Designing of Solar Process Heating System for Indian Automobile Industry

Anubhav Uppal*, Dr. J P Kesari**, Mohd. Zunaid***

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

** Associate professor, Delhi Technological University, Delhi, India

*** Assistant professor, Delhi Technological University, Delhi, India

(Anubhav3365@gmail.com, drjpkesari@gmail.com, mzunaid3k@gmail.com)

Anubhav Uppal, Postal Address: - Delhi Technological University, Delhi, India, Tel: +919868262681, anubhav3365@gmail.com

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Abstract

Indian Automobile industry is under tremendous pressure to make their products more environmentally sound. Not only the automobile 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 Automobile industry is one of the major industries in India which have very high share in India’s Gross Domestic Product (GDP) with annual production of over 22 million automobiles in 2015-2016. Also automobile industry has huge energy requirements in the form of both thermal and electrical energy. Manufacturing of automobiles and auto components involves many steps such as casting, forging, 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 automobile 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 Paper presents the Techno-Economic Designing of Solar industrial process heating (SIPH) system based on Paraboloid dish type concentrated solar technology (CST) for Indian Automobile Industry. SIPH system designed will be integrated with the existing steam generation system of Automobile industry based on fossil fuels and can achieve a soar fraction of 10% for total energy requirement of the Automobile industry. Economic analysis is also presented for the SIPH system with payback period of 1.5 years.

KEYWORDS: - Solar thermal, Industrial Process heat, Automobile industry, Paraboloid dish, India, concentrated solar heat

NOMENCLATURE

Q_{useful} = instantaneous rate of thermal energy coming from receiver useful heat
A_{app} = area of concentrator aperture
Arec = 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
 = 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)
ρ = 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)

1. Introduction

Demand for thermal energy accounts for around 70% of total energy consumption in automobile 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.

2. Indian Automobile Industry

According to Society of Indian Automobile manufacturers (SIAM), The Indian automobile industry is one of the largest in the world. The industry accounts for 7.1 per cent of the country's Gross Domestic Product (GDP). As of year 2014-15, around 31% of small cars sold globally are manufactured in India. The Two Wheelers segment with 81% market share is the leader of the Indian Automobile market because of growing middle class and a young population. The overall Passenger Vehicle (PV) segment has 13 % market share. India is also major auto exporter. In 2015, exports of Commercial Vehicles registered a growth of 18.36 % over 2014. The automobile industry produced a total 19.84 million vehicles in 2015, including passenger vehicles, commercial vehicles, three wheelers and two wheelers, as against 19.64 million in 2014. Following figure 1 gives the brief history of automobile production in India for last few years **[1]**:-

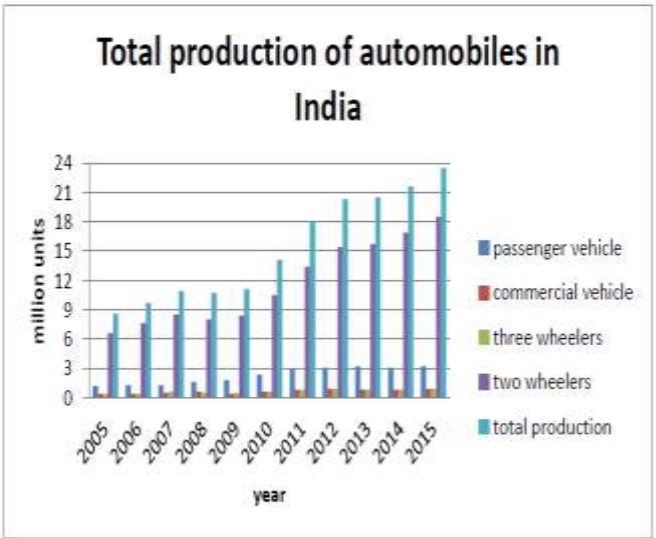

Figure1:- total automobile production in India for year 2015 (source:- SIAM)

Hence automobile industry has become 3rd larges t in the world in 2016 just behind Germany and Japan. Therefore to meet this growing demand, several automobile manufacturers have started investing heavily in industry during the last few months. The industry has attracted Foreign Direct Investment (FDI) of worth US 14.32 billion dollars from period 2000 to 2015, according to Department of Industrial Policy and Promotion (DIPP).

3. Automobile Manufacturing Process Flow Chart

Manufacturing of automobile is achieved through well designed and sequenced processes which are executed in 3 main production shops i.e. paint shop, body shop and assembly shop. Foundry shop includes processes like metal melting furnace, tempering furnace, anti corrosion coating and drying of castings. Body shop include processes like press shop, dip zinc phosphate. Engine shop includes processes like engine components machining, component cleaning, and component drying. Axle shops include processes like components machining, component cleaning, and component drying. Paint shop includes processes like electrode position, paint baking, primer coat, paint baking, base coat, paint baking, finish coat, paint baking. All these final products are send to assembly shop where they are assembled together to make completely functional automobile. Following figure 2 shows the automobile industry manufacturing process flow chart indicating he direction of material flow in all major production shops:-

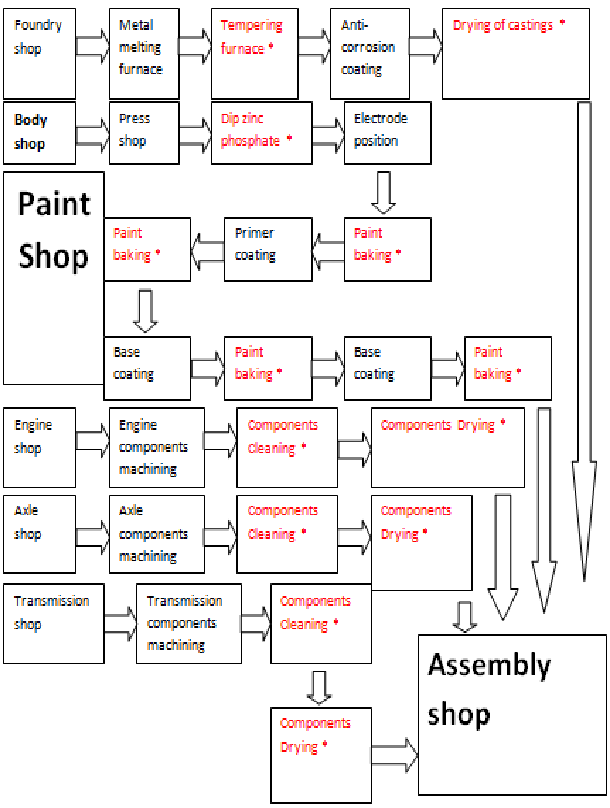

Figure2:- Automobile Manufacturing Process flow chart

Some of the manufacturing process requires thermal energy at different temperature range. These manufacturing processes are shown in figure 2, marked with * require thermal energy at temperature range appropriate for that process. All these 6 manufacturing processes along with their temperature range required, current fuel source being used, and heat transfer medium being used in shown in following table 1:-

Table 1:- Automobile Manufacturing processes requiring thermal energy

S. No.	Process Name	Fuel source used	Working medium	Temperature (°C)
1	Tempering furnace	Natural gas	Hot air	200
2	Drying of castings	Natural gas	Hot air	100
3	Dip zinc phosphating	Electricity	Pressurized hot water	80
4	Paint curing process	Natural gas	Steam	200
5	Components washing	Electricity	Pressurized hot water	90
6	Components drying	Natural gas	Hot air	90

4. 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. 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. Following figure 3 shows the major components of solar paraboloid dish collector:-

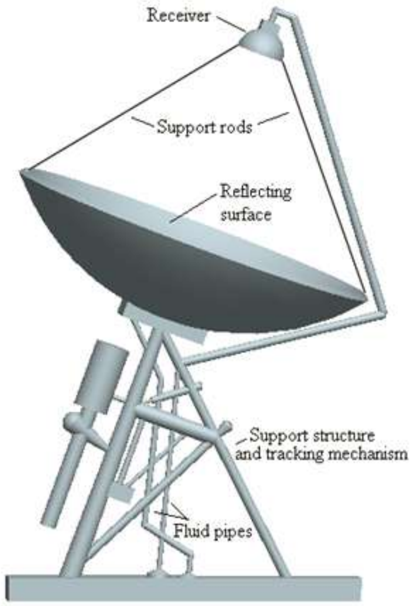

Figure3:- Paraboloid Dish solar collector with major components

High solar to thermal efficiency of this solar paraboloid system is about 60%. Simple energy balance equation also called fundamental solar collection equation governs the performance of solar paraboloid dish collector. 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 no. 1 gives the basic design energy balance equation **[2],[8],[9]**:-

$$Quseful = Ib,n * Aapp * E * (cos\theta i) * \rho * \Phi * \square * \alpha - Arec\,[U * (Trec - Tamb) + \sigma * F * (Trec4 - Tamb4)]$$

15 m diameter solar paraboloid dish at 1000 w/m2 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/m2, 55.8% receiver efficiency and 45.3% overall system efficiency at 150 W/m2. 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 Table 2 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 **[8],[9]**:-

Table 2:- Design Calculation procedure for Solar Paraboloid dish

diameter of paraboloid 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

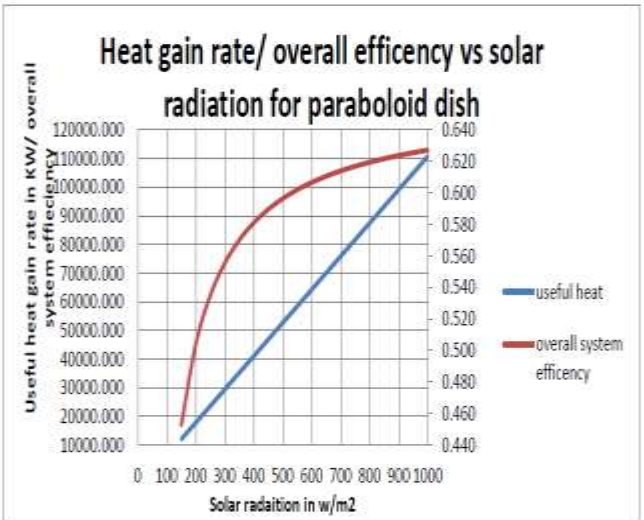

Figure 4:- overall system efficiency/ useful heat gain rate Vs solar radiation curve

Overall system efficiency curve follows parabolic relationship with increasing solar radiation and reaches peak value of 62.7% for 1000 W/m2 and low value as possible for 150 w/m2 of 45.3%. On the other hand useful heat gain rate follows linear relationship with increasing solar radiation. Following figure 4 gives the variation for overall system efficiency and useful heat gain rate with DNI values as follows:-

5. Integration of Siph System with Automobile Industry

Solar industrial process heating system designed in previous chapter needs to be integrated in existing steam generation and distribution network of automobile industry. Smooth integration in the existing thermal energy system can result in lower payback periods and optimum performance. Also system needs to be reliable so backup system is also provided based on existing fossil fuels to supply energy continuously to industry for non solar hours. Also proposed layout of SIPH system is discussed along with necessary control instruments, other accessories etc. VECV manufacturing facility is located at pithampur, Indore in Madhya Pradesh. Facility is spread over 100 acres in special economic zone (SEZ). It is situated at a distance of 32 KM from Indore railway station and 28 KM from Indore airport. Location of the VECV manufacturing plant is given by the following coordinates **[3]**:-

Latitude:- 22.614088° N
Longitude:- 75.673688° E

The following figure 5 shows the VECV manufacturing plant at Indore on google satellite images along with physical installation model of 10 number of 15 m diameter solar paraboloid dish erected along vehicle testing track to save space and parallel to it lies the space which can be used for future expansion if needed, as follows:-

Figure 5:- Satellite image for VECV Manufacturing facility at Indore

Site for installation of 15 m diameter solar paraboloid collectors have been identified near testing track built for Vehicle testing behind the Main Assembly line building. Selected collector site area has dimension given by 280 m by 70 m which gives the total area available as 19600 m2 which is totally shade free area. Single 15 m diameter solar paraboloid dish concentrator has a total aperture area of 176 m2 which will require total shade free area of 250 m2. Hence 10 number of solar collectors need to be installed in phase 1 for technology demonstration, hence total shade free area required is 250 * 10 = 2500 m2. Following figure 6 shows the 10 number of solar collectors installed at site stated above along with shadow analysis for 23rd December as follows:-

Figure 6:- Shadow analysis for 15 m diameter solar collector array

Solar paraboloid based Process heating system needs to be integrated in existing steam generation and distribution system to make SIPH system more reliable and easy to incorporate. Existing steam system is based on fossil fuel fired boiler and solar thermal collectors are integrated with it via steam pipelines, solenoid valve and pumps, etc. Solar paraboloid dish concentrator produces the steam at 225°C and 25 bar pressure which is fed to steam insulated pipelines indicated by red arrows along with their direction of flow. Steam now enters the steam separator where steam is separated from water, steam is send to header pipe and water is send to recirculation pump to pump it back to dish receiver. Steam passes through solenoid valve to enter steam distribution header where it is distributed to 3 main production shops to cater thermal load i.e. paint shop, body shop and assembly shop.

Steam after losing its heat gets converted back to condensate which is trapped and sends back to condensate tank via condensate insulated pipeline indicated by blue arrows. Condensate pump pumps the condensate to feed water tank and make up water is also added to compensate water lost in circuit. Recirculation pump pumps the condensate back to solar collector receiver to complete the circuit. The fossil fuel fired boiler is used as heat source in case on non solar hours as back up or used continuously in night time if night shifts are also working. Hence P&I diagram consists of two steam water circuits i.e. one based on boiler system and other based on solar collector array. Programmable Logic circuit (PLC) based control system is used to control operations of all pumps and solenoid valve based on preset levels of steam temperature and pressure.

Following figure 7 shows the Schematic Pressure and Instrumentation (P & I) diagram for SIPH system for automobile industry as follows **[7]**:-

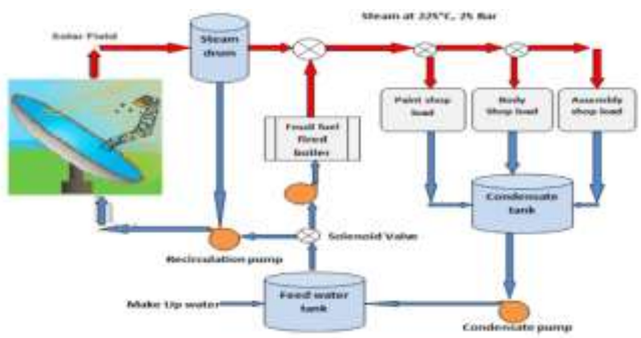

Figure 7:- Schematic P&I diagram for SIPH system at automobile industry

6. Economic Analysis of Siph System

After designing the 15 m diameter solar paraboloid dish system for SIPH system at automobile industry, we integrated the SIPH system into existing steam generation system. Now we discuss the economic feasibility of SIPH system in terms of solar fraction achieved and payback period expected by the Automobile industry for the investment made by them. First Annual energy estimation for the VECV manufacturing plant is estimated and also annual energy generation potential for the solar collector array is also estimated. VECV manufacturing plant works for 275 days in a year. It remains closed only on national holidays and weekends. 10 hours shift work is done every day but shift can be increased depending upon the amount of work pending in future. 600 to 800 KWh thermal energy is required for each automobile being manufactured in the plant depending upon the type of model i.e. light commercial vehicle (LCV) or heavy commercial vehicle (HCV). Mostly LCV is manufactured therefore we consider 600 KWh for calculation basis. 12 numbers of vehicles are produced per working hour on heavily automated manufacturing lines. Hence 120 automobiles are produced daily on a working day at VECV plant, Indore. Also number of working days per month is also listed in above table which estimates the Annual thermal energy required in plant at 1,98,00,000 KWh or 19800 MWh thermal units.

Annual thermal energy requirement for the VECV manufacturing plant at Indore is calculated by multiplying total number of vehicles being produced daily with number of working days in a year and also with thermal energy required in KWh for each vehicle being produced. Following table 3 shows the annual thermal energy required in KWh_{th} for the plant on monthly basis as follows [3]:-

Table 3:- Design Calculation procedure for Annual energy estimation for VECV plant

month	average dni values in KWH/m2/day	no. of sunny days in month	no. of working hours in month	rated thermal power (KW) at 1000 w/m2	monthly units generated by one dish (KWH thermal)	monthly units generated by 10 dishes (KWh)
jan	6.27	25	156.75	110	17242.5	172425
feb	7.15	26	185.9	110	20449.0	204490
mar	7.03	28	196.84	110	21652.4	216524
apr	6.78	29	196.62	110	21628.2	216282
may	6.86	29	198.94	110	21883.4	218834
jun	4.60	27	124.2	110	13662.0	136620
jul	2.23	23	51.29	110	5641.9	56419
aug	1.89	22	41.58	110	4573.8	45738
sep	4.12	26	107.12	110	11783.2	117832
oct	6.70	26	174.2	110	19162	191620
nov	6.24	25	156	110	17160.0	171600
dec	6.22	24	149.28	110	16420.8	164208
total		310			191259.2	1912592

Annual energy generation potential for single 15 m diameter solar paraboloid dish is estimated on the basis of solar resource at the site at Indore as stated above. Monthly DNI values are stated along with number of sunny days at plant site which are above 300+ for Indore region. Rated thermal power for one solar dish is 110 KW at 1000 w/m2 irradiance for design purpose. Monthly thermal units generated by one dish are calculated by multiplying rated thermal power with number of sunny hours in given month. Annual thermal units generated are 191259.2 KWh for one dish. As 10 numbers of dishes are present in the array, total number of thermal units generated annually is 1912592 KWh or 1912.592 MWh. Following table 4 gives the design procedure for calculating annual energy estimation for solar paraboloid dish based SIPH system as follows[4]:-

Table 4:- Design Calculation procedure for Annual energy generation for SIPH system

month	no. of working days for plant	amount of thermal energy required per vehicle (KWh)	no. of vehicles produced per hour	no. of hours per day	monthly thermal units required for plant (KWH thermal)
jan	22	600	12	10	1584000
feb	22	600	12	10	1584000
mar	25	600	12	10	1800000
apr	22	600	12	10	1584000
may	23	600	12	10	1656000
jun	23	600	12	10	1656000
jul	22	600	12	10	1584000
aug	24	600	12	10	1728000
sep	23	600	12	10	1656000
oct	23	600	12	10	1656000
nov	23	600	12	10	1656000
dec	23	600	12	10	1656000
total	275				19800000

Now we have data for total energy required for the plant annually along with energy that can be generated through solar collectors. Now we calculate individually for each month how much energy demand can be met for the plant through solar route i.e. solar fraction defined as ratio of amount of energy generated by solar divided total energy requirement for the industry annually, can be estimated. Month for which performance for solar collectors is high, solar fraction would also be high. Also during monsoon period when performance levels are low. Solar fraction will also be low. Annual average for Solar fraction is calculated by dividing thermal energy output of solar collector array i.e. 1912592 KWh by annual thermal energy required for the plant i.e. 19800000 KWh, which comes around 9.7 % i.e. around 10%. Following data can be represented in
the form of parallel bar graphs indicating energy requirements for industry alongside with energy generation levels for each month in figure 8 **[4]**:-

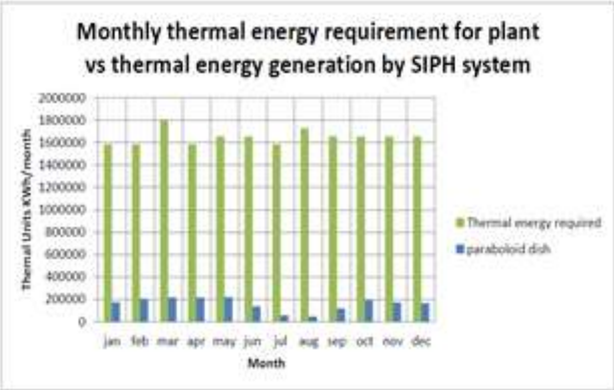

Figure 8:- Monthly Thermal energy requirement Vs generation for SIPH system at Indore

After designing the solar paraboloid dish based SIPH system and integrating the system into existing steam system at VECV plant, we estimated the solar fraction possible for the system. Finally Economic analysis for the SIPH system should be done by estimating the annual savings due to use of solar energy for replacing fossil fuels for thermal energy requirement. This fuel cost of Rs 8.54/- per thermal unit will be used for calculation of payback period for the system. Following table 5 shows the calculation steps for the payback period estimation of Solar paraboloid dish based SIPH system at VECV plant , Indore as follows[4],**[5],[6]**:-

Table 5:- Calculation table for Payback period for SIPH system at VECV, Indore

Design Parameter Description	Design Values
Rated Power of 15 m diameter solar paraboloid dish at 1000 W/m^2	110 KW
Average annual DNI value for VECV manufacturing site, Indore	5.51 KWh/m^2/day
Annual number of clear sunny days for VECV plant site at Indore	310 days
Annual thermal energy generation of one 15 m diameter solar dish (= rated power * annual DNI * Sunny days)	191259.2 KWh
Number of Solar paraboloid dishes installed at VECV	10
Total thermal energy generation for solar collector field	1912592 KWh
Number of working days annually for VECV plant	275 days
Capacity of manufacturing line at VECV	12 vehicles/ working hour
Number of working hours per day	10 working hours/ day
Number of vehicles produced annually at VECV plant (= working days * line capacity * working hours per day)	33000 Vehicles annually
Specific thermal Energy requirement for each vehicle produced for all production processes at VECV	600 KWh/ vehicle
Annual thermal Energy requirement for the VECV plant (= annual production * energy required per vehicle)	19800000 KWh annually
Solar Fraction achieved for designed SIPH system (= annual energy generation/ annual energy requirement)	**9.65 %**
Concentrating Aperture Area of one 15 m solar dish	176 m^2
Concentrating Aperture Area of Ten 15 m solar dish	1760 m^2
Cost of Two axes tracking based solar concentrator per m^2 as per MNRE standards	Rs 20000/- per sq m
Cost of 176 m^2 solar paraboloid dish (= MNRE cost per sq m * aperture area of one dish)	Rs 3520000/-
Cost of Installation of dish at site i.e. civil foundation work, steam piping work and annual Operation and Maintenance charges @ 20 % of total project cost as per MNRE standards	Rs 704000/-
Total cost of one 176 m^2 solar dish (= concentrator cost + installation/O & M cost)	Rs 4224000/-
Total cost of Ten 176 m^2 solar dish for complete array	**Rs 42240000/-**
Capital Subsidy available for Two axes tracking based solar concentrator per m^2 as per MNRE standards	Rs 6000/- per sq m
Total capital subsidy available for 1760 m^2 of solar concentrator aperture area installed at VECV plant (= capital subsidy @ per sq m * total sq m installed)	**Rs 10560000/-**
Actual Cost to be incurred by VECV management after cutting subsidy benefits	Rs 31680000/-
Tax benefits available for industrial consumer under 80 % accelerated depreciation rule under Income tax act 32 @ 30 % central tax rate (= Actual cost * 0.8 * 0.3)	**Rs 7603200/-**
Final investment required for the SIPH system at VECV plant, Indore (= Actual cost – Tax benefits)	**Rs 24076800/-**
Cost of fuel source (mix of electricity and natural gas)charged to VECV plant management	Rs 8.54/- per KWh
Annual savings due to installation of SIPH system for automobile industry (= Annual energy generation * fuel cost)	**Rs 16333536/-**
Payback period for SIPH system at VECV, Indore (= Final investment made / Annual savings due to solar energy)	**1.47 years**

7. Result of the Present Work

After studying the energy consumption profile of automobile industry and its manufacturing process flow chart, we designed the solar paraboloid dish based industrial process heating system. This SIPH system was integrated into the existing automobile industry steam generation and distribution network. Finally economic analysis of designed SIPH system was done to show its economic viability. In last chapter we compile the results of the present work along with conclusions and future recommendations if any.

Results of the performance of 15 m diameter solar paraboloid dish at VECV plant site has been compiled in the form of table with major parameters mentioned like physical dimensions of the paraboloid dish, Energy generation potential of single dish and complete array, total energy requirement for the VECV plant, integration within the VECV plant, costing of the installation of SIPH system and its economic analysis in the form of payback period. Following table 6 shows the results of the present work titled Designing of Solar process hearting system for Indian automobile industry as follows:-

Table 6:- Results table of present wok of SIPH system at VECV, Indore

Design Parameter Description	Design Values
Rim angle of paraboloid dish	45°
Focal length to diameter ratio	0.6
Diameter of paraboloid dish	15 m
Focal length of receiver	9 m
Reflectivity for solar grade mirror	95%
Angle of incidence	0°
Un shaded aperture area fraction	95%
Capture fraction of the receiver	90%
Transmittance of the receiver	90%
Absorptance of the receiver	90%
Overall heat loss coefficient at 7.5 m/sec wind velocity	30 W/m^2- K
Receiver operating temperature	225° C
Geometric concentration ratio of dish	225
Equivalent radiative conductance	50%
Useful heat gain rate at 1000 w/m^2	114 KW
Rated Steam delivery conditions from solar paraboloid dish	225°C, 25 Bar
Steam enthalpy at 225°C, 25 Bar	2801 KJ/ KG
Rated steam delivery output	140 KG per hour
Peak overall system efficiency at 1000 w/m^2	64%
Average annual DNI at VECV plant, Indore	5.51 KWh/m^2/day
Number of sunny days in a year at site	310 days
Annual thermal units generated by single dish	191259.2 KWh
Annual thermal units generated by 10 dish array	1912592 KWh
Daily production capacity of VECV plant	120 vehicles/working day
Number of working days in a year for plant	275 days
Annual thermal energy requirement of VECV plant	19800000 KWh
Cost of fuel replaced per unit (Electricity/ Natural gas)	Rs 8.54/- per KWh
Total cost of one solar dish	Rs 4224000/-
Total cost for 10 dishes	Rs 42240000/-
Actual cost incurred by the VECV management after subtracting subsidies and associated tax benefits	Rs 24076800/-
Total annual savings due to SIPH system at Indore	Rs 16333546/-
Payback period for the project	1.47 years
Solar fraction achieved for SIPH system	9.65%

8. Conclusion and Recommendations for the Siph System

Finally the technical feasibility of the solar process heating system for the industry has been proved along with is economic feasibility. Thus solar paraboloid based SIPH system can be installed at various automobile 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 automobile industry is suitable for this type of concentrating solar thermal technology because of following reasons:-

1. Automobile 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.
2. All these automobile 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.
3. Automobile 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.
4. Also automobile 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 pharmacy sector, textile sector, food and beverages sector, paper and pulp sector, etc. For future, VECV industry can install more number of Solar paraboloid dishes at area vacant next to current solar filed which can raise further solar fraction of existing SIPH system from 10% to 20%.

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