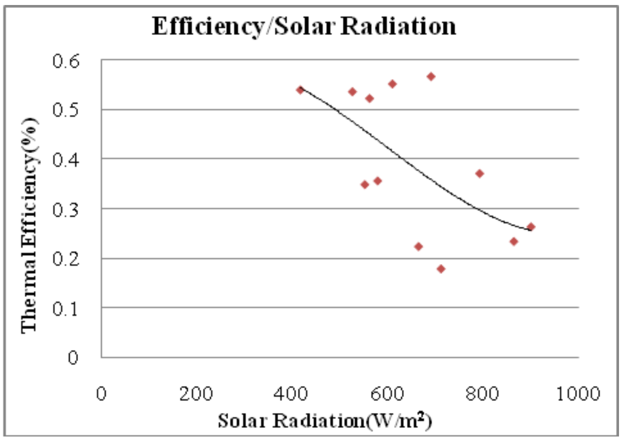


Fig.7.Variation of Efficiency with Solar Radiation for Cylindrical Receiver

 

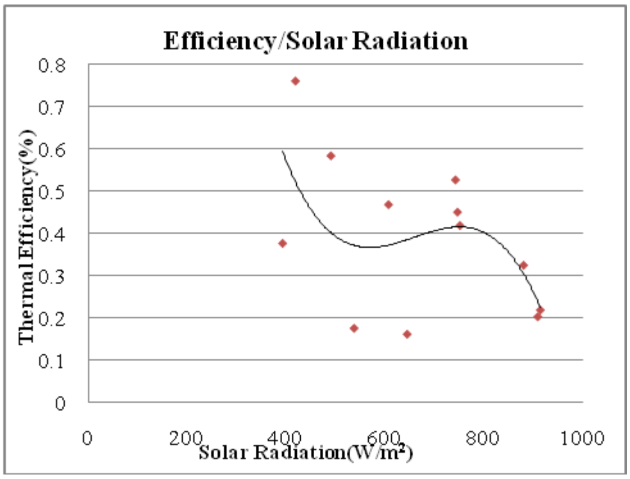


Fig.8.Variation of Efficiency with Solar Radiation for Conical Receiver

Fig 7 and Fig 8 shows that variation of thermal efficiency against solar radiation .The graph shows that the thermal efficiency decreases with increase in solar radiation as solar radiation not absorbed properly. At higher value of solar radiation, convective and radiation losses increases which causes for decrease in heat gain by receiver.

### *A. Optimization of Thermal Efficiency*

In general thermal efficiency is depending on the incident solar radiation and mass flow rate of steam as given in equation 1. The general mathematical model developed to determining the value of thermal efficiency by using Response surface method (RSM) method. Response surface method is used for optimizing the value thermal efficiency [9]. In this case Historical Data Design Method is used for optimizing the thermal efficiency. Design Expert 7.00 design tool software has been used for optimization. In this case optimization of thermal efficiency has been done for Cylindrical and Conical Receiver. For RSM input factors are average solar radiation and mass flow rate of steam. Thermal Efficiency is response for the given input variable for both receivers. The general mathematical model for cylindrical and conical receiver is given equation below 4 and 5 respectively.

Thermal Efficiency = +77.53190 – (0.2145* Average Solar Radiation) + (58.98620* Mass Flow Rate of Steam)-(0.050118 *Average Solar Radiation * Mass Flow Rate of Steam) + ($1.55941*10^{-4}$* Average Solar Radiation$^2$) + (5.51488 * Mass Flow Rate of Steam$^2$)………. (4)

Thermal Efficiency = +49.76474 – (0.14978* Average Solar Radiation) + (71.14067* Mass flow Rate of steam)-(0.068909*Average Solar Radiation*Mass flow Rate of steam) + ($1.16949*10^{-4}$* Average Solar Radiation$^2$) + (7.23585 * Mass flow Rate of steam$^2$)………………………….. (5)

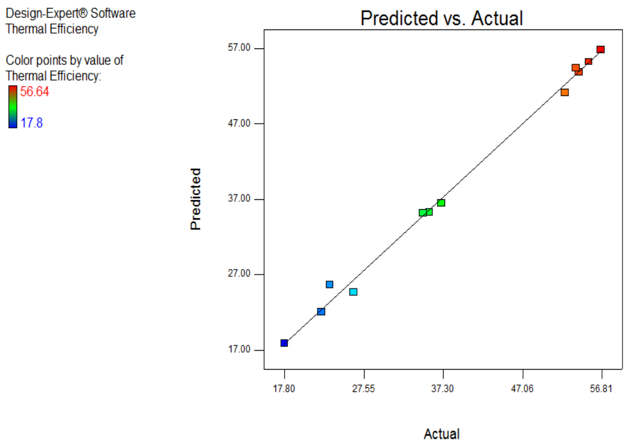


Fig.9Comparison between Predicated Value and Actual Value of Thermal Efficiency for Cylindrical Receiver

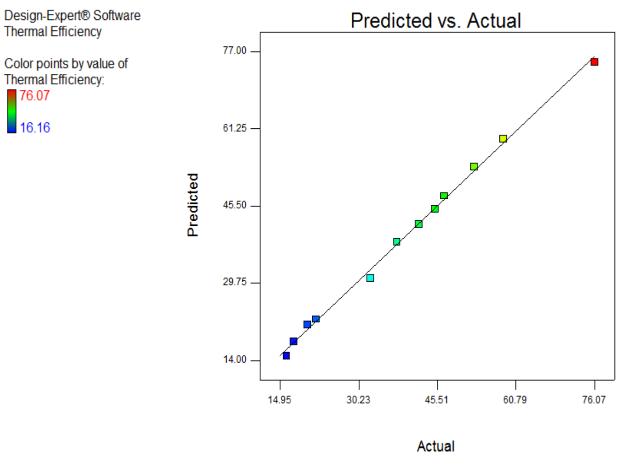


Fig.10Comparison between Predicated Value and Actual Value of Thermal Efficiency for Conical Receiver

Predicted value of response is calculated by general equation obtained.Graph shows that good agreement between actual value and predicted value of response with minimum residuals.

Fig.11 and Fig.12 shows model graph for optimum thermal efficiency as given below:

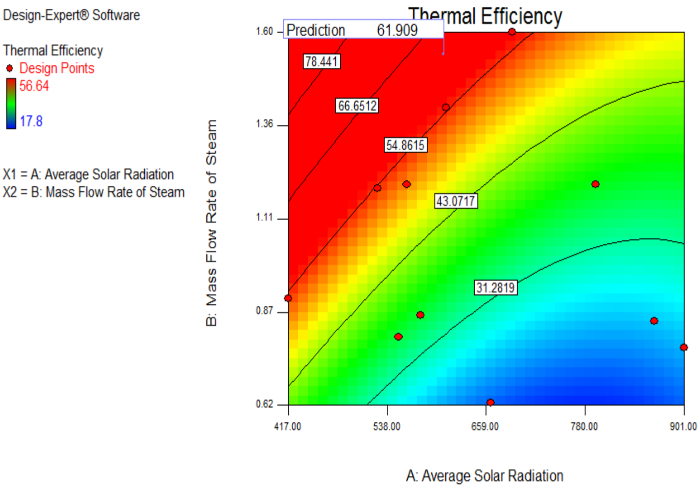


Fig.11 Model Graph of Optimum Thermal Efficiency for Cylindrical Receiver

Correlation values between input factors and response shows the dependency of input factor on response. In this case correlation value between average solar radiation and thermal efficiency is negative which indicates that as solar radiation value increases, the thermal efficiency decreases. Positive correlation value between input mass flow rate and response thermal efficiency shows that as mass flow rate of steam increases, the thermal efficiency increases.An optimum value of thermal efficiency is predicted by equation 4 and 5.This optimum value of thermal efficiency is depends upon average solar radiation, mass flow rate of steam.

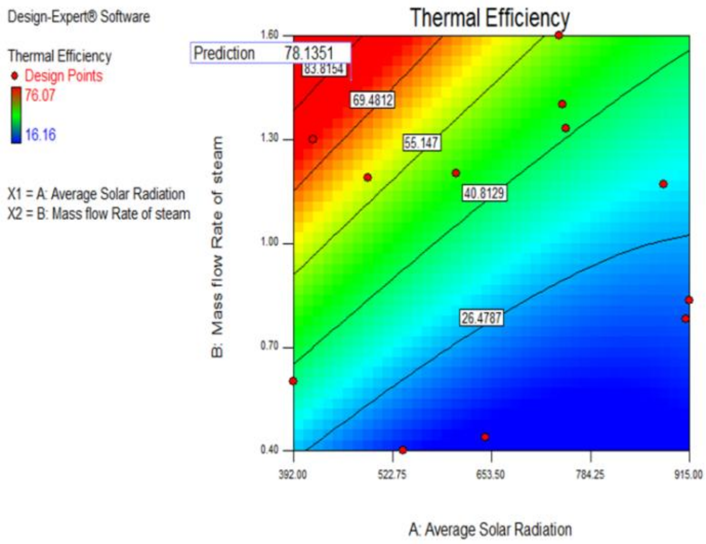


Fig.12 Model Graph of Optimum Thermal Efficiency for Cylindrical Receiver

The corresponding values of optimum thermal efficiency are given table 2;

TABLE II
PREDICTED VALUE OF OPTIMUM THERMAL EFFICIENCY

| **Type of Receiver** | **Average Solar Radiation ($w/m^2$)** | **Mass Flow Rate of Steam (kg/hr)** | **Thermal Efficiency (%)** | **Condition** |
|---|---|---|---|---|
| **Cylindrical Receiver** | **606.82** | **1.54** | **61.90** | **Initial Heating** |
| **Conical Receiver** | **468** | **1.47** | **78.13** | **Tilt Effect** |

## V. CONCLUSION

Scheffler Collector System suitable for water heating and low pressure and temperature steam generation. Receiver of Scheffler Collector System with lower concentration ratio (<20) can be used for dual purpose of absorber and steam storage device. Thermal efficiency of receiver is depends upon the shape of receiver, inlet temperature of water, tilt angle of receiver and glass cover to surface of receiver.The efficiency is increases by preheating of water at $50^oC$.For initial heating case cylindrical receiver shows average maximum thermal efficiency 55.13%.Tilting of receiver also have significant effect on thermal efficiency .In case of tilting of receiver conical receiver shows average maximum thermal efficiency 60.42%.Due to coating of black paint, efficiency increases because of increase in heat absorptivity. Wind speed and solar radiation have significant effect on the thermal efficiency. Cylindrical receiver gives satisfactory performance with wind speed up to 1 m/s whereas conical receiver shows better performance with wind speed up to 1.5 m/s. At higher value of solar radiation in between 800-900 W/m$^2$ thermal efficiency of receiver decreases due to increase in thermal losses.

Response surface method is found effective tool for optimization of thermal efficiency. The general mathematical model has been developed for both receivers by using response surface method. An optimum value of thermal efficiency for cylindrical receiver is 61.90% and for conical receiver is 78.13%.

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