DESIGN AND PERFORMANCE ANALYSIS OF SOLAR PARABOLID DISH CONCENTRATOR SYSTEM FOR PROCESS HEATING

Anubhav Uppal*, Dr. J P Kesari^ , Dr. R S Mishra''

*Masters in Renewable Energy Technology, Delhi Technological University, Delhi, India

Anubhav3365@gmail.com

^ Associate professor, Delhi Technological University, Delhi, India

drjpkesari@gmail.com

'' Professor, Head of Department, Mechanical Engineering Department, Delhi Technological University, Delhi, India

rsmishra@dce.ac.in

ABSTRACT

Indian industry is under tremendous pressure to make their products more environmentally sound. Not only the products themselves, but also the whole production process has to become more sustainable to Achieve India's pledge to stop climate change at world forum. The Indian industry is one of the major sectors in India which have very high share in India's Gross Domestic Product (GDP) with annual share of 25% in 2015-2016. Also Indian industry has huge energy requirements in the form of both thermal and electrical energy. Manufacturing of final components and their sub components involves many steps such as casting, forging, and painting and electroplating etc that require thermal energy in form of hot air, water or steam. Thermal energy requirement accounts for around 70% of all India industry's total energy consumption. Max thermal energy requirement is well below 200°C and solar thermal collectors can provide a large share of this industrial process heat demand easily. The solar thermal collector technology used depends upon a great deal on the temperature levels involved. The use of an appropriate solar thermal technology can have a positive impact on the energy and environmental scenario of Indian industry at a large. There are various solar thermal technologies including CST technologies that are available for Indian industries.

1. INTRODUCTION

Demand for thermal energy accounts for around 70% of total energy consumption in Indian industry. Thermal energy required in the form of process hot air, pressurized hot water or saturated steam is up to temperature levels of 200°C, therefore solar thermal collectors can be perfect application of solar technology as solar thermal collectors can provide most of this heat energy demand efficiently. Also the India has a great potential for solar industrial process heat (SIPH) because of high solar irradiation values with almost 300+ sunny days in year. Apart from above reasons, Shortage of fossil energy sources such as oil, natural gas or coal with rapidly rising energy prices in developing countries like India have also made solar collectors integration with the industrial process more lucrative. From now integration of solar thermal technology with industrial heat sources will increase India's independence from future energy price hikes and also will help to lessen industrial production costs.

Industrial process heat demand of various industrialized nations like USA, European Union is up to 40% of total energy demand of the country. This energy consumed is mainly supplied in form of electricity, natural gas, oil or coal. Pattern of energy consumption in developing countries like India is 39% of total energy is consumed in industrial sector followed by 32% in transportation sector, rest 20% and 10% in residential and agricultural sector. Following figure gives the pattern of energy consumption for developing countries like India **[1]**:-

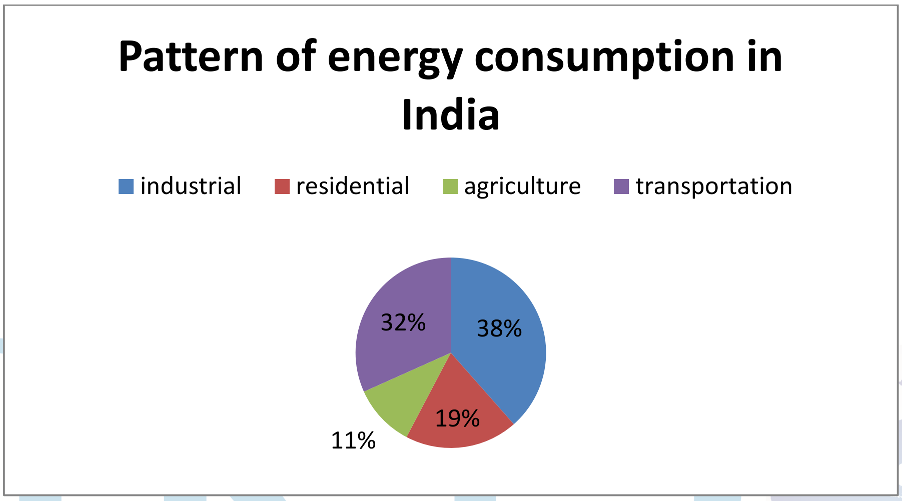

Figure1:- pattern of total energy consumption in India (source:- planning commission)

Quality and quantity of energy required for industry depends upon temperature levels of that industry. Size of SIPH system required also depends upon site solar radiation, process heat requirement, load profile, etc. Also solar energy can meet only a share of process heat demand in industry due to some limitations like unreliability of solar radiation and available, user load profile, land is also limited for a given industry. Coverage of part of process heat demand by solar energy is known as solar fraction which can go maximum up to 40% in most cases. Hence most of the SIPH system requires backup boiler. Hence solar energy as industrial process heat demand has a great potential in industry requiring energy from coal, oil or natural gas.

2. DESIGN OF PARABOLOID DISH SOLAR COLLECTOR

Concentrator of solar paraboloid dish intercepts radiation from sun over large aperture area and concentrates on to a small receiver area. Receiver absorbs the solar energy and transfers most of the absorbed solar energy to working medium i.e. water which turn s into saturated steam. Simple energy balance equation also called fundamental solar collection equation governs the performance of solar paraboloid dish collector. Paraboloid dish solar concentrator uses paraboloid shaped concentrating dish to focus sunlight on cavity type thermal receiver. Receiver gets heated to high temperature up to 400°C which turns water flowing inside tubes to steam. Steam produced can be used for industrial applications. Tracking system is also used to maximize solar radiation by tracking sun movement accurately up to 0.2 degrees error and concentration of solar radiation can reach up to 1000X. High solar to thermal efficiency of this solar paraboloid system is about 60%. Following figure shows the major components of solar paraboloid dish collector **[2,4]**:-

Figure2:- Paraboloid Dish solar collector components (source: - NREL)

Paraboloid dish collector consists of following major components with each subsystem having well defined function as follows:-

Collector:- collector collects the incoming solar radiation and concentrates it on to receiver fixed at its focus point. Thus high concentration ratios due to large collector aperture area of 15 m diameter and small receiver aperture area of 1m diameter can be achieved up to 600 to 1000. Collector surface area is covered with highly reflective solar grade mirrors which reflect sunlight on to receiver with high optical efficiency of around 80%. Collector is supported by the space frame structure built of aluminium or MS tubes mounted on a long MS pedestal and supported by concrete foundation at the ground. Following figure gives the reflecting concentrator surface as follows:-

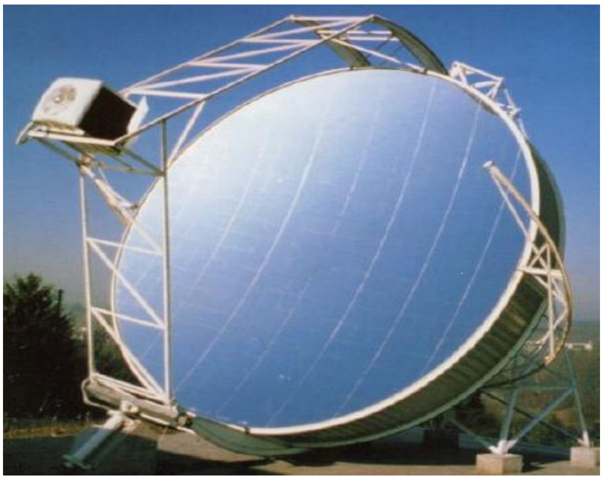

Figure3:- Collector of solar Paraboloid Dish (source: - NREL)

Receiver:- Receiver absorbs the solar radiation from the collector reflecting surface and transfers it to flowing working fluid like water or heat transfer oil continuously in helical tubes. Receiver is placed at focal point of paraboloid to achieve high temperatures' due to concentration of solar radiation. Receiver is generally of inverted cavity type made of MS material. Following figure gives the receiver mounted on a support structure of dish as follows:-

Figure4:- Cavity Receiver of solar Paraboloid Dish (source: - NREL)

Tracking system:- Solar paraboloid dish collector consists of dual axis electro-mechanical tracking system to optimize efficiency of solar energy collection for particular location by moving collector towards the sun throughout the day and also seasons. Tracking system also acts as support to the collector. Two axes tracking moves collector east- West i.e. Azimuth tracking and North – South i.e. elevation tracking. Tracking can be two types:-

- **Chronological tracking:-** in this type of tracking system, tracker moves the collector at preset time intervals according to azimuth- elevation position of sun for that latitude and longitude for any given time of the year which are already fed to microcontroller.
- **Light sensing tracking:-** in this type of tracking system, tracker has light sensors to sense sun, give feedback signal to microcontroller and microcontroller gives the command to tracker motors to track the sun by following it.

Following figure gives the working of dual axis tracking system mounted on a support structure of dish as follows:-

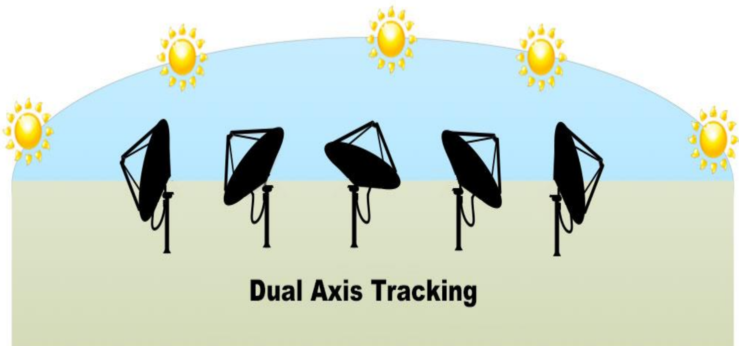

Figure5:- Azimuth- Elevation (Az-El) type Tracking for solar Paraboloid Dish (source: - NISE)

Circulation system:- it circulates working fluid through receiver to transfers solar heat to fluid to be used for desired application. It controls the mass flow rate of fluid at desired value to quickly and efficiently transfer heat from receiver. Circulation system has number of major components like pumps, insulated pipes for steam, flow control valves, temperature control sensors, etc.

Control mechanism:- control mechanism is the brain that controls tracking system and circulation system. Microcontroller sends the control signals to tracker to follow the sun continuously and circulating pumps to get desired pressure and temperature of working fluid suitable for end use application. Following figure gives the working principle of circulation system and control system of dish as follows **[7]**:-

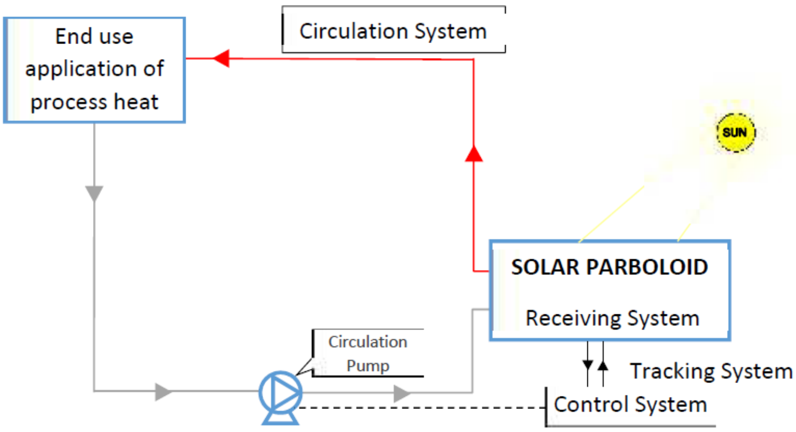

Figure6:- Circulation system and control system for solar Paraboloid Dish (source: - NISE)

3. ENERGY BALANCE EQUATION

Fundamental solar collection equation is used to calculate the amount of heat going into the receiver. Amount of solar radiation entering the receiver depends upon solar source availability i.e. Direct Normal irradiance values (DNI) of site, size of concentrator i.e. Diameter and reflective surface i.e. reflectivity. Thermal efficiency depends upon receiver design and heat losses due to conduction, convection and radiation. Following equation gives the basic design energy balance equation **[8]:-**

$$\mathbf{Q_{useful} = I_{b,n}*A_{app}*E*(\cos\Theta_i)*\rho*\Phi*\tau*\alpha - A_{rec}[U*(T_{rec} - T_{amb}) + \sigma*F*(T_{rec}^4 - T_{amb}^4)]}$$

Where

$\mathbf{Q_{useful}}$ = instantaneous rate of thermal energy coming from receiver useful heat

$\mathbf{A_{app}}$ = area of concentrator aperture

$\mathbf{A_{rec}}$ = area of receiver aperture

E = fraction of concentrator aperture area not shaded by receiver, struts and so on

F = equivalent radiative conductance

$I_{b,n}$ = beam normal solar radiation (insolation)

T_{amb} = ambient temperature

T_{rec} = receiver operating temperature

U = convection conduction heat loss coefficient for air currents within receiver cavity and conduction through receiver walls

α = receiver absorptance

τ = Transmittance of anything between the reflector and the absorber

Θ_i = angle of incidence (angle between the sun's rays and the line perpendicular to The concentrator aperture, for paraboloid dish this angle is 0 degrees)

P = concentrator surface reflectance

σ = Stefan Boltzmann radiant energy transfer constant

Φ = capture fraction or intercept (fraction of energy leaving the reflector that Enters the receiver)

4. DESIGN OF DISH CONCENTRATOR AND RECIEVER

The function of the concentrator is to intercept solar radiation with a large opening i.e. aperture and reflect it on to a smaller area. The parameters associated with the design of the concentrator are as follows:-

- Concentrator aperture area, A_{app}
- Receiver aperture area, A_{rec}
- Un shaded concentrator aperture area fraction, **E**
- Angle of incidence, Θ_i
- Surface reflectance, **P**
- Capture fraction, Φ

CONCENTRATOR DESIGN

Paraboloid concentrator is a surface generated by rotating a parabola about its axis. Resulting shape directs all the parallel sunrays on to single point on its axis called focal point. Paraboloid dish is governed by the equation in x, y, z coordinate system as follows:-

$$X^2 + Y^2 = 4fz$$

Where

X = coordinate in aperture plane
Y = coordinate in aperture plane
Z = distance from the vertex parallel to symmetry of paraboloid
F = focal length

Focal length to diameter ratio **f/d** defines the shape of the paraboloid and relative location of focus. The shape is also described by rim angle Ψ_m which is angle measured at focus from the axis to the rim where paraboloid is truncated. The relationship between **f/d** ratio and rim angle is given as follows:-

$$f/d = 1/4 * \tan(\Psi_m/2)$$

Geometry of paraboloid is shown in following figure:-

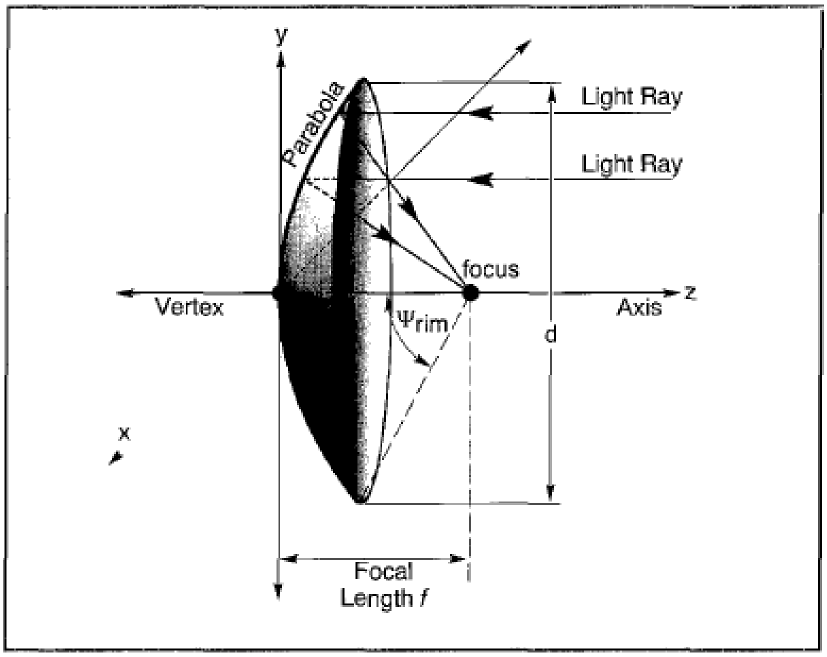

Figure7:- Paraboloid Dish with focal length, rim angle, diameter (source: - NREL)

Geometric concentration ratio is defined as extent to which aperture area of the receiver is reduced relative to that of concentrator. Expression for geometric concentration is given as follows:-

$$CR_g = A_{app}/A_{rec}$$

Concentrator or optical efficiency is primary measure of concentrator performance that how much of the insolation arriving at the collector aperture passes through an aperture of specified size located at the focus of the concentrator. This is given as follows:-

$$\eta_{conc} = E * (\cos\Theta_i) * P * \Phi$$

RECEIVER DESIGN

Receiver absorbs concentrated solar flux and converts it to thermal energy. Design of receiver depends upon following parameters:-

- Transmittance, **τ**
- Absorptance, **α**
- Receiver aperture area, $\mathbf{A_{rec}}$
- Convection- conduction heat loss coefficient, **U**
- Equivalent radiation conductance, **F**
- Receiver operating temperature, $\mathbf{T_{rec}}$

Receiver performance is given by the term receiver thermal efficiency which is defined as useful thermal energy delivered to working fluid divided by solar energy entering receiver aperture. Receiver thermal efficiency is given by equation as follows:-

$$\eta_{rec} = \tau * \alpha - [U * (T_{rec} - T_{amb}) + \sigma * F * (T_{rec}^4 - T_{amb}^4)] / \eta_{conc} * CR_g * I_{b,n}$$

Receiver efficiency can be increased by increasing cover transmittance, surface absorptance, reducing operating temperature, reducing capacity of receiver cavity to lose heat by conduction, convection and radiation.

Solar to thermal conversion efficiency is important parameter which is determined by combining optical efficiency and receiver thermal efficiency. This equation is given as follows:-

$$\eta_{overall} = \eta_{rec} * \eta_{conc}$$

5. DESIGN CALCULATIONS AND PERFORMANCE ANALYSIS

Design calculations are done for solar paraboloid dish to be used for industrial process heating system by using the basic heat gain equation and equations used for Concentrator and receiver design as stated above. Basic input variables are selected and constants necessary for calculations are assumed from appropriate reference to calculate the daily performance of solar dish. Design performance parameters are calculated like Useful Heat gain rate ($\mathbf{Q_{useful}}$), geometric concentration ratio ($\mathbf{CR_g}$), concentrator optical efficiency ($\boldsymbol{\eta_{conc}}$), receiver thermal efficiency ($\boldsymbol{\eta_{rec}}$) and overall system efficiency ($\boldsymbol{\eta_{overall}}$). Following table gives the value of basic input parameters and design coefficients assumed for calculations of solar paraboloid dish:-

Table 1:- Design Parameters for Solar Paraboloid dish

Design Parameters	Design Value
Rim Angle $\boldsymbol{\Psi_m}$ (°)	45
F/d ratio	0.60
Diameter of Paraboloid dish (m)	15
Focal length (m)	9.05
Reflectivity for solar grade mirrors **P**	0.95
Angle of incidence for two axis tracking $\boldsymbol{\theta_i}$ (°)	0
Un shaded aperture area fraction **E**	0.95
Capture/ Intercept fraction $\boldsymbol{\Phi}$	0.9
Transmittance $\boldsymbol{\tau}$	0.9
Absorptance $\boldsymbol{\alpha}$	0.9
Overall heat transfer coefficient of air currents **U** (W/m2 K) at 7.5 m/sec maximum wind velocity at VECV plant, Indore	30
Receiver operating temperature/ Temperature for Steam produced $\boldsymbol{T_{rec}}$ (°C)	225
Receiver cavity opening diameter (m)	1
Equivalent radiative conductance **F** for selective coating on receiver surface	0.3
Beam solar radiation For rated design value $\boldsymbol{I_{b,n}}$ (w/m^2)	1000
Ambient temperature $\boldsymbol{T_{amb}}$ (°C)	25
Stefan Boltzmann constant $\boldsymbol{\sigma}$ (W/m2 K4)	5.67 * 10^-8

Following design parameters are now used for calculation for various performance parameters of 15 m diameter solar paraboloid dish. Overall heat transfer coefficient **U** for the selected VECV plant site is calculated for the air currents flowing through cavity receiver are calculated by given formula as follows **[9]**:-

$$\mathbf{U = 10.45 - v + 10\, v^{1/2}}$$

Where

V = wind velocity in m/sec

Different values of U are calculated for Different V values for plant location at Indore with corresponding value for maximum wind velocity of 7.5 m/sec is calculated as 30 W/m^2 K. This value is chosen for maximum heat loss that is possible from cavity receiver i.e. solar paraboloid dish is designed for worst case. Following figure gives the values for U for different wind speeds:-

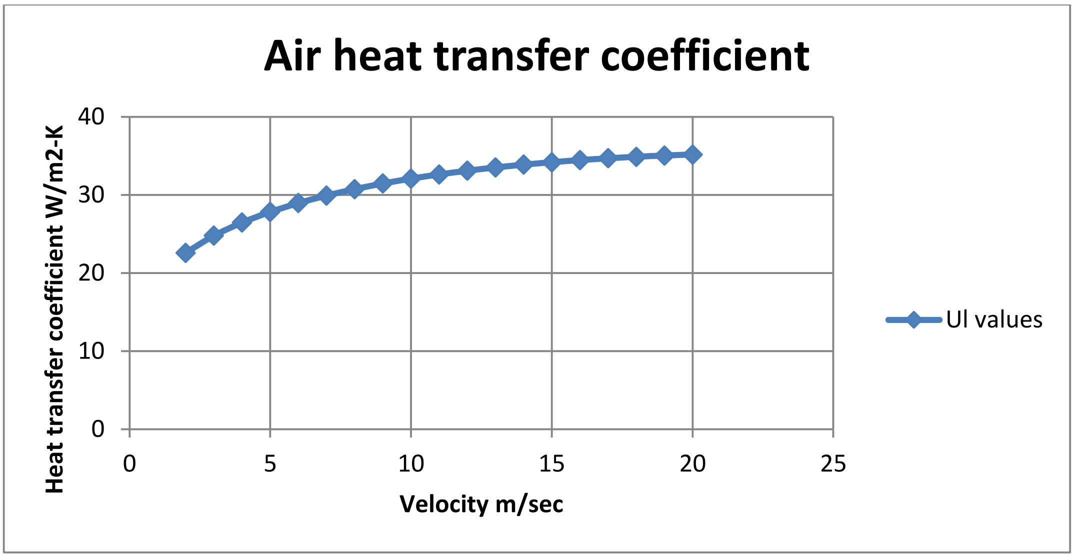

Figure 8:- overall heat transfer coefficient VS wind speed curve

Following Table gives the calculation procedure for estimating concentration optical efficiency, geometric concentration ratio, heat gain rate, heat loss rate, useful heat gain rate, receiver thermal efficiency and overall system efficiency as follows:-

Table 2:- Design Calculation procedure for Solar Paraboloid dish

diameter of parabolid dish	optical efficency	reciever operating temp in kelvin	area of concentrating aperture	reciever diameter	reciever opening area	geometric concentration ratio	solar radiation	ambient temperature	heat gain	heat loss	useful heat	reciever efficency	overall system efficency
15	0.812	498	176.715	1	0.785	225	1000	298	116264.503	5428.730	110835.773	0.772	0.627
15	0.812	498	176.715	1	0.785	225	950	298	110451.278	5428.730	105022.548	0.770	0.626
15	0.812	498	176.715	1	0.785	225	900	298	104638.052	5428.730	99209.323	0.768	0.624
15	0.812	498	176.715	1	0.785	225	850	298	98824.827	5428.730	93396.098	0.766	0.622
15	0.812	498	176.715	1	0.785	225	800	298	93011.602	5428.730	87582.872	0.763	0.620
15	0.812	498	176.715	1	0.785	225	750	298	87198.377	5428.730	81769.647	0.760	0.617
15	0.812	498	176.715	1	0.785	225	700	298	81385.152	5428.730	75956.422	0.756	0.614
15	0.812	498	176.715	1	0.785	225	650	298	75571.927	5428.730	70143.197	0.752	0.611
15	0.812	498	176.715	1	0.785	225	600	298	69758.702	5428.730	64329.972	0.747	0.607
15	0.812	498	176.715	1	0.785	225	550	298	63945.476	5428.730	58516.747	0.741	0.602
15	0.812	498	176.715	1	0.785	225	500	298	58132.251	5428.730	52703.522	0.734	0.596
15	0.812	498	176.715	1	0.785	225	450	298	52319.026	5428.730	46890.296	0.726	0.590
15	0.812	498	176.715	1	0.785	225	400	298	46505.801	5428.730	41077.071	0.715	0.581
15	0.812	498	176.715	1	0.785	225	350	298	40692.576	5428.730	35263.846	0.702	0.570
15	0.812	498	176.715	1	0.785	225	300	298	34879.351	5428.730	29450.621	0.684	0.556
15	0.812	498	176.715	1	0.785	225	250	298	29066.126	5428.730	23637.396	0.659	0.535
15	0.812	498	176.715	1	0.785	225	200	298	23252.901	5428.730	17824.171	0.621	0.504
15	0.812	498	176.715	1	0.785	225	150	298	17439.675	5428.730	12010.946	0.558	0.453

15 m diameter solar paraboloid dish at 1000 w/m^2 will deliver useful heat gain rate of 110 KW at optical efficiency of 81.2%, receiver efficiency of 77.2% and overall system efficiency i.e. solar to heat conversion ratio of 62.7%. As DNI values decreases, all performance parameters start decreasing to 12 KW heat gain rate at 150 W/m^2, 55.8% receiver efficiency and 45.3% overall system efficiency at 150 W/m^2. However, optical efficiency remain constant with changing DNI values at 81.2% due to two axes tracking which keeps cosine losses always zero as it tracks the sun continuously for both Sun's Azimuth and elevation

positions. Geometric Concentration ratio for 15 m concentrator diameter and 1 m receiver diameter is calculated as dividing concentration aperture area by receiver aperture area which gives the value of 225 i.e. radiation falling on receiver cavity gets intensed by the factor of 225 X. Following figure gives the variation for overall system efficiency and useful heat gain rate with DNI values as follows:-

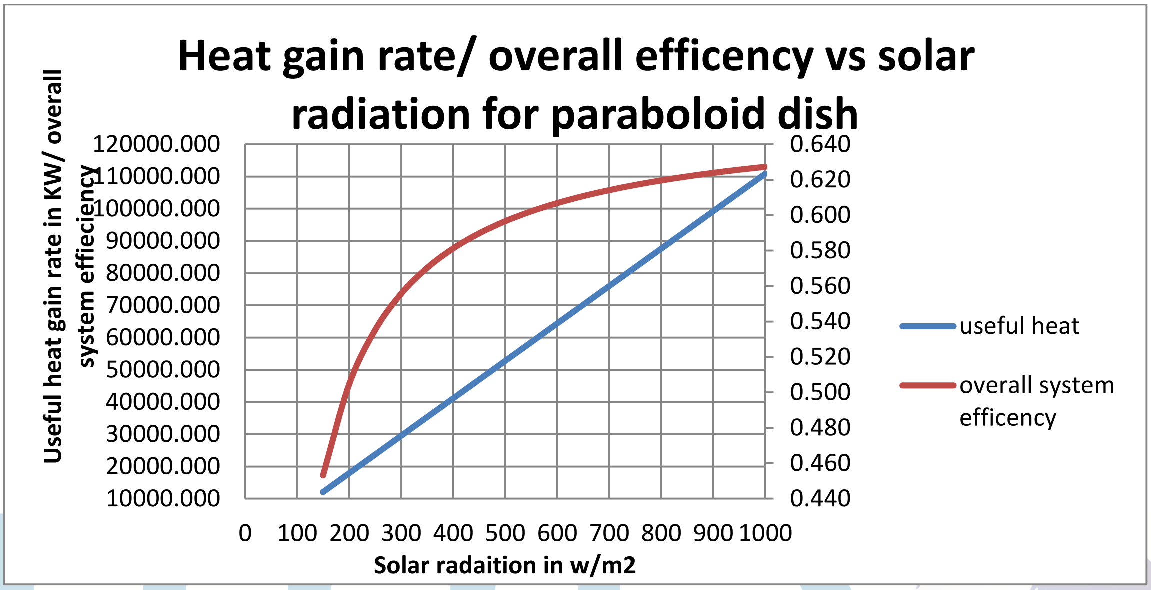

Figure 9:- overall system efficiency/ useful heat gain rate Vs solar radiation curve

Overall system efficiency curve follows parabolic relationship with increasing solar radiation and reaches peak value of 62.7% for 1000 W/m^2 and low value as possible for 150 w/m^2 of 45.3%. On the other hand useful heat gain rate follows linear relationship with increasing solar radiation. Following figure gives the variation of receiver thermal efficiency vs solar radiation as follows:-

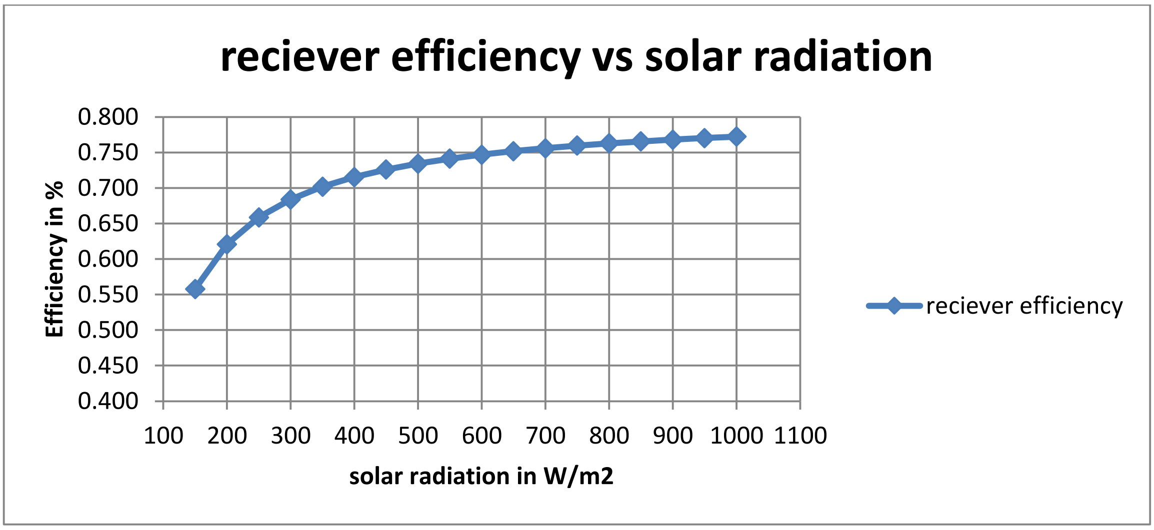

Figure 10:- Receiver thermal efficiency Vs solar radiation curve

Receiver thermal efficiency increases from 55.8% at 150 w/m^2 to 77.2% at 1000 W/m2. Receiver thermal efficiency increases rapidly with increasing solar radiation but becomes almost constant at higher values of DNI. Now the daily performance of 15 m solar paraboloid dish was evaluated over the day with variation in DNI values from 6 AM to 6 PM on 23rd March, 2016. The variation of DNI was recorded over the whole day at VECV plant weather station which recorded DNI varying from 57 W/m^2 to 858 W/m^2 at solar peak time. Following figure shows the variation of DNI at VECV plant site for 23rd March, 2016 as follows **[10]**:-

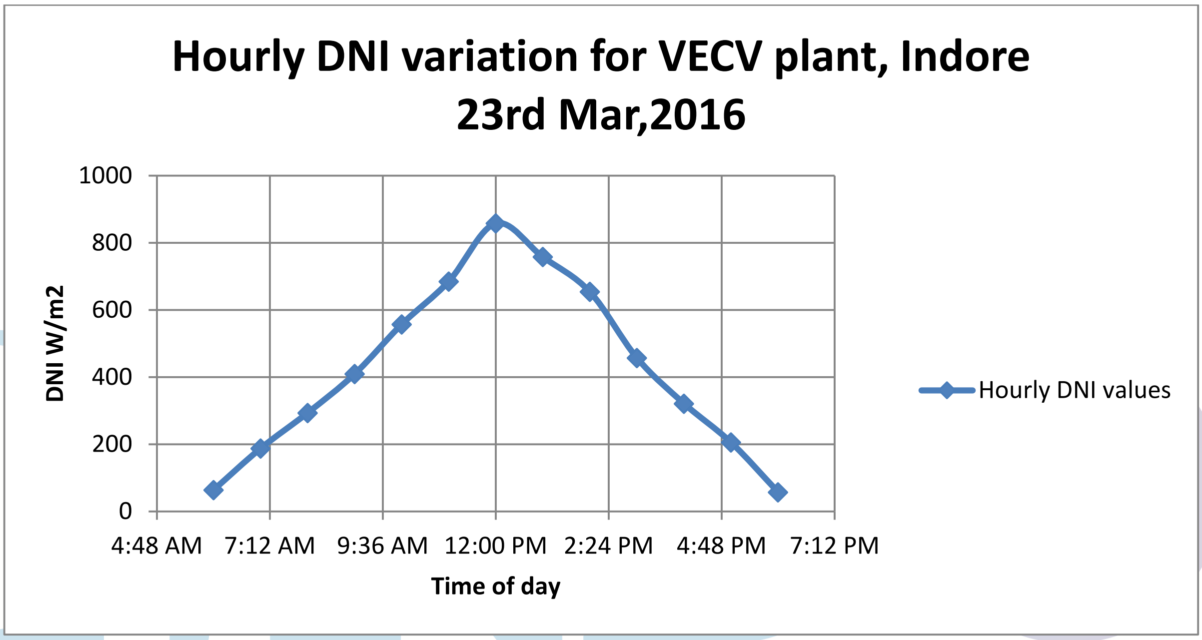

Figure 11:- Hourly DNI variation at VECV Plant, Indore (source:- VECV weather station)

With varying DNI values recorded, important performance parameters i.e. optical efficiency, geometric concentration ratio, Useful heat gain rate, thermal efficiency, overall system efficiency were calculated based on equation as stated above. Results showed in the table are compiled in the form of curves showing the variation of each parameter calculated i.e. as variation of useful heat gain rate along with DNI. Useful heat gain rate varies from 1.9 KW at 63 W/m^2 in morning at 6 AM to 94 KW at 12 PM when radiation is at 858 W/m^2 and then again drops to 1.2 KW for 57 W/m^2 radiation in 6 PM in evening. Hence the curve for hourly DNI variation and hourly useful heat gain rate variation are almost same in shape. Following table shows the calculation procedure followed to calculate above performance parameters for varying DNI over the whole day as follows:-

Table 3:- Design Calculation procedure for Daily performance Analysis for Solar dish

rim angle	diameter of parabolid dish	optical efficency	reciever operating temp in kelvin	area of concentrating aperture	reciever diameter	reciever opening area	geometric concentration ratio	time of day	solar radiation	ambient temperature	heat gain	heat loss	useful heat	reciever efficency	overall system efficency
45	15	0.81	498	176.71	1	0.79	225	6:00 AM	63	298	7324.66	5428.73	1895.93	0.21	0.17
45	15	0.81	498	176.71	1	0.79	225	7:00 AM	187	298	21741.46	5428.73	16312.73	0.61	0.49
45	15	0.81	498	176.71	1	0.79	225	8:00 AM	293	298	34065.50	5428.73	28636.77	0.68	0.55
45	15	0.81	498	176.71	1	0.79	225	9:00 AM	409	298	47552.18	5428.73	42123.45	0.72	0.58
45	15	0.81	498	176.71	1	0.79	225	10:00 AM	557	298	64759.33	5428.73	59330.60	0.74	0.60
45	15	0.81	498	176.71	1	0.79	225	11:00 AM	685	298	79641.18	5428.73	74212.45	0.75	0.61
45	15	0.81	498	176.71	1	0.79	225	12:00 PM	858	298	99754.94	5428.73	94326.21	0.77	0.62
45	15	0.81	498	176.71	1	0.79	225	1:00 PM	758	298	88128.49	5428.73	82699.76	0.76	0.62
45	15	0.81	498	176.71	1	0.79	225	2:00 PM	654	298	76036.98	5428.73	70608.26	0.75	0.61
45	15	0.81	498	176.71	1	0.79	225	3:00 PM	457	298	53132.88	5428.73	47704.15	0.73	0.59
45	15	0.81	498	176.71	1	0.79	225	4:00 PM	321	298	37320.91	5428.73	31892.18	0.69	0.56
45	15	0.81	498	176.71	1	0.79	225	5:00 PM	205	298	23834.22	5428.73	18405.49	0.63	0.51
45	15	0.81	498	176.71	1	0.79	225	6:00 PM	57	298	6627.08	5428.73	1198.35	0.15	0.12

Following results stated in above table are shown in following figure for variation of useful heat gain rate throughout the day as follows:-

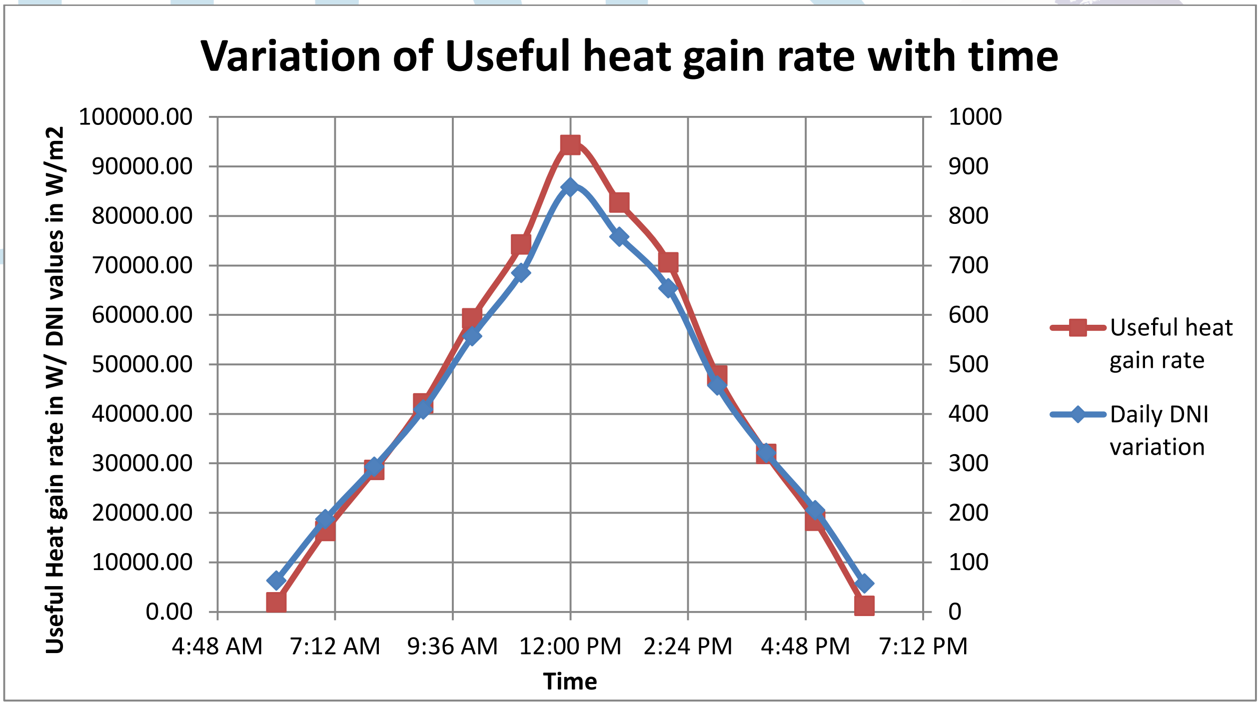

Figure 12:- Hourly Useful heat gain rate variation for 23rd Mar, 2016 at VECV Plant, Indore

Now the variation of all 3 efficiencies i.e. concentration optical efficiency, receiver thermal efficiency and overall system efficiency with variation of DNI with time of the day is complied. Optical efficiency remains constant throughout the day due to two axes tracking system, receiver efficiency starts increasing from morning, reaches peak value at solar noon and again drops to minimum value in the evening, while overall system efficiency follows the same curve as receiver thermal efficiency. Following figure shows the variation of efficiency with time of day as follows:-

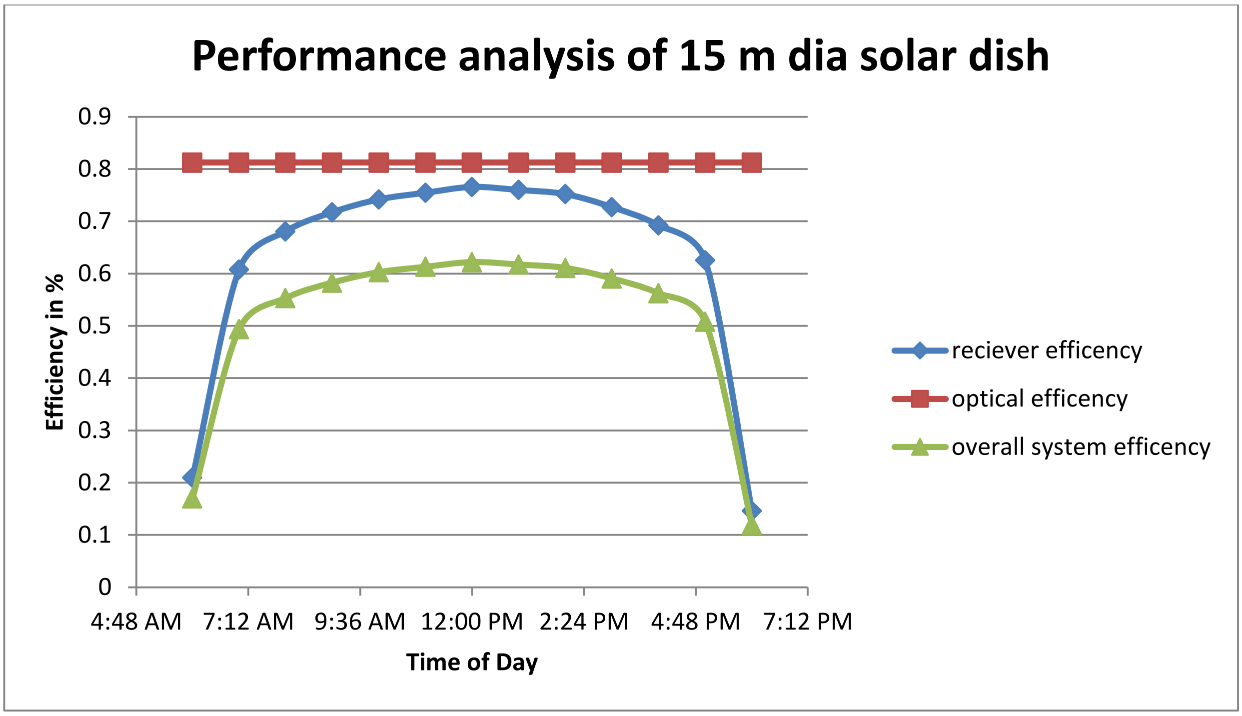

Figure 13:- Hourly Efficiency variation for 23rd Mar, 2016 at VECV Plant, Indore

6. CONCLUSIONS AND RECOMMENDATIONS

Finally the technical feasibility of the solar process heating system for the industry has been proved. Thus solar paraboloid based SIPH system can be installed at various industrial plants with region of high DNI values to make automobile production more environment friendly by reducing green house gas (GHG) emissions. Also SIPH system will help companies' dependence of quickly depleting fossil fuels for thermal energy requirement and save them from highly fluctuating fossil fuel prices. Particularly Indian industry is suitable for this type of concentrating solar thermal technology because of following reasons:-

- Indian industry is usually spread over hundreds of acres of area with vast shade free rooftops available on production shed which make them viable for large collector areas.
- All these Indian industries are located in arid or semi arid areas of India which receiver very high levels of solar radiation which makes them viable site for solar thermal technologies.
- Indian industry falls under industrial consumer category which is charged heavily for energy prices. Hence solar thermal technology can provide these industries with energy at very cheap prices.
- Also Indian industry is run by big corporate house which have no capital problem associated with them. So they can bear the initial high investment cost required for SIPH system.

Also this SIPH system can be used for other huge energy consuming industries like automobile sector, pharmacy sector, textile sector, food and beverages sector, paper and pulp sector, etc.

REFERENCES

1. India Energy Outlook 2015 published by International Energy Agency (IEA), New Delhi, April 2015.
2. H P Garg, J Prakash, Solar Energy: Fundamentals and Applications, Mc Graw Hill Education, 2013 edition.
3. Technical study report on Solar heat for industrial processes (SHIP) state of the art in the Mediterranean region, GEF.
4. S P Sukhatme, J K Nayak, Solar Energy: principles of thermal collection and storage, Mc Graw Hill Education, 2014 edition.
5. www.powerfromthesun.net, Book, chapter 11, Energy storage.
6. Ministry of new and renewable energy (MNRE), www.mnre.gov.in, retrieved on 14th April, 2016.
7. Paraboloid dish based solar system Operation & Maintenance Manual, UNDP – GEF project on concentrated solar heat, MNRE, November 2014.
8. A compendium of solar dish technology, William B. Stine, California state polytechnic University, Richard B. Diver, Sandia National laboratory, January 1994.
9. Engineering Toolbox/Convective Heat transfer, www.engineeringtoolbox.com, retrieved on 19th April 2016.
10. Indian Solar resource map, National institute of solar energy (NISE), Ministry of New and Renewable Energy (MNRE).