Project Report of Major – II

DESIGNING OF SOLAR PROCESS HEATING SYSTEM FOR INDIAN AUTOMOBILE INDUSTRY

Submitted in the partial fulfilment of the requirement for the award of degree of

Master of Technology

In

Renewable Energy Technology

Submitted by:

Anubhav Uppal

(2k14/RET/07)

Under the guidance of:

Dr J.P Kesari (Associate Professor)

Mr Mohd. Zunaid (Assistant Professor)

Department of Mechanical Engineering and Production & Industrial Engineering

DELHI TECHNOLOGICAL UNIVERSITY, Shahbad Daulatpur, Main Bawana Road, Delhi -42

DECLARATION

I hereby declare that the work, which is being presented in this dissertation, titled "**DESIGNING OF SOLAR PROCESS HEATING SYSTEM FOR INDIAN AUTOMOBILE INDUSTRY**" towards the partial fulfilment of the requirements for the award of the degree of **Master of Technology** with specialization in **Renewable Energy Technology**, from Delhi technological University Delhi, is an authentic record of my own work carried out under the supervision of **Dr. J.P. Kesari**, Associate Professor, Department of Mechanical Engineering, at Delhi Technological University, Delhi.

The matter embodied in this dissertation report has not been submitted by me for the award of any other degree.

ANUBHAV UPPAL

2K14/RET/07
Place: Delhi
Date: 01/06/2016

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

DR J.P. Kesari

Associate Professor
Department of Mechanical Engineering
DTU
Delhi-110042

Mr Mohd. Zunaid
Assistant Professor
Department of Mechanical Engineering
DTU
Delhi-110042

CERTIFICATE

It is certified that Anubhav Uppal Roll No. 2K14/RET/07, student of M. Tech Renewable Energy Technology, Delhi Technological University, has submitted the dissertation titled "**DESIGNING OF SOLAR PROCESS HEATING SYSTEM FOR INDIAN AUTOMOBILE INDUSTRY**" under my guidance towards the partial fulfilment of the requirements for the award of the Degree of Master of Technology.

His work is found to be satisfactory and his discipline impeccable during the course of the project. His enthusiasm, attitude towards the project is appreciated.

I wish him success in all his endeavours.

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Mr Mohd. Zunaid

Assistant Professor
Department of Mechanical Engineering
DTU
Delhi-110042

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ANUBHAV UPPAL

2K14/RET/07

ABSTRACT

Indian Automobile industry is under considerable strain 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 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 heat or steam. Thermal energy accounts for around 70% of all automobile industry's total energy consumption and while solar thermal collectors can provide a large share of this industrial process heat, the collector technology used depends upon a great deal on the temperatures involved. The use of an appropriate solar thermal technology can have a positive impact on the energy and environmental scenario of Automobile industry at a large. There are various solar thermal technologies including CST technologies that are available for Automobile industries. Flat plate collectors and evacuated tube collectors can be used with a reasonable level of efficiency at temperatures of up to around 130°C but for temperatures higher than this, concentrating collector systems such as Fresnel-Collectors, parabolic dishes and Parabolic-Trough-Collectors can give greater efficiency. Objective of the present work is to design solar paraboloid dish based process heating system for Indian Automobile Industry at VECV Indore plant.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

CASE : Commission for additional sources of energy

CEA : Central Electricity Authority

DNI : Direct Normal Irradiance

GHI : Global Horizontal Irradiance

IEA : International Energy Agency

IREDA : Indian Renewable Energy Development Agency

IRENA : International Renewable Energy Development Agency

KWh : Kilo watt hours

MNES : Ministry of Non Conventional Energy sources

MNRE : Ministry of New and Renewable Energy

MTOE : Million Tonnes of oil Equivalent

MW : Mega Watts

RET : Renewable Energy Technology

UNDP : United Nation Development Program

LPG : liquefied Natural Gas

MOP : Ministry of Power

TERI : The Energy Resource Institute

CHAPTER 1: INTRODUCTION

Energy is the basic need of human life. Also it is one of the major inputs required for the development of nation. In fact energy is used as a parameter to compare development levels of developing nation with those of developed countries. As the population of the world is increasing day by day, energy demand is also increasing exponentially. Today majority of this energy demand is met through fossil fuels (coal, oil and natural gas) which have created a major problem for mankind in form of global warming. Limited nature of these sources of fuel and relatively high prices has forced the world to make huge investments in the field of alternate sources of energy (wind, solar, tidal, etc).

Energy can be classified as:-

1. **Renewable energy: -** energy obtained from the sources that are inexhaustible in nature i.e. energy from sun, biomass, wind, oceans, etc. these energy sources can be harnessed without any release of harmful pollutants.
2. **Non renewable energy: -** energy obtained from the sources that are exhaustible in nature i.e. energy from conventional fuels like coal, oil and gas which will be gone by next 50 to 75 years.

Despite major dependence on fossil fuels in power sector and transportation sector, now world has decided to move towards sustainable way of development in form of recent growth in worldwide renewable energy power generation plants.

1.1 WORLD ENERGY SCENARIO

International organisations like international energy agency have published the **World Energy Outlook 2015: global energy trends to 2040.** Important highlights of this report show the recent trends and current energy consumption data of the world. Analysing this data will help us to understand the current issues in the energy sector and associated problems with current energy scenario. We will use this analysed data to find out useful solutions to this current problem which is sustainable and environment friendly in nature.

1.1.1 GLOBAL ELECTRICITY GENERATION BY SOURCE

Worldwide electricity is generated from variety of different sources like fossil fuels like coal, oil and natural gas, Nuclear power and renewable energy sources like hydro power, wind power, solar power, other renewable sources, etc. majority of power still comes from fossil fuel based power plants with an share of 67% in total electricity generation for year 2014 which is equivalent to 15000 TWh and more units generated. Related CO_2 emissions with fossil fuel based generation source for year 2014 was 12 gigatons. Following table gives the 2014 vs. 2040 scenario of world electricity generation based on different sources **[1]**:-

Table1:- Global Electricity Generation by source for 2014 vs. 2040 (source: - IEA)

source	Global electricity Generation by source (2014)	Global electricity Generation by source(2040)
renewables	5000	13500
coal	10000	11800
gas	4800	9000
nuclear	2500	4500
oil	750	1250

Following data shows that after fossil fuels, Renewable energy and Nuclear Energy sources are major sources used worldwide for electricity generation with a share of 22% and 11% respectively. Following pie chart Gives the percentage share of different sources in worldwide scenario:-

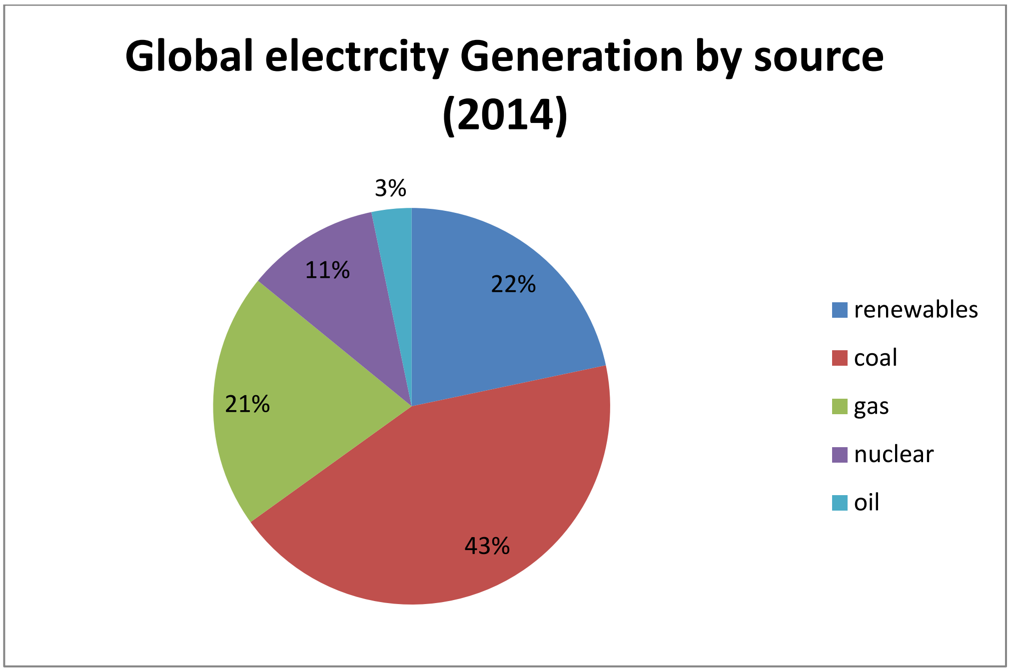

Figure1:- percentage share of different energy sources 2104 (source: - IEA)

Also high share of fossil fuel based electricity generation is directly related to high levels of CO_2 Emissions annually. From the last 2 decades, CO_2 Emissions have increased from 6 Gt in 1990 to 12.50 Gt in 2015 i.e. Green house Gas emissions have doubled with total electricity generated from 11000 TWh in 1990 to 23000 TWh in 2015. This shows that in last 2 decades only fossil fuel based sources were developed throughout world at very fast rate resulting in problem of Global warming and climate change. Following table shows the relationship between carbon dioxide emissions and electricity generated from 1990 to 2030:-

Table2:- year wise carbon dioxide emissions and electricity generation (source: - IEA)

Year	**CO2 emissions (Gt)**	**Electricity generation (1000 TWh)**
1990	6.40	10.8
1995	7.50	11.8
2000	9.00	15.7
2005	11.00	19.6
2010	11.80	20.7
2015	12.50	23.0
2020	12.00	27.0
2025	12.50	30.5
2030	12.50	33.4

After Paris climate change summit in 2015, whole world decided to lay more emphasis on carbon free sources of generation for electricity purpose to have sustainable development of whole world. Therefore it is clear from table 2 that after 2015 till 2030 the CO_2 emissions have become constant at around 12 Gt or more but electricity generation has increased from 23000 TWh in 2015 to 33000 TWh in 2030. This constant CO_2 emissions shows that new generation sources mainly came from Renewables (hydro, solar, wind, other), Nuclear and Gas based sources. Following figure gives the comparison between total electricity generation by different source for year 2014 vs. 2040:-

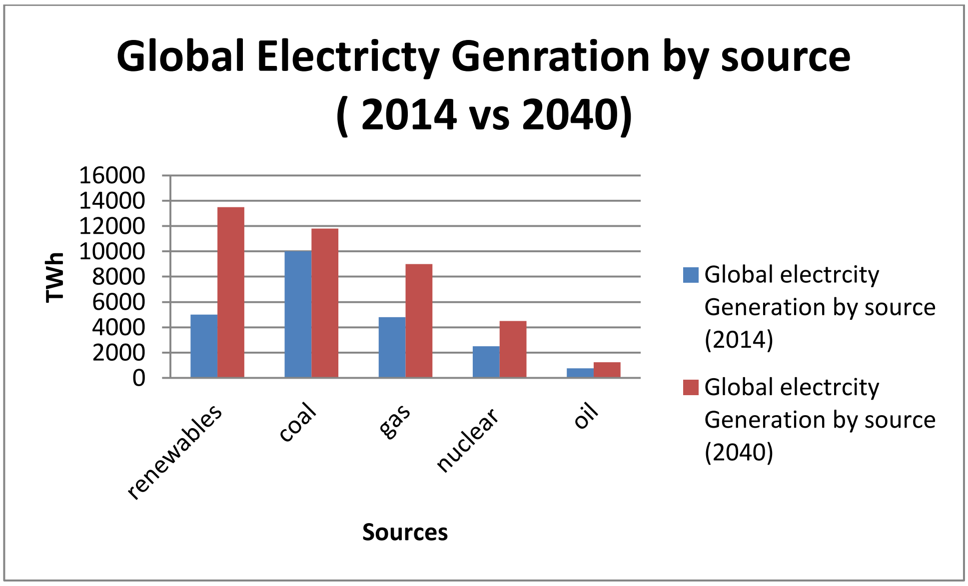

Figure2:- Global electric generation for year 2040 (source: - IEA)

Electricity generation from Renewable energy sources have changed from 5000 TWh in 2014 to 13500 TWh in 2040 i.e. almost it has become 3 times from 2015. Percentage share of fossil fuel based generation has gone down from 67% in 2015 to 55% in 2040 and at the same time renewable energy based sources has gone up from 22% in 2015 to 34% in 2040 which shows that 12% in fossil fuels usage in next 25 years to 12% more renewable energy usage in next 25 years. This historic shift in world energy scenario is directly linked with stabilization of world CO_2 Emissions from 2015 t0 2030 as shown in this figure:-

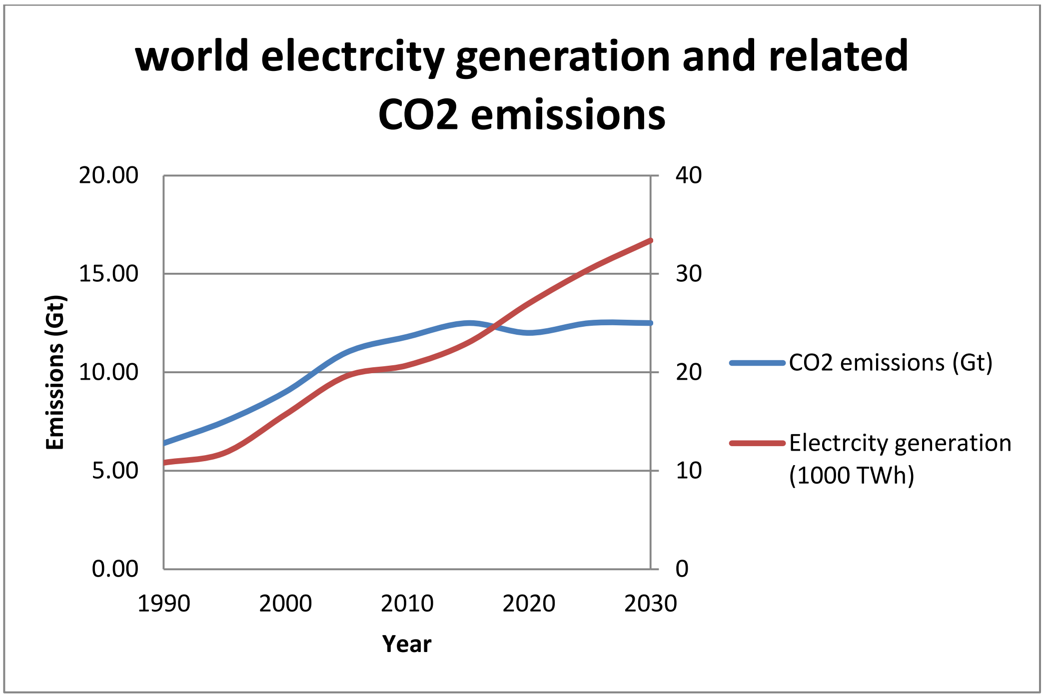

Figure3:- world electricity generation and related CO_2 emissions (source: - IEA)

1.2. INDIAN ENERGY SCENARIO

India's energy demand has grown exponentially in last few decades which are directly related to its recent economic and population growth. Recent trends like urbanisation and industrialization has fuelled the energy demand in India. Keeping in view of this situation government of India are making efforts to invest heavily in energy sector to supply energy for all its population. Energy demand in India has a percentage share of 5.7% in global energy demand for year 2013. With 18% of total world population, per capita energy consumption is still very low at 1/3rd of world average which allows for a strong energy demand growth. Main reason for this low energy consumption is that large population i.e. 240 million people still remains without modern energy as they are out of reach of power system. Following figure gives the comparison between per capita energy consumption between India and world **[2]**:-

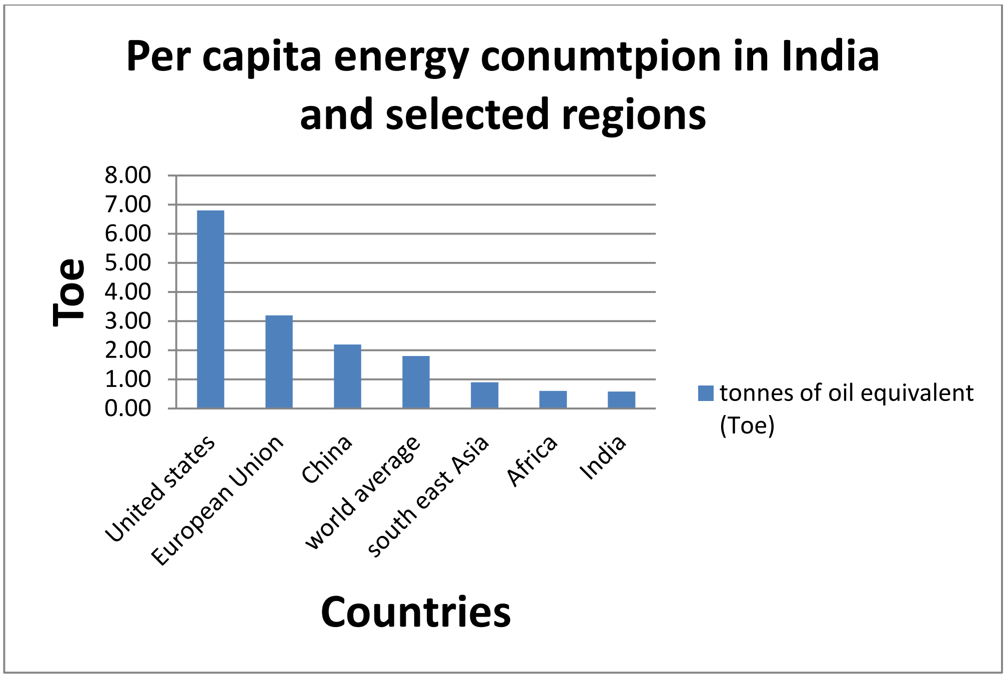

Figure4:- Per capita energy consumption in India and selected regions (source: - IEA)

Primary energy demand and Gross domestic product (GDP) in India is related directly as GDP of India has resulted in growth from 3600 Billion US dollars in 1990 to 7800 billion US dollars in 2013 along with primary energy demand from 260 Million tonnes of oil equivalent in 1990 to 680 Million Toe in 2013. Also India GDP growth for 2015 was at 7.5% with an equivalent growth in Energy demand. Following figure gives the relationship between GDP and total primary energy demand as discussed above:-

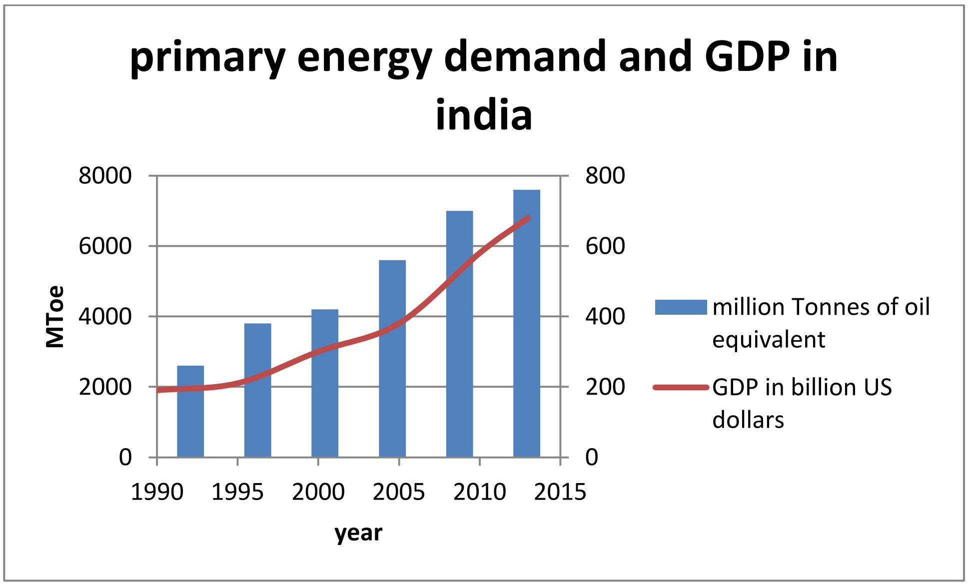

Figure5:- primary energy demand and GDP in India (source: - IEA)

1.2.1 PRIMARY ENERGY DEMAND IN INDIA BY FUEL

70% of the Indian energy demand is met by fossil fuels due to rapid rise in consumption of coal with a share of 44% in total energy demand of 775 MToe for year 2013. On the other hand demand for bio energy i.e. solid biomass like fuel wood, straw, charcoal, or dung have decreased as households have moved to Liquefied petroleum gas (LPG) for cooking purposes. Oil consumption is mainly for transportation sector with diesel having 70% share in oil market. Natural gas has small share about 6% in energy mix used mainly for power production and fertilizer industries. Hydropower, nuclear power, renewable sources like wind, solar, geothermal is used at very small scale in power sector. Following pie chart gibes the current scenario of India energy mix:-

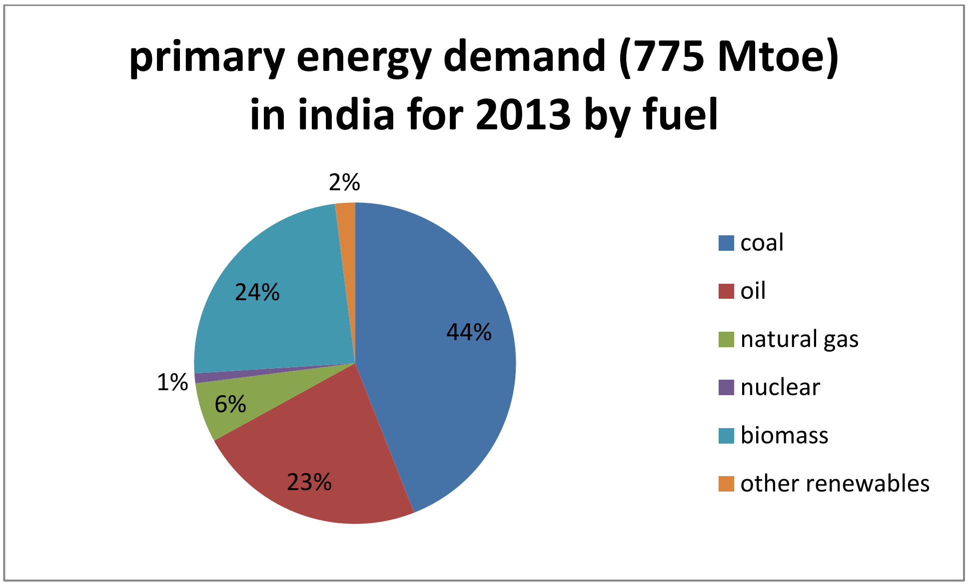

Figure6:- primary energy demand in India by fuel (source: - IEA)

1.2.2 FOSSIL FUEL BALANCE IN INDIA

Fossil fuel balance in India is more on the import side than export side with 200 Mtoe of crude oil imports, 120 Mtoe of coal imports and 15 Mtoe of natural gas imports for year 2013. All these imports have a very acute effect on India economy as high fuel prices means high economic trade deficit for India. Also domestic production of fossil fuels in India is not at very high level to ensure energy security for India in recent future. Following figure gives the balance between fossil fuels export- import for year 2013:-

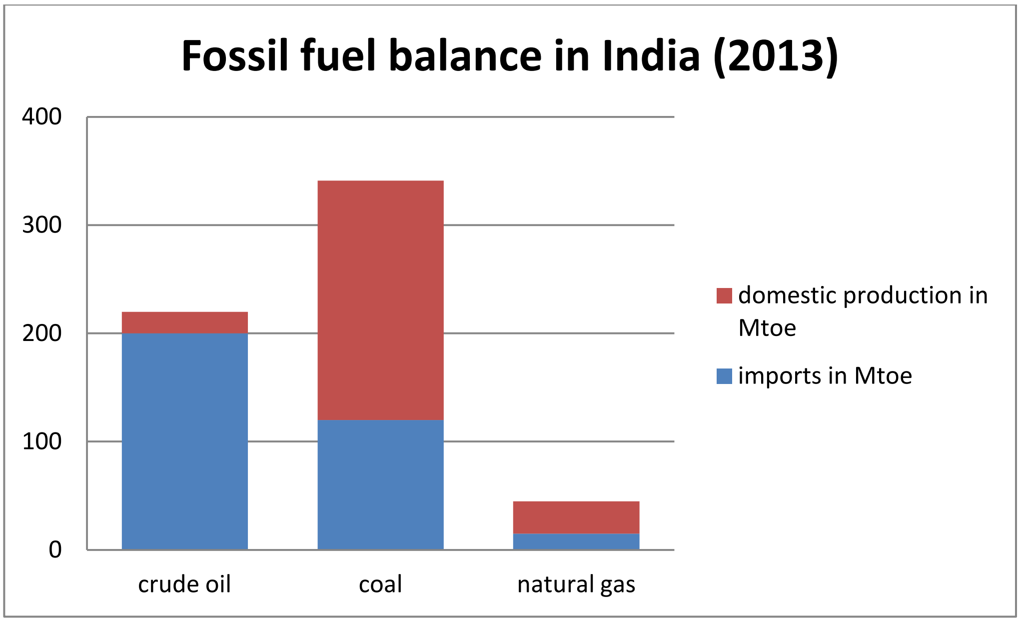

Figure7:- fossil fuel balance in India 2013 (source: - IEA)

COAL

India has third highest coal reserves in the world i.e. 12% of the world total but these deposits are of low quality due to less calorific value and high ash content; hence India faces major problems in meeting the coal demand of its country with current resources. In 2013, India produced a 340 million tonnes of coal equivalent (Mtce) and imported 140 million tonnes of coal equivalent from Indonesia, Australia, and South Africa. To curb imports Government of India has ordered to double its coal production by 2020. Coal sector is dominated by government organisations like Coal India limited (CIL) with 80% of total coal production in India. This heavy reliance on coal for primary energy demand has associated environmental costs with it like land degradation, deforestation, erosion and acid water runoff. Also coal reserves are mainly concentrated in eastern and central India, while demand centres are mainly in North West India, south India which makes it mandatory to transport this coal from source to demand centre via railways which makes energy process high.

OIL

India mainly depends upon crude oil imports for primary energy demand fulfilment as domestic crude oil production is just 900,000 barrels per day and demand is nearly 4.4 million barrels per day. India has low oil reserves i.e. around 5.7 billion barrels mostly located in western part of country like Rajasthan, Gujarat, Maharashtra , in northeast India like Assam , etc. oil sector is dominated by state owned agencies like Oil and natural gas corporation (ONGC) and Oil India Limited (OIL).

NATURAL GAS

Natural gas has small 6% share in domestic energy demand. Main onshore gas producing fields are located in states of Assam, Gujarat, Tamil Nadu, and Andhra Pradesh. Offshore field include Krishna Godavari basin. Total natural gas production was 34 billion cubic metres in 2013. Major gas producing companies are state owned like Gail authority of India limited (GAIL). Also unconventional sources of gas like coal bed methane and shale gas are still in early stages of development in India.

HYDROPOWER

Current hydro power based generation capacity stands at 45 GW with 10% of it falling in small hydro power (SHP) category. Only 1/3rd of total hydro potential has been harnessed and future has much more to achieve mostly in north east India. But major issues in the development of these plants are technical and environmental problems like public opposition. Apart from being clean source of power, hydro power projects also help in water management for flood control, irrigation and domestic proposes. High upfront costs especially for large hydro projects with long term dept financing issues have stalled the further growth in last decade. Hence government has laid more emphasis on small hydro project with upper limit as 25MW for power generation with total installed capacity as of 2016 over 4GW.

BIOENERGY

Bio energy is responsible for 25% share of total energy consumption of India with major usage in cooking in rural households. This traditional use of biomass has given rise to major issues like adverse effects on heath due to indoor polluting. As of 2016 nearly 8 GW of biomass base power in India is operational i.e. mainly bagasse cogeneration. National bio energy mission has been launched by government to popularise use of biomass gasifiers, bio fuels, etc. blending of bio fuels in conventional fuel up to 20% has been set up a s target of National Bio energy mission.

WIND AND SOLAR

Renewable energy is rapidly growing in India to achieve Re Invest 2015 targets of 175 GW renewable energy by 2022. Wind power and solar power are major constituents of these targets set by government of India with 100 GW and 60 GW target respectively. India is currently 4th in wind power installed capacity in the world with 26 GW as of 2016 and in solar power its capacity is over 6.5 GW as of 2016. Gujarat, Rajasthan, Tamil Nadu are three states with 1 GW of solar power alone. Out of 100 GW, 40 GW target has been setup in the target of rooftop which will help in reducing distribution and transmission losses. Also cost of both solar and wind has been under Rs 6 corers per MW with tariff Between Rs 5 To 6 per unit.

NUCLEAR POWER

India has 21 operating nuclear reactors at seven sites with a total installed capacity of 6 GW as of 2016. Another 6 nuclear power plants are under construction stage with capacity around 4 GW. The operation of the existing nuclear plants has been low in the past due to severe fuel shortages i.e. the average load factor was at 40%. This problem was solved after India became a party to the Nuclear Suppliers Group in 2008, allowing access to uranium. The average plant load factor rose to over 80% in 2013. The current share of nuclear power in the generation mix is very small at 3%. India has limited low-grade uranium reserves. The nuclear industry in India is also subject to the challenges faced by worldwide nuclear industry, including project economical difficulties like financing and the consequences of the Fukushima Daiichi accident in Japan.

1.3. INDIAN AUTOMOTIVE 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.Domestic sales of Passenger Vehicles grew by 8.13 % in 2015 over the same period last year. Within the Passenger Vehicles, Passenger Cars rose by 10.18% during 2015 over 2014.The domestic sales of Commercial Vehicles increased by 9.43 % in 2015 over the same period last year. Sales of Medium & Heavy Commercial Vehicles (M&HCVs) increased at 30.19 %. Following figure gives the brief history of automobile production in India for last few years [3]:-

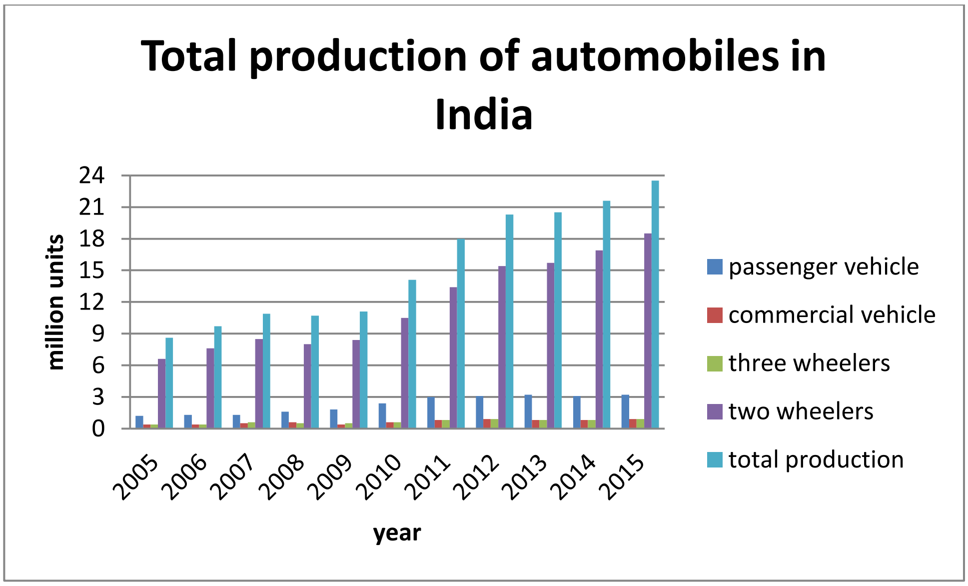

Figure8:- total automobile production in India 2015 (source:- SIAM)

Over 21 million units of automobile were produced in the year 2015 as compared to 9 million units in 2005 which means automobile industry has grown more than twice in last 10 years. 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). Some of the major recent developments in the automobile sector in India are as follows:-

- Japanese two-wheeler manufacturer Honda Motorcycle and Scooter India (HMSI) has opened world's largest scooter plant in Gujarat.
- Nissan Motor Co. Ltd is in discussion with Government of India to bring electric and hybrid technologies to India to reduce air pollution caused by vehicles.
- General Motors to invest US 1 billion dollars in India by 2020 to increase the capacity at the Talegaon plant in Maharashtra.
- US-based car maker Chrysler has planned to invest Rs 3,500 crores in Maharashtra to manufacture Jeep model.
- Mercedes Benz has decided to double its India assembly capacity per annum.

Major players in Indian automobile industry are as follows:-

- AMW motors limited
- Ashok Leyland limited
- Bajaj auto limited
- BMW India private limited
- Daimler India commercial vehicles private limited
- Fiat India automobiles private limited
- Force motors limited
- Ford India private limited
- General motors India private limited
- Hero motor corp
- Hindustan motor limited
- Honda cars India limited
- Honda motorcycle and scooter India private limited
- Hyundai motor India
- Mahindra two wheelers limited
- Maruti Suzuki India limited'
- Mercedes bens India private ltd
- Nissan motor India private limited
- Renault India private limited

The Indian automotive industry has the potential to generate up to US 300 billion dollars annually in revenue by 2026, to create 65 million additional jobs and contribute over 12% to India's Gross

Domestic Product (GDP) according to the Automotive Mission Plan 2016-26 prepared jointly by the Society of Indian Automobile Manufacturers (SIAM) and Indian government.

1.3. OBJECTIVES OF THE PRESENT WORK

Aim of this thesis is to develop automobile manufacturing which is sustainable and environmental friendly by reducing the use of fossil fuels and maximizing the use of solar energy to fulfil thermal needs of industry. Following objectives need to be achieved for successful design of solar industrial process heating system for Indian automobile industry:-

- To study the manufacturing processes involved in automobile industry and select the processes requiring thermal energy.
- To find out the temperature range at which thermal energy is required in these processes in what form.
- To design the feasible concentrated solar heat (CSH) solution to fulfil thermal energy requirement of automobile industry.
- To integrate designed solar industrial process heating system with existing steam generation and distribution system based on fossil fuels in automobile industry.
- To estimate the generation potential of designed SIPH system at selected automobile industry and other parts of India.
- To estimate solar fraction achieved by SIPH system at selected automobile industry.
- To calculate economic feasibility and payback period of the Designed SIPH system

CHAPTER 2: LITERATURE REVIEW

2.1. LITERATURE REVIEW

Martin haagen et al[4]: designed and installed first SIPH system in Jordan at RAM pharmacy based on linear Fresnel reflector (LFR) solar thermal technology. Principle of direct steam generation was applied. Pharma sector plays an important role in GDP of Jordan i.e. around 20% but on the same time has large heat demand. High Direct Normal irradiance (DNI) values in Jordan and fluctuating fuel prices makes a Jordan industry a important market for solar industrial process heat applications. In pharma industry, 65% of the total energy demand is for heating, ventilation and air conditioning (HVAC). Central steam generation system produces steam at 160°C to 180°C to supply all production processes. Fresnel collector modules are installed on the roof of factory with total aperture area of 396 m2 and 222 KW thermal peak capacity.

Oliver iglauer et al[5]: solar industrial process heating system for sustainable automobile production was proposed. Solar process heat is used in paint shop for curing of automobile paint at 200°C. Process heat is generated by using linear Fresnel collector based solar thermal technology. Utilizing renewable solar thermal energy can offset fossil fuel consumption up to 70%. Feasibility of the technology had been evaluated on paint shop of automobile factory in India where integration of solar industrial process heat system has reduced energy demand by 14000 MWh and reduction of 2800 tons of carbon dioxide. Payback time occurs within five years depending on irradiance conditions of the site.

Franz mauthner et al[6]: production of malt and beer requires large amount of thermal energy which is generally produced by burning fossil fuels. Process temperature required is in range of 25°C to 105°C. Solar thermal technologies based on evacuated tube collectors (ETC) are used to integrate solar process heat in production system. Large vessels receive hot pressurized water from solar thermal collectors where production process takes place. 30% solar fraction is achieved with annual generation of 1570 MWh thermal units by solar process heating system. In the above exercise a savings of 38000 tons of carbon dioxide emissions is possible. 1620 m2 gross collector area was installed at rooftop with solar energy storage tank of 350 m3 volume. Solar process heat is used for pasteurization of canned beer at temperature of 85°C.

Thiago P Lima et al[7]: high levels of solar insolation in Brazil have made solar thermal energy with very high potential in Brazil industry to provide thermal energy. Most of industrial process needs hot water which can be easily obtained from flat plate collectors. Technical and financial feasibility of solar water heating system was studied for hospital laundry. System parameters like tilt angle of collector, water flow rate, area of collector and water storage tank size were optimized. Economic analysis was made on the basis of comparing life time savings due to solar water heating system against the current system based on natural gas burner. Finally results showed the consumption in natural gas consumption due to use of solar hot water system and making it a viable option.

Ricardo silva et al[8]: use of parabolic trough solar thermal collector to generate process heat for food processing plant in Spain is studied. Solar industrial process heating system was able to produce saturated steam at 7 bar. SIPH system had parabolic trough collector solar field, thermal energy storage and backup steam boiler. Food sector has thermal energy demand in huge quantities with over 90% energy demand in low temperature to medium temperature range. Southern Spain region enjoys high DNI levels of 1700 KWh/m2/year and above, thus allowing the use of concentrating solar technology to reach high temperature levels with reasonable high efficiency. Solar thermal plant will be integrated with central steam supply system. Total process heat demand is 148 MWh per year supplied currently by fuel oil based boiler.

Christian zahler et al[9]: now a day there is huge pressure on Automobile industry to make their manufacturing processes more environment friendly and sustainable in long term. Curing of car paint is the major manufacturing process with highest share in total energy consumption. Temperature in convection ovens are at 200°C which is in range of concentrated solar technology such as linear Fresnel reflector (LFR). Pilot system has been installed at Durr campus in Germany which consists of 6 modules of LFR with total aperture area of 132 m2. Fossil fuel fired backup boiler is used in case on non sunny hours to meet thermal demand of ovens fully. Heat is released in convective ovens through steam air heat exchanger. Energy consumption is around 700-900 KWh per car body which requires huge amount of fossil fuels to be burned.

Marco Calderoni et al[10]: feasibility study for integration of solar thermal collectors in industrial processes in Tunisia is evaluated in this paper. Textile industry manufacturing processes are evaluated i.e. payback period was calculated and amount of fossil fuel substituted by solar energy was also estimated. Huge potential is already there for solar heat for industrial process in Tunisia as 30% of the total industrial heat demand is required at temperatures between 100°C and 400°C which is in range of concentrating solar thermal technologies. Also highly subsidized fossil fuels in Tunisia have become major cause for low penetration of solar thermal in industry. Main industrial processes in textile industry suitable for solar thermal technology integration are dyeing and ironing. Dyeing process need thermal energy at 98°C.

A Frein et al[11]: design of solar industrial process heat plant for integration with dyeing process of Benetton facility in Tunisia. Total aperture area is 1000 m2. Main aim is to optimize solar plant and sizing of other main components is also done. Dyeing process require huge amount of energy. Hot water is required at 60°C. Use of solar energy for process heating has a potential of saving of 100 MWh annually. 30000 l hot water storage is also being built to increase share of solar energy in total thermal energy requirement. Also government support in form of subsidy to solar thermal plant will help solar process heat market to develop further in Tunisia. Currently highly subsidised fossil fuel mainly natural gas is major hindrance in growth of solar thermal technology.

C. Lauterbach et a[12]l: process heat generation by solar thermal technology has large potential but remains unexploited. Solar thermal system can achieve very large solar fraction for industrial applications. System set up can be very complex due to presence of different heat consumers, temperature sensors and hydraulic circuits. Therefore to design and operate solar thermal system optimally, possible faults that can occur in the system are evaluated. Simulation model for solar process heat system is made and validated against actual setup based on data collected during project monitoring. Faults identified and their influence is evaluated on the system. Final results show that reduced load on system is influential and system yield can be maximised if all faults are eliminated. Important factors for plant optimisation are system efficiency, mass flow rate and temperature.

R J Fuller[13]: research and development for solar industrial process heating system has been going on in Australia for last 30 years. Commonwealth science and industrial research organisation (CSIRO) is carrying out all these activities. Future of SIPH looks very bright in Australia. For Australia to decarbonise its economy, huge growth of Solar industrial process heating system is required at national level for those industries which use huge amount of fossil fuels for producing hot water. Author has reviewed the past installations of SIPH in Australia and analysed the results to find out problems to optimize the systems to be installed in future.

2.2. SOLAR INDUSTRIAL PROCESS HEATING (SIPH) SYSTEM

Process heat required in industries is thermal energy which is used in direct preparation of items manufactured by industry. Traditionally this thermal energy is generated by burning furnace oil, natural gas, coal or electricity. Also large amount of industrial heat is required at low temperatures which can be easily achieved by solar thermal collectors. Yearly usage of solar thermal collectors can allow highest solar fraction. SIPH system consists of solar appropriate solar collector field, storage system (optional), heat exchanger if required, fluid flow piping, pumps and control circuits. Advantages of using solar energy for industrial process heating are as follows:-

- Solar heat can replace limited and environmentally dangerous fossil fuels like coal, oil and natural gas.
- Most of the industrial processes are within temperature range that can be achieved by solar thermal technologies.
- Year around load requirement of processes can give maximum utilization of solar equipments.
- Direct usage of solar thermal collectors without thermal energy storage is also possible. This type of SIPH system can save up to 30% of total fossil fuel requirement.

- Even large size installations of SIPH system can have payback period under 2 years because of economics of scale.
- As no heat engine is involved, hence high efficiencies can be achieved up to 65% from solar to thermal conversion.

Various industrial surveys suggest that 40% of industrial processes require thermal energy in the temperature range of 180°C which can be supplied economically through range of solar thermal collectors like flat plate, evacuated tube, solar ponds, parabolic trough, linear Fresnel and paraboloid dish type collectors. **[14]** Techno-Economical feasibility of solar industrial process heat system depends upon following factors:-

- Heat must be supplied in required quantity only.
- Heat must be of adequate quality i.e. at required temperature for process.
- Heat must be transferred directly from solar collectors to required process vessel.
- Solar energy must be used profitably.

Also because of intermittent nature of solar radiation, SIPH system is integrated with a backup boiler based on alternative fossil fuels so that industrial process gets uninterrupted thermal energy supply. Process heat in industries in supplied in generally three following modes:-

- **Process hot water:-** in these type of SIPH systems, direct solar water heating system is used where hot water from solar collector is directly supplied to process. This system work at higher efficiencies.
- **Hot air:-** these types of SIPH system are used for drying or dehydration industrial processes. Hot air heated by solar energy is supplied directly or further heated up by auxiliary heaters before going to serve load. Use of inexpensive Rock bed storage can be used to supply hot air during non sunshine hours.
- **Process steam:-** low pressure steam is produced using solar thermal collectors and directly fed to industrial load through existing steam distribution system. Flash steam or direct steam generation system can be used to meet thermal requirement.

2.2.1 Process hot water SIPH system

Large amount of hot water in temperature range of 50 to 100°C is required in industry like food processing; building materials for applications like cooking, washing, anodizing, curing etc. also solar hot water can be used as pre heated feed water to existing boiler. This system can be used with or without thermal energy storage system. Following figure gives the schematic of hot water industrial process heat system:-

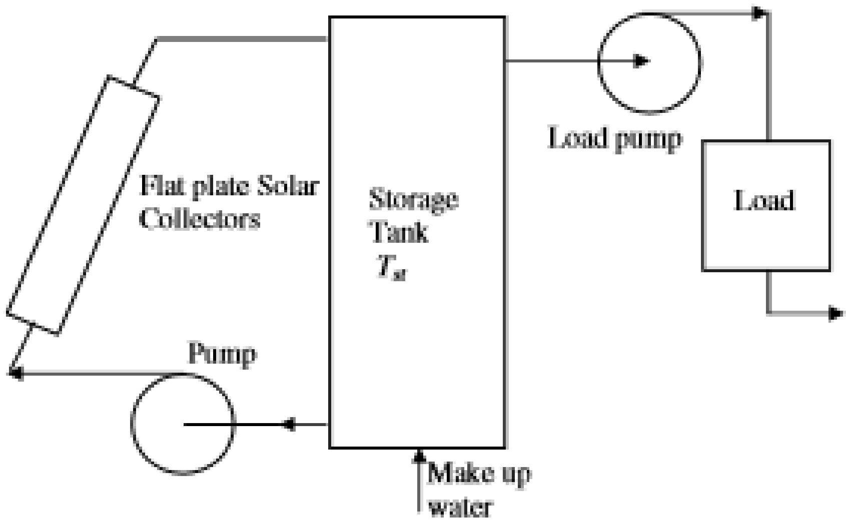

Figure9:- Schematic of solar hot water system (source:- IIT Bombay)

SIPH system consists of flat plate/evacuated tube solar collectors to provide hot water up to 85°C. Hot water can be directly supplied to load or stored in storage tank for later use. Make up water is added via pump and load pump is used to feed load. Example of hot water industrial process heat system include York building products, USA, for curing of concrete blocks and Campbell Soup plant, USA for washing soup cans.

2.2.2 Hot air SIPH system

Huge quantity of hot air is required in food industries. Two methods of supplying hot air are heat air directly by the collectors or heat the heat transfer fluid in collectors and use liquid to air heat exchanger. Example of this technology is in Lamanuzzi Dehydrators, USA consisting of large array of evacuated tube collectors. Water is supplied to collectors connected in parallel and supplied to dehydrators continuously. Liquid- air heat exchanger transfers solar energy to drying air stream. Back up natural gas burner is installed to supply hot air during cloudy or rainy days. This system generally consists of following elements:-

- Large array of flat plate of conventional flat plate air collectors.
- Rock bed storage vessel to supply heat during night shift of plant.
- Heat exchanger system to transfer heat from liquid flat plate collector to working medium air.
- Air duct to connect dehydrator and solar collector array, heat storage system.

Following figure shows the solar hot air collector supplying hot air to industrial process:-

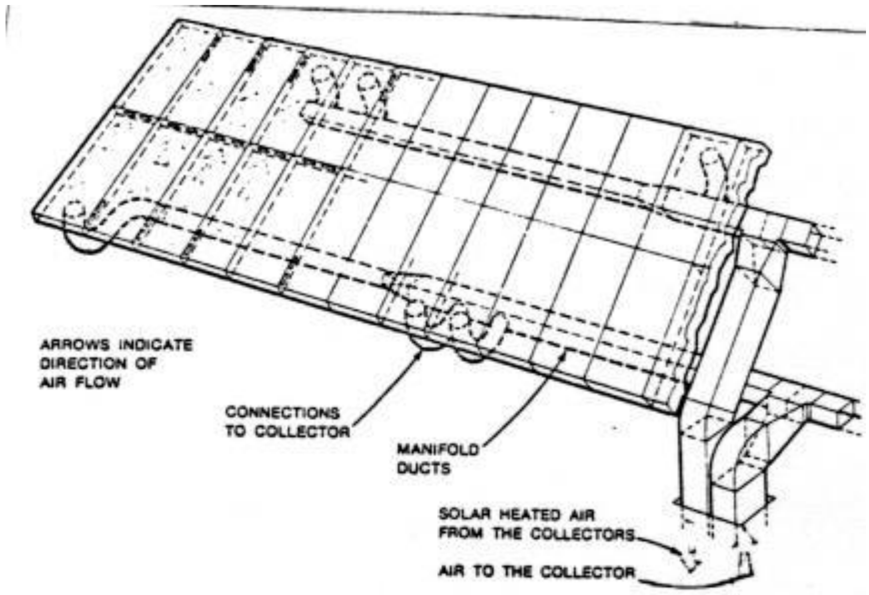

Figure10:- Schematic of solar hot air system (source:- Purdue University)

Air is made to pass through collector manifolds in multiple passes and finally solar heated air comes out of collector and sends to load.

2.2.3. Process steam SIPH system

Almost 2/3rd of all industrial process heat is supplied in form of steam in industry. Number of concentrating solar thermal collectors is connected in parallel to generate saturated steam to supply to industrial process along with pumps and other controller systems. Example is use of paraboloid dish collectors to produce steam at 250°C to fulfil thermal energy requirement of automobile industry or hospital/hotel industry.

Many schemes are possible to produce steam with solar thermal collectors such as:-

- Circulating pressurized water in the collectors and passing it to flash chamber to produce steam.
- Direct steam generation in the solar concentrating collectors.
- Pre heating the water up to that extent which is possible by selected solar thermal technology and feeding it to fossil fuel fired boiler.

Number of concentrating solar thermal collectors is connected in parallel to generate saturated steam to supply to industrial process along with pumps and other controller systems. Example is use of paraboloid dish collectors to produce steam at 250°C to fulfil thermal energy requirement of automobile industry or hospital/hotel industry. Following figure gives the schematic of direct steam generation system based on commercially available paraboloid dish known as ARUN dish:-

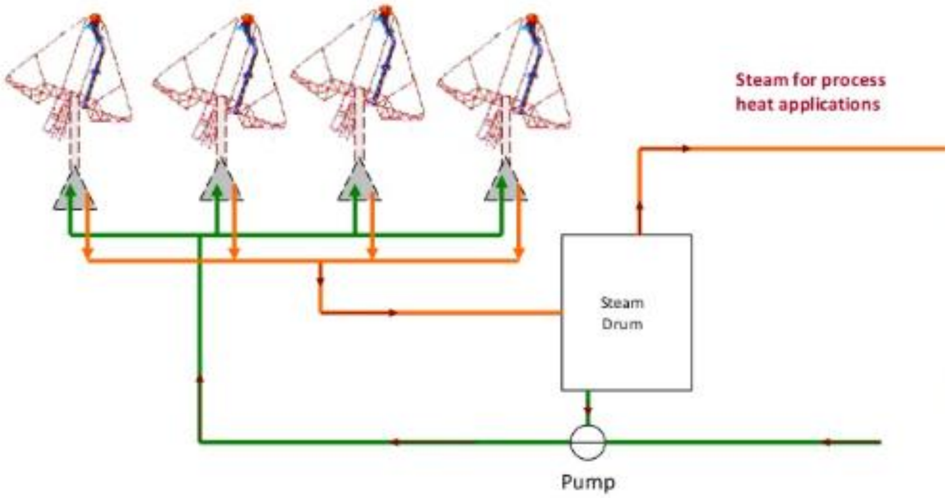

Figure11:- Schematic of solar process steam generating system (source:- clique solar)

2.3. POTENTIAL OF SOLAR PROCESS HEAT IN INDUSTRY

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:-

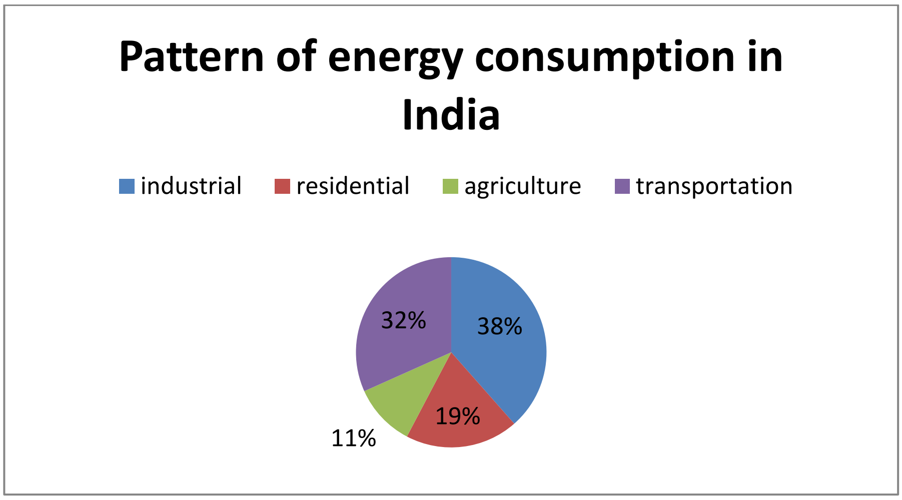

Figure12:- pattern of total energy consumption in India (source:- planning commission)

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.

Potential of SIPH system for various industrial processes for medium range temperatures is huge. Industry is selected first, and then process is shortlisted with details like heat transfer medium and temperature range of the process. For selected process, appropriate solar thermal technology is chosen. Major industrial sector which consume large amount of energy met by fuels like electricity, coal, oil, etc are:-

- Petroleum refining
- Chemical
- Steel
- Paper
- Glass
- Plastics
- Cements
- Textiles
- Food processing
- Dairy products/ milk
- Wine and Beverage
- Food preservation
- Meat
- Automobile

Following table gives the details of various industrial sectors mentioned above along with major industrial processes requiring thermal energy and their respective temperature ranges **[15]**:-

Table3:- Examples of medium temperature industrial processes (source: - UNDP GEF)

Sector	Processes	Temperature (°C)
Brewing and malting	Wort boiling Bottle washing Drying Cooling	100 60 90 60
Milk	Pasteurization sterilization	60-85 130-150
Food preservation	Pasteurization Sterilization Cooking Scalding bleaching	110-125 80 70-100 95-100 90
Meat	Washing, cleaning cooking	90 90-100
Wine and beverage	Bottle washing Cooling (single effect)	60-90 85
Textile	Washing, bleaching cooking	90 140-200
Automobile	Paint drying Degreasing	160-220 35-55
Paper	Paper pulp processing Boiler feed water Bleaching Drying	170-180 90 130-150 130-160
Tanning	Water heating for damp processes	165-180 (steam)
Cork	Drying, cork baking	40-155
Chemical	Biochemical reaction Distillation Compression Cooking Thickening	30-50 100-200 120-170 90-110 130-140
Rubber and plastic	Drying Pre heating	50-130 50-70
wood	Steaming Compression drying	70-90 120-170 40-130

CHAPTER 3: CONCENTRATED SOLAR TECHNOLOGY

Solar energy is inexhaustible source of energy with 1.8 * 10^{11} MW of power radiated by sun on earth **[16]**. This amount of power is thousand times larger than present consumption of mankind from all commercially available energy sources. Therefore solar energy can supply all our future energy needs on continuous basis. Two major benefits of solar energy as most promising renewable source of energy is that first it is environmental friendly clean source of energy and secondly it is freely available in large quantities in all parts of world where people generally lives.

Solar energy can be used directly or indirectly i.e. direct usage includes solar photovoltaic and solar thermal conversion, indirect usage include hydropower, wind power, biomass, wave power, temperature differences in oceans, etc. Solar thermal conversion method has different available technology depending upon that different temperature range can be achieved. Different methods of classifying solar energy utilization is as follows:-

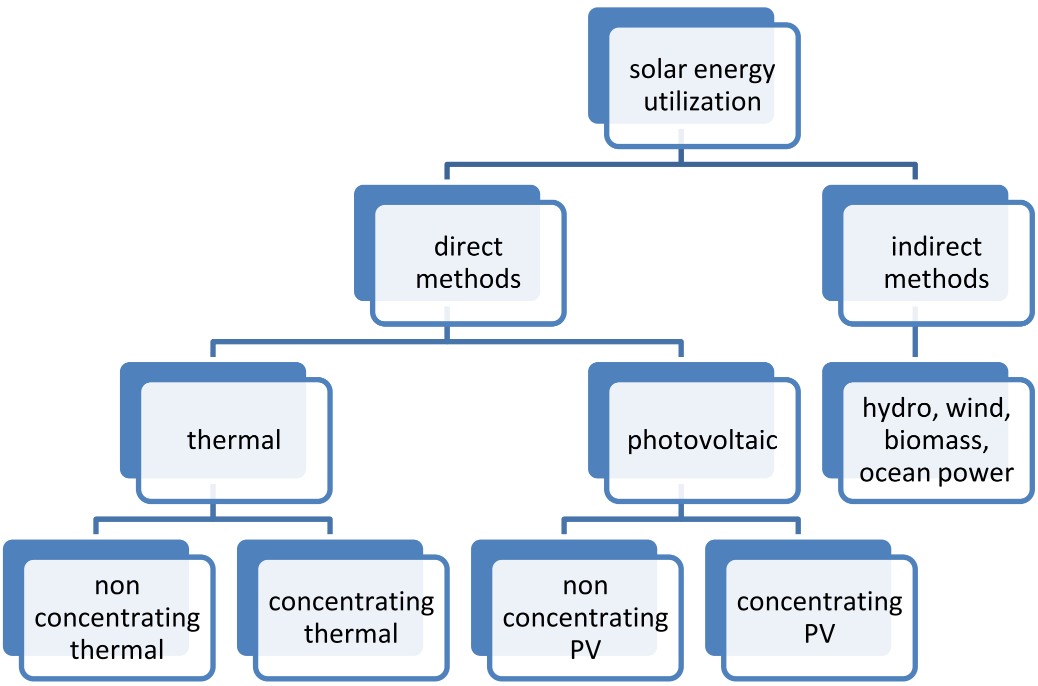

Figure13:- classification of methods of solar energy utilization (source:- Internet)

Solar thermal technology include flat plate collectors, evacuated tube collectors, cylindrical parabolic collectors, parabolic trough collectors, linear Fresnel collectors, paraboloid dish collectors, etc.

3.1. SOLAR ENERGY RESOURCE IN INDIA

Solar Energy is available in huge quantity and is environment friendly with large potential to meet the energy demand and reduction of green house gas (GHG) emissions to make India future sustainable. Ministry of New and Renewable Energy (MNRE) has sanctioned National Institute of Wind Energy (NIWE) to set up the network of solar radiation resource assessment (SRRA) stations all over the country to estimate the availability of investor solar radiation which is crucial for implementation of solar power projects. 121 SRRA stations were installed in 29 States and 4 Union Territories by 2014. SRRA station assesses and quantifies solar radiation data, process it, and makes solar atlas of the country **[17]**. Following figure gives an overview of Solar radiation resource assessment station:-

Figure14:- Solar radiation resource assessment (SRRA) station (source:- NIWE)

A SRRA station consists of two towers of 1.5 m and 6 m tall for measuring solar data and meteorological parameters respectively. The 1.5 m tall tower houses Pyranometer to measure GHI, Pyranometer with shading disc to measure diffused radiation and Pyroheliometer to measure DNI. The 6 m tall tower houses sensors for measuring ambient temperature, relative humidity, atmospheric pressure, wind speed, wind direction, rain fall and data acquisition system. Each SRRA station is powered by solar panels. Data is sampled every second and transmitted to the Central Receiving Station (CRS) established at NIWE through GPRS.

3.1.1 GLOBAL HORIZONTAL IRRADIANCE (GHI)

Flat solar collectors require Global Horizontal Irradiance data for design purpose. GHI is global irradiance i.e. sum of Direct/beam irradiance and Diffuse irradiance falling on horizontal surface. Pyranometer is instrument generally used for measuring global radiation falling on horizontal surface over hemispherical field of view. National Institute of Solar Energy (NISE) along with National Renewable energy Laboratory (NREL) developed the GHI solar map for India. Following map gives the annual average of GHI for all places that lies in India:-

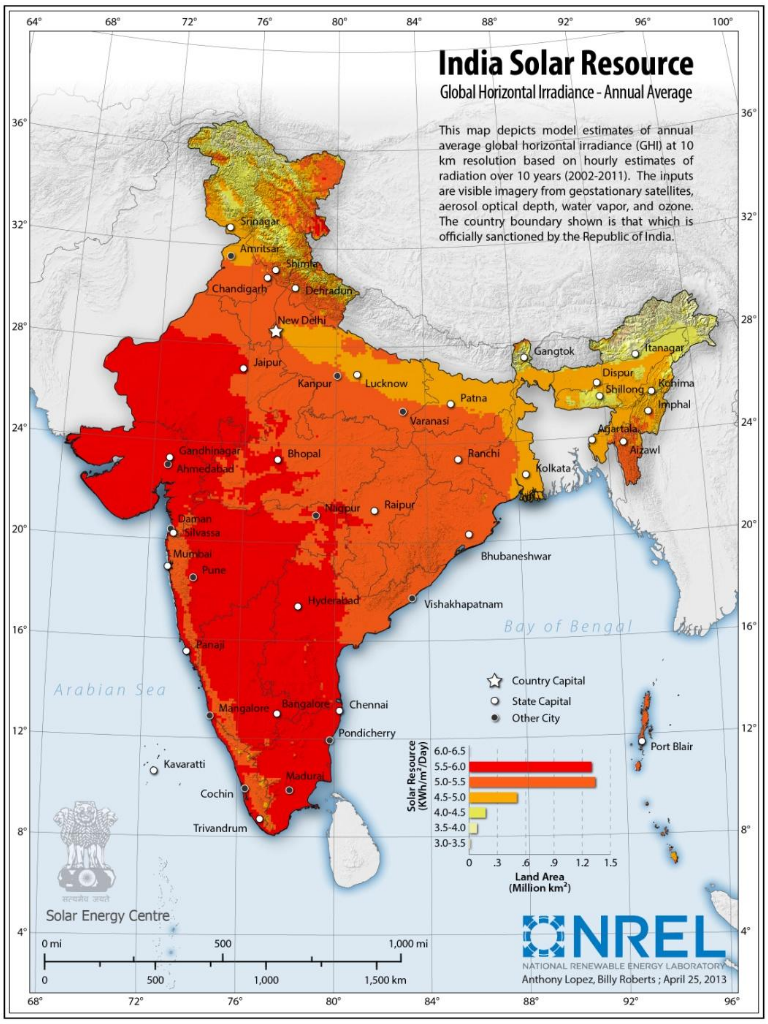

Figure15:- Global horizontal Irradiance Resource- Annual average (source:- NISE)

3.2.2 DIRECT NORMAL IRRADIANCE (DNI)

Concentrating solar collectors require Direct Normal Irradiance data for design purpose. DNI is direct beam radiation falling on surface normal to sun rays. Pyrheliometer is instrument generally used for measuring direct normal radiation falling on normal surface to sun. Also shaded ring type pyranometer is used to measure diffuse radiation and diffuse radiation is subtracted from Global radiation to get DNI values. National Institute of Solar Energy (NISE) along with National Renewable energy Laboratory (NREL) developed the DNI solar map for India. Following map gives the annual average of DNI for all places that lies in India:-

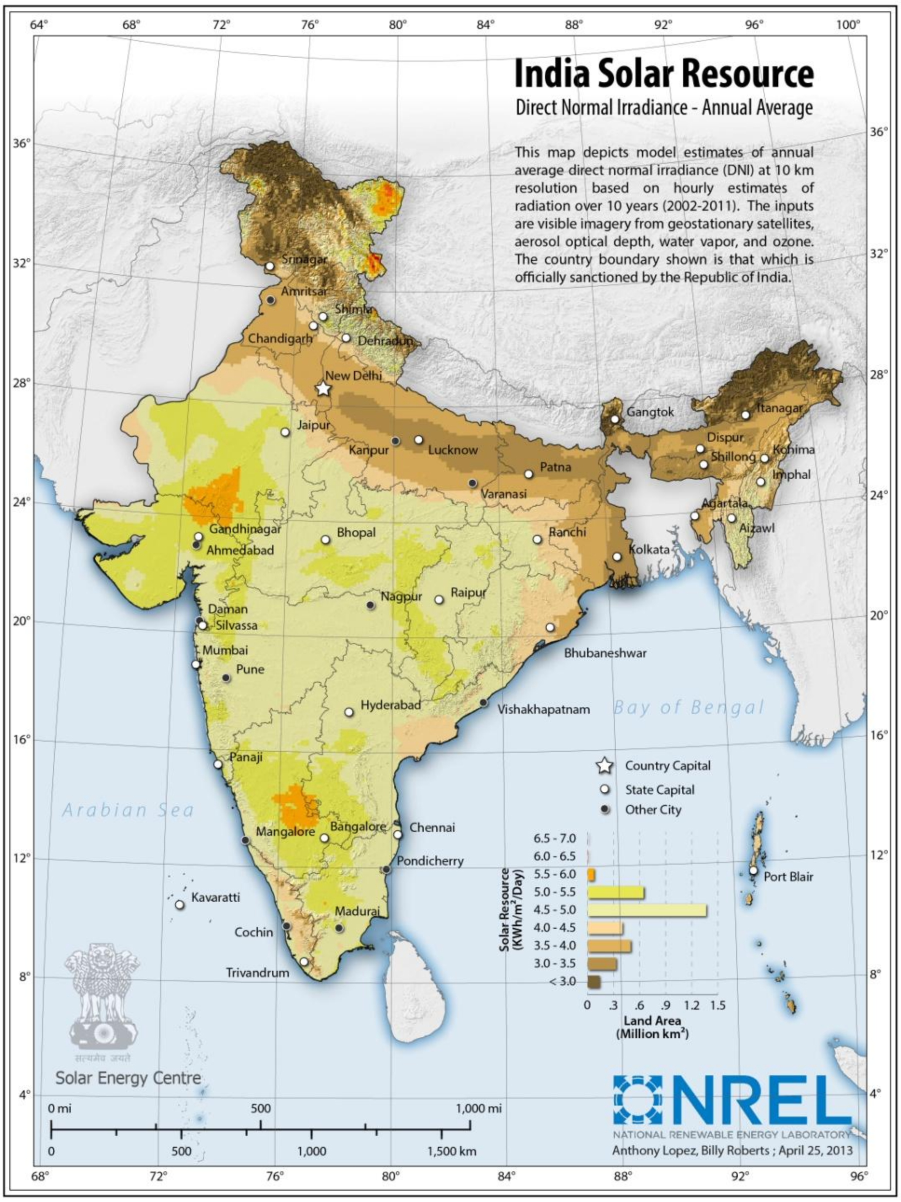

Figure16:- Direct Normal Irradiance Resource- Annual average (source:- NISE)

3.2. BASIC PRINCIPLES OF SOLAR CONCENTRATION

Solar radiation concentration is achieved by using reflecting mirror array or refracting lens array. Optical arrangement directs the solar radiation on to small area absorber surrounded by transparent cover. Optical arrangement introduces certain losses like reflection losses, absorption losses in mirrors, geometric imperfection losses. Combined effect of all losses is indicated by term called **optical efficiency**. Flux incident on absorber surface is very large, thermal losses are minimized; hence high collector efficiency is achieved.

Due to presence of optical system, concentrating collector track the sun so that beam radiation is directed onto absorber surface. Low concentration ratio collectors have arrangement for 1 or 2 manual adjustments every day. High concentration ratio collectors make continuous adjustments. Example of line focussing cylindrical parabolic collectors which can yield up to 400°C.

3.2.1 DEFINITIONS

Concentrating collector consists of concentrator which directs solar radiation on to absorber and receiver consisting of absorber, cover, etc. four important terms are:-

- **Aperture (W)** :- plane opening of concentrator through which solar radiation passes. For linear/cylindrical concentrator, it is defined by its width and for surface of revolution; it is defined by diameter of opening.
- **Area/geometric concentration ratio (C)** :- ratio of effective area of aperture to surface area of absorber. Concentration ratio varies from 1 (for flat plate collectors) to 1000 (for paraboloid dish).
- **Intercept factor (γ)** :- fraction of radiation reflected from concentrator and incident on absorber. Value of intercept factor is close to unity.
- **Acceptance angle ($2\theta_a$)** :- angle over which beam radiation deviate from normal to aperture plane and yet reach absorber. Hence collectors with large acceptance angle values make only few adjustments, while collectors with small acceptance angle values make continuous adjustments.

3.2.2. METHODS OF CLASSIFICATION

Concentrating collectors can be of reflecting mirrors type or refracting lens type. Reflecting surface may be of parabolic, spherical or flat shape. This surface may be of continuous or segmented profile. On the basis of point of view of image formation, concentrator can be classified as imaging or non-imaging. Further imaging type concentrator can be classified as line or point.

On the basis of concentration ratio, collectors are classified according to their operating temperature range. Type of tracking i.e. acceptance angle also classifies collectors as intermittent or continuous type tracking collectors. Also tracking can be of single or double axis type.

3.2.3. THERMAL ANALYSIS OF CONCENTRATING COLLECTORS

For given acceptance angle ($2\Theta_a$) the maximum possible concentration ratio of 2D/ line focus concentrator is given by this formula:-

$$C_{m,\,2D} = 1/\sin(\Theta_a)$$

For 3D/ point focus concentrator, the maximum possible concentration ratio is given by this formula:-

$$C_{m,\,3D} = 1/\sin^2(\Theta_a)$$

Half angle subtended by sun at earth is 0.267°. Putting this value in above formulas, maximum possible concentration ratio for line focussing and point focussing concentrator is calculated as 215 and 46000 respectively. But for practical systems, concentration ratio is lower as acceptance angle is greater than 0.267°. Also tracking errors, imperfections in reflecting surface, mechanical misalignment between concentrator and receiver also lowers concentration ratio values. Energy balance on absorber yields the following equation to be used for thermal analysis of concentrating collector:-

$$Q_u = Aa * S - Q_l$$

Where Q_u = useful heat gain rate

A_a = aperture effective area

S = solar beam radiation absorbed in absorber

Q_l = absorber heat loss rate

$$Q_l = U_l * A_p * (T_{pm} - T_a)$$

Where U_l = overall heat loss coefficient

A_p = absorber surface area

T_{pm} = average temperature of absorber surface

T_a = ambient air temperature

$$Q_u = Aa * [S - U_l/C * (T_{pm} - T_a)]$$

Where C = (A_a/A_P) is concentration ratio

3.3. TYPES OF SOLAR THERMAL COLLECTORS

Basic principle of solar thermal collector involves exposing dark surface to solar radiation to absorb it. Fraction of absorbed radiation is transferred to fluid like air or water. Most basic types of solar thermal collectors used in industry are as follows:-

- Liquid Flat plate collector
- Evacuated tube collector
- Solar air heater
- Parabolic trough collector
- Paraboloid concentrating collector

3.3.1. Liquid flat plate collector

No optical concentration is done in flat plate collector (FPC). It is simple in design with no moving parts, little maintenance. It is used for different industrial processes with temperature requirement up to 70°C. It consists of absorber plate on which solar radiation falls by passing through transparent glass cover which helps in reducing heat losses. Absorbed radiation is transferred to liquid i.e. water flowing through tubes which are fixed to absorber plate. Absorbed radiation is useful heat gain and rest is lost by convection, re radiation or conduction to surroundings from top, back surface and edges. Thermal insulation on back surface and edges also reduce losses. Collector is held tilted on supporting structure, facing true south located in northern hemisphere. Selective coating is also applied on absorber plate with high value of absorptivity for incoming solar radiation and low value for emissivity for outgoing solar radiation. Following figure gives the schematic view of liquid flat plate collector:-

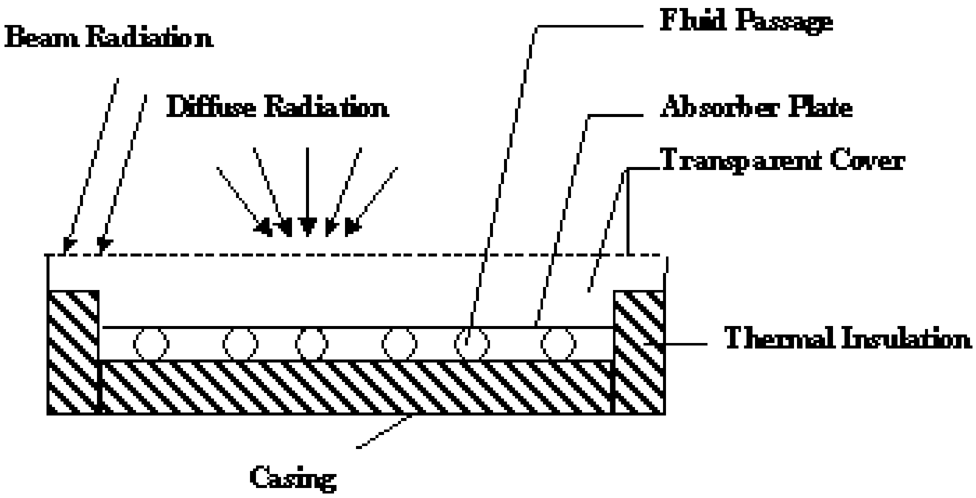

Figure17:- liquid flat plate collector (source:- Solar energy book)

3.3.2 Evacuated tube collector

Evacuated tube collector (ETC) has number of cylindrical modules mounted in a common frame. Evacuated tube consists of two concentric glass tubes with evacuated annular space between them. Selective coating is done on inner glass tube. Solar radiation is absorbed on selective surface and partly conducted to water flowing inside glass tube. Also heat loss by convection to surroundings is minimized due to vacuum in annular space. Temperature range lies between 70°C and 100°C which is way above flat plate collectors. Following figure gives the schematic diagram of evacuated tube collector module:-

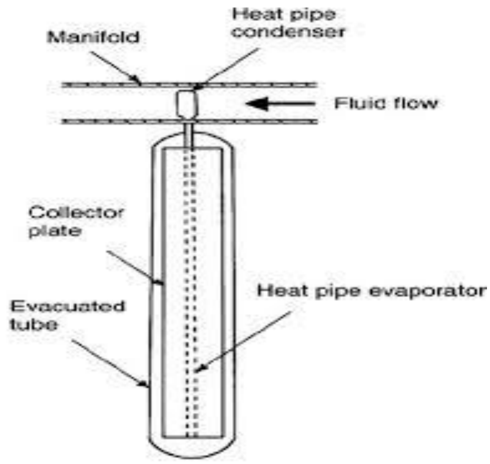

Figure18:- schematic diagram of evacuated tube collector (source:- Solar energy book)

3.3.3 Solar air heater

Flat plate collector when used for heating air is known as solar air heater. Construction of solar air heater is similar to liquid flat plate collector. But passage for air flow differs from passage used for liquid flow. Air passage is made larger to keep pressure drop across collector at minimum value. Air passage is parallel plate ducts. Temperature range are achieved up to 70°C and used for drying and evaporating processes in industry. Following figure gives the schematic cross section of solar air heater:-

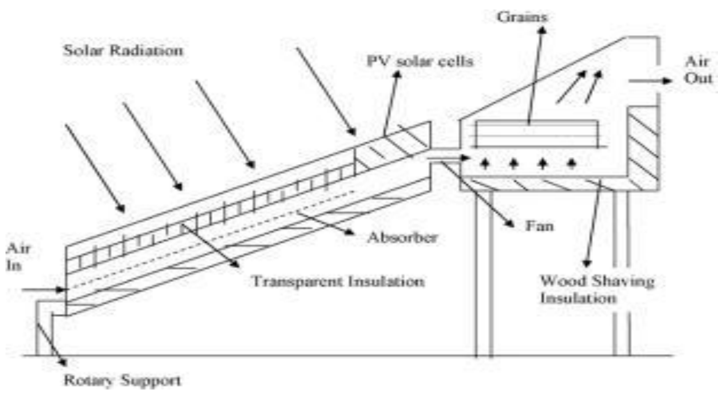

Figure19:- schematic diagram of solar air heater (source:- Solar energy book)

3.3.4. Cylindrical Parabolic concentrating collector

To achieve higher temperature over 120°C and above, radiation needs to be concentrated. This can be achieved by using concentrating collectors. Line focussing concentrating collector consist of concentrator and receiver. Concentrator is a cylindrical parabola shaped reflective mirror which focuses the sunlight on its axis. Radiation is absorbed at surface of absorber tube and transferred to water flowing through it. Concentric glass cover is place d around absorber tube to reduce convective and radiative heat losses to surroundings. To keep sun rays always focussed on absorber tube, concentrator has tracker i.e. it is rotated about single axis. Following figure shows the schematic of cylindrical parabolic concentrating collector:-

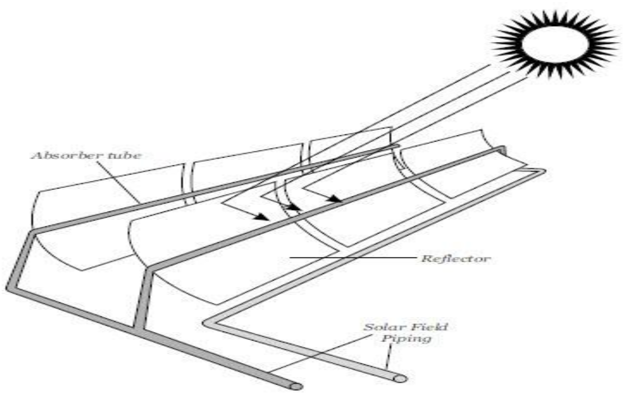

Figure20:- cylindrical parabolic concentrating collector (source:- Solar energy book)

3.3.5. Paraboloid concentrating collector

Fluid temperatures up to 400°C can be achieved in paraboloid concentrating collector which is appoint focusing type concentrating collector. This system requires two axes tracking to keep sun rays always focus onto receiver. Highest thermal collection efficiency is achieved in this configuration. Following figure shows the schematic of paraboloid concentrating collector:

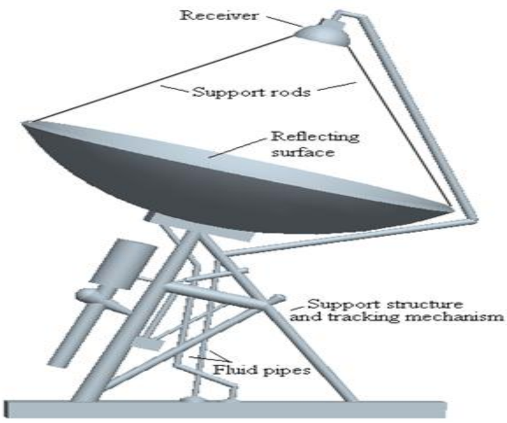

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Figure21:- paraboloid concentrating collector (source:- Solar energy book)

3.4. SIPH CASE STUDIES IN INDIA

Two solar industrial process heat case studies have been discussed in detail here which shows the successful implementation of solar thermal technologies in industry for providing thermal energy for processes. Two case studies discussed are as follows:-

- Using parabolic trough for phosphating process
- Using Arun dish for washing application

3.4.1 Using parabolic trough for phosphating process

Parabolic trough based solar concentrators were installed at SKF technologies private ltd, Mysore for process heat applications. System consisted of 40 parabolic trough collectors of 6.41 m2 aperture area connected in series parallel arrangement at plant rooftop to provide pressurized hot water at 130°C. Diesel fired boiler is kept as a backup to SIPH system in case on non sunny days. Each parabolic trough collector has thermal output of 1.8 KW and 250 kg of weight. Single axis automatic tracking is used in collectors. Pressurized hot water generated through parabolic trough collector is used to circulate in treatment tanks used for 11 tank phosphating process (to make metal parts free of rust) where desired temperature is 95°C. Major details about the installation have been given in this table **[18]**:-

Table4:- System details for SIPH case study at SKF, Mysore (source: - MNRE)

System Details For SKF technolgies	
Aperture area of trough	6.41 m^2
Number of troughs	40
Total aperture area	256.4 m^2
Total shade free area required	40 * 10 = 400 m^2
Weight of trough	250 kg
Total weight of system	40 * 250 = 10000 kg
Tracking	Single axis tracking
Heat delivery	11000 Kcal/day
Cost of diesel fuel replaced	Rs 60/- per litre
Annual fuel savings	14000 litres
Days of system operation	275
Annual fuel savings	Rs 850000/-
Total system cost	Rs 7055000/-
MNRE subsidy @ Rs 5400/- per m^2	Rs 1384560/-
Project cost for SKF Mysore	Rs 5670440/-
Payback period	5.2 years

Therefore this project resulted in payback period of 5.2 years and 14000 litres of annual diesel savings due to SIPH system installed at the location.

3.4.2. Using Arun dish for washing application

Mahindra Vehicle Manufacturers Limited installed one ARUN dish to generate hot water for four washing machines to degrease engine components. The ARUN dish is a two axis tracked dish installed on a column of 3m * 3m and on 8 m height column. The area below the dish is used as a test facility for the vehicles therefore minimising space requirement. The Arun dish delivers pressurised hot water at 120°C for seven hours daily which is used in degreasing process of the engine components. The dish is Fresnel paraboloid solar concentrator with a point focus. The automatic two-axis tracking system ensure the highest thermal energy output per square metre of the collector area coupled with minimum maintenance over an extended period of time. Arun dish however can deliver steam at 25 bar pressure at a temperature of 400°C. Each module of ARUN dish (169 m2 aperture area and a weight of 18 tonnes) has an output capacity of up to 125 kW_{th}. Major details about the installation have been given in this table **[19]**:-

Table5:- System details for SIPH case study at MVML, Pune (source: - MNRE)

System Details for MVML	
Aperture area of dish	169 m^2
Number of Arun dish	1
Total aperture area	169 m^2
Total shade free area required	180 * 1 = 180 m^2
Weight of Arun dish	18000 kg
Total weight of system	1 * 180000 = 18000 kg
Tracking	Two axis tracking
Heat delivery	700000 Kcal/day
Annual fuel savings (electricity)	200000 KWh
Days of system operation	275
Monthly fuel savings	Rs 180000/-
Total system cost	Rs 3900000/-
MNRE subsidy @ Rs 6000/- per m^2	Rs 1014000/-
Project cost for MVML	Rs 2886000/-
Payback period	2.1 years

Therefore the project had a payback of 2.1 years and MVML would recover the entire investment made from the savings made in electricity purchase costs. The monthly savings of electricity are of 22,500 units resulting into savings of almost Rs 180000 /- monthly. Also Arun dish shall reduce GHG emissions. System would run the plant at minimal operational costs for the entire project life of 25 years. Thus it makes a successful case study for other industries to go for solar thermal systems for industrial process heat needs.

3.5. HEAT STORAGE AND ITS NEED

Major problem associated with solar energy utilization is its variable nature. Hence to overcome this variability, most of the SIPH system requires some sort of thermal energy storage. This storage system stores energy when it is in excess than requirement and energy can be made available for application use when solar energy is absent. Thermal energy can be stored as sensible heat or latent heat.

- **Sensible heat storage** is done in insulated container containing fluid like water or in porous solid like pebbles or rock. Water is stored in insulated container for liquid based collectors and rock bed storage is used for solar air heaters. Sensible heat storage systems operate over wide range of temperatures.
- **Latent heat storage** is done in substance which melts when heat is added to it and freezes when heat is extracted. Latent heat storage system operates at temperature at which phase change occurs.

Need of thermal energy storage in SIPH system can be justified from the following figure which shows that thermal load profile for a given industrial process remains constant for whole day but solar energy is available only during daytime.

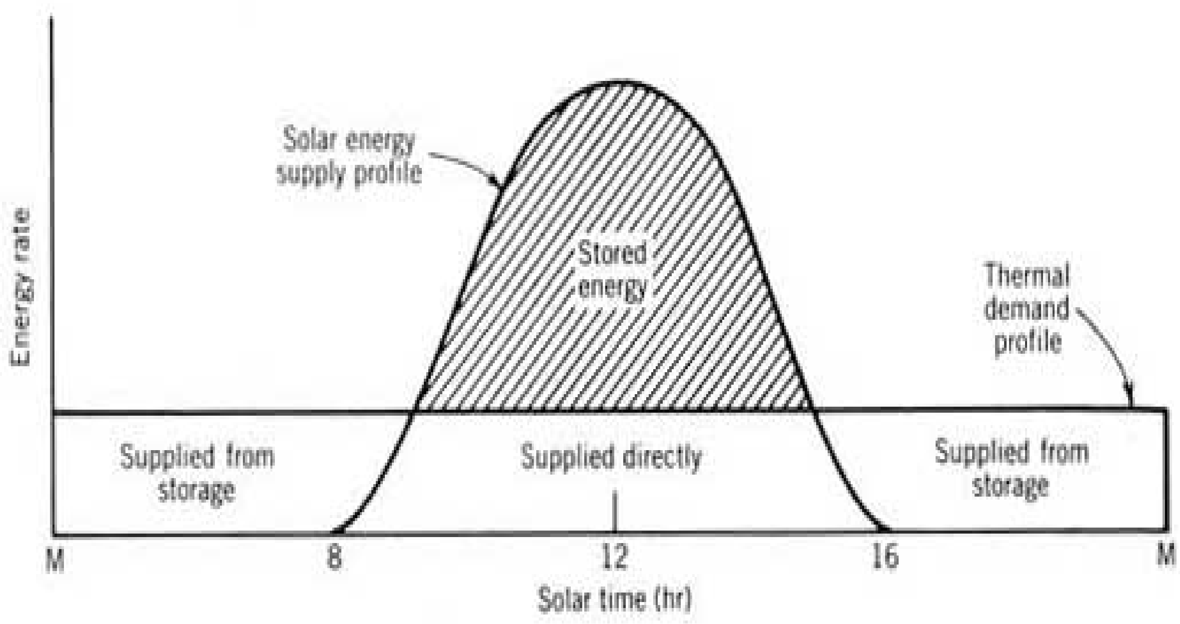

Figure22:- Need for solar thermal energy storage (source: - powerfromthesun.net)

Also solar energy is available in excess to thermal load during daytime. This excess energy can be stored in form of sensible or latent heat which can be used to supply thermal energy during night time. Hence thermal energy storage can increase the share of solar energy in thermal load i.e. high solar fraction can be achieved due to storage and higher fuels savings can also be achieved. **[20]**

3.6. MINISTRY OF NEW AND RENEWABLE ENERGY

The Ministry of New and Renewable Energy (MNRE) is the nodal Ministry in the Government of India for all matters relating to renewable energy. The main objective of the Ministry is to develop and implement renewable energy to supplementing the energy requirements of the India. MNRE has a brief history which is given as follows [21]:-

- Commission for Additional Sources of Energy (CASE) in 1981.
- Department of Non-Conventional Energy Sources (DNES) in 1982.
- Ministry of Non-Conventional Energy Sources (MNES) in 1992.
- Ministry of New and Renewable Energy (MNRE) in 2006.

The aim of ministry is to increase significance of renewable energy in recent times keeping in view of growing concern for the country's energy security. Energy independence is identified as the major driver for renewable energy in the country in the aftermath of the oil crisis of the 1970s. The sudden and huge increase in the price of oil, uncertainties or limited availability and the adverse impact on the financial position led to the establishment of the Commission for Additional Sources of Energy (CASE) in the Department of Science & Technology (DST) in March 1981. The Commission was given with responsibility of formulating policies and their implementation, propagating programmes for development of new and renewable energy and intensifying R&D in this sector. In 1982, name was changed to Department of Non-conventional Energy Sources (DNES) under Ministry of Energy. In 1992, DNES became the Ministry of Non-conventional Energy Sources (MNES). In October 2006, the Ministry was re-organised as the Ministry of New and Renewable Energy (MNRE). The Mission of the Ministry is as follows:-

- Energy Security
- Increase in the share of clean power
- Energy Availability and Access
- Energy Affordability
- Energy Equity

3.6.1 INSTALLATION COST OF VARIOUS CONCENTRATED SOLAR TECHNOLOGIES (CST)

Investment required for various CST depend upon various factors such as new project is being developed or CST is being retrofitted in existing system as new system can cost 15 to 30% higher due to additional costs of boilers and its other accessories like water treatment, piping, insulation etc. Also high altitude areas with difficult terrain, cost may be up further by 20 to 25%. 5% of total cost is taken as Operating and Maintenance cost. Following table gives the overview of investment required for setting up various CST:-

Table6:- installation cost of various CST for retrofitted system (source: - MNRE)

Technology	Installation cost Rs per sq m in plains (approx)
Fixed receiver elliptical dish (single axis tracked)	16000
Fixed receiver elliptical dish (dual axis tracking)	18000
Parabolic trough collector (PTC) with non evacuated heat receiver	16000
Parabolic trough collector (PTC) with evacuated heat receiver	18000
Linear Fresnel reflector (LFR) single axis tracked	18000
Arun dish (Dual axis tracked)	20000
Paraboloid dish (dual axis tracked)	20000

3.6.2 SUBSIDY PATTERN FOR VARIOUS CONCENTRATED SOLAR TECHNOLOGIES (CST)

Ministry of New and Renewable energy (MNRE) provide subsidy up to 30% of project investment to promote CST in India. Capital subsidy is provided on basis of concentrated solar technology employed for process heat in Rs per sq m of collector installed to make payback periods lucrative.

Besides subsidy, soft loan @ 5% interest rate is provided by Indian Renewable Energy development Authority (IREDA) for balance cost of system after deducting capital subsidy. For special category states like Himalayan region, islands and North east India, subsidy is up to 60%. For special case of non electrified villages of India, subsidy for solar thermal systems is up to 60%. Following table gives the overview of subsidy pattern available for setting up various CST:-

Table7:- Subsidy pattern for various CST for retrofitted system (source: - MNRE)

Technology	**Capital subsidy (Rs per sq m of collector area) or 30% of project cost whichever is less**
Evacuated tube collectors (ETCs)	3000
Flat plate collectors (FPC) with liquid as the working fluid	3300
Flat plate collectors with air as the working fluid	2400
Solar collector system for direct heating applications	3600
Concentrators with manual tracking	2100
Non imaging concentrators	3600
Concentrators with single axis tracking	5400
Concentrators with double axis tracking	6000

CHAPTER 4: STUDY OF AUTOMOBILE MANUFACTURING PROCESS

Indian Automobile industry is under considerable pressure from various sections of society to make their products more environmentally sound. Not only the automobile themselves, but also the whole manufacturing process has to become more sustainable to Achieve India's pledge at Paris climate summit to stop climate change. The Automobile industry is one of the major industries in India which have huge energy requirements in the form of 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 water, hot air or steam. Thermal energy accounts for around 65% of all automobile industry's total energy consumption. Thus solar collectors can provide a large share of this industrial process heat with the collector technology mainly depending upon levels of the temperatures involved. The use of an appropriate solar thermal technology can have a positive impact on the energy and environmental scenario of Automobile industry.

4.1. PATTERN OF ENERGY CONSUMPTION IN AUTOMOBILE INDUSTRY

The Automobile industry has a very high energy demand. According to a study over 65% of the total energy Demand is for heating and rest is for electricity. Automobile industries have number of different production processes in these shops that need large amounts of energy in form of electricity or heat. Various energy sources currently used in Automobile industry for production are mainly electricity with major share of 59% in total energy consumption followed by petroleum products like natural gas as second largest source with share of 40% and followed by others sources of energy with share of merely 1%. Following figure shows share of various energy sources in automobile industry **[22]**:-

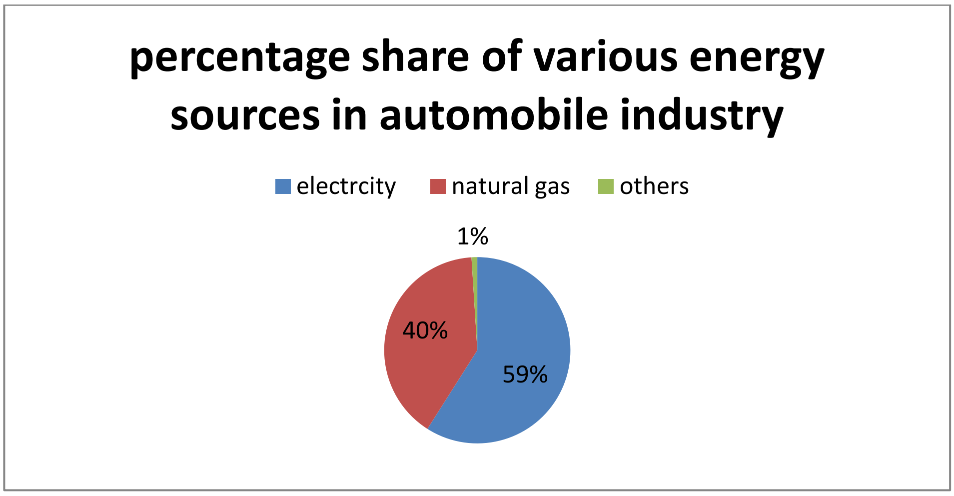

Figure23:- share of energy sources in automobile industry (source: - Eicher Motors Ltd Plant)

Automobile manufacturing process involves number of inter related, well defined sequential industrial processes which can be grouped into major 3 production shops. The three major production shops involved in automobile manufacturing are as follows:-

- **Body shop** where automobile body is formed by welding different sections of sheet metal together to give final shape.
- **Paint shop** where automobile body is coated with anti rust phosphate solution, base coat and final coat of automobile grade paint for required body colour.
- **Assembly shop** where different automobile parts are assembled together to make completely functional automobile for dispatching it to market.

Total energy consumed from all the sources of energy can be grouped according to 3 different production shops. Most of the energy consumed is in Paint shop with share of 73% in total energy consumption, followed by 17% in body shop and 10% in assembly shop. Following figure gives the percentage share of total energy consumption in various production shops:-

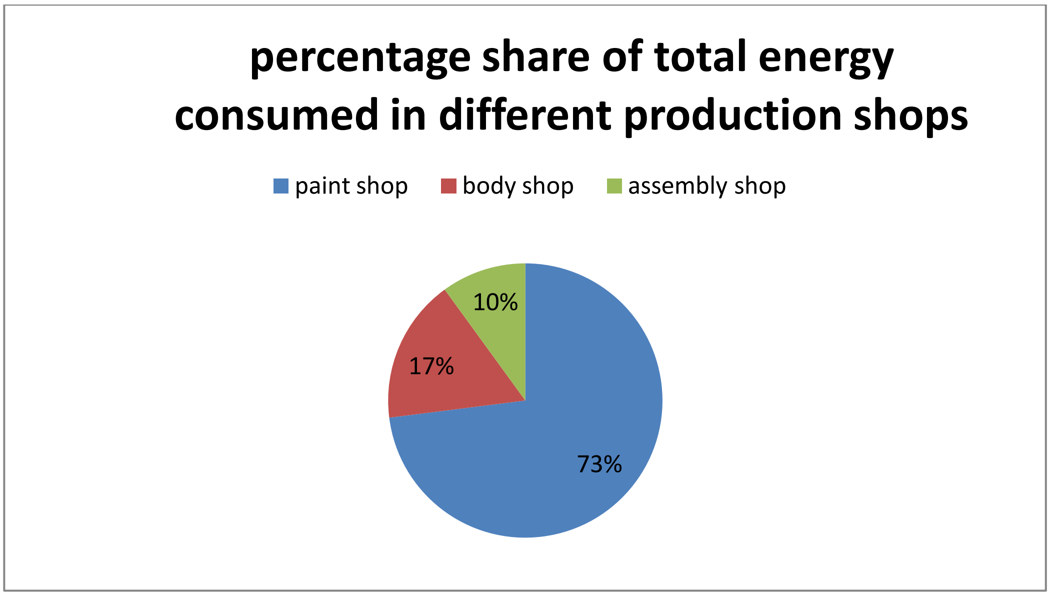

Figure24:- share of total energy consumption in production shops (source: - Eicher Motors Ltd)

For total thermal energy consumed from natural gas and other petroleum sources, it can also be divided among different production shops with almost 92% of total thermal energy is consumed in paint shop processes, followed by 4% in both body shop and assembly shop. Following figure gives the percentage share of total thermal energy consumption in different production shops:-

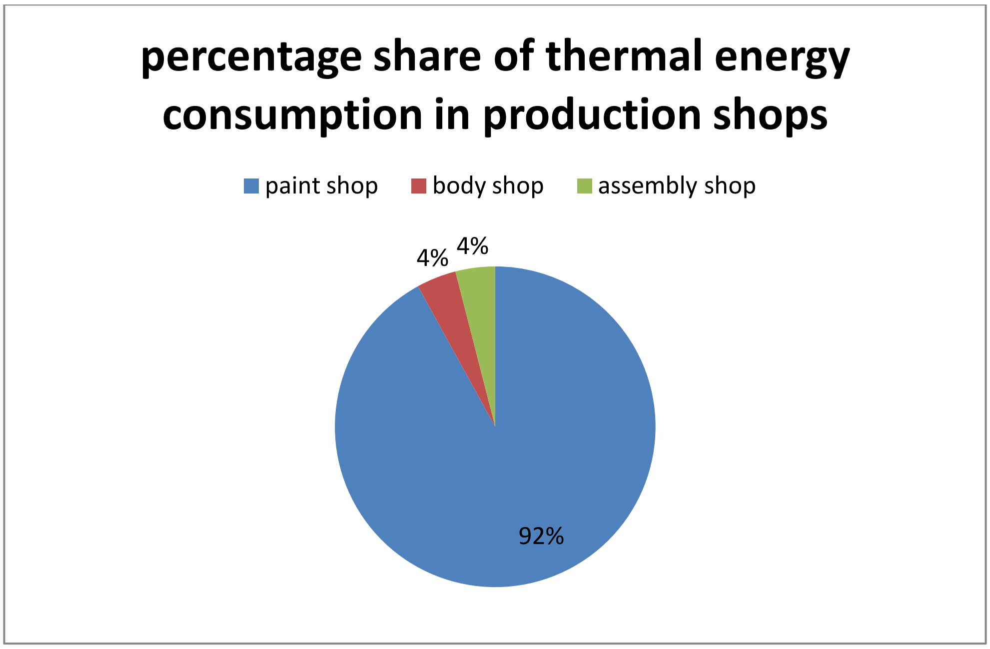

Figure25:- share of thermal energy consumption in production shops (source: - Eicher Motors Ltd)

Total electricity consumption can also be grouped for each production shop as 45% in paint shop with largest share, followed by 35% in body shop and rest 20% in assembly shop. Following figure gives the percentage share of electricity consumption in different production shops:-

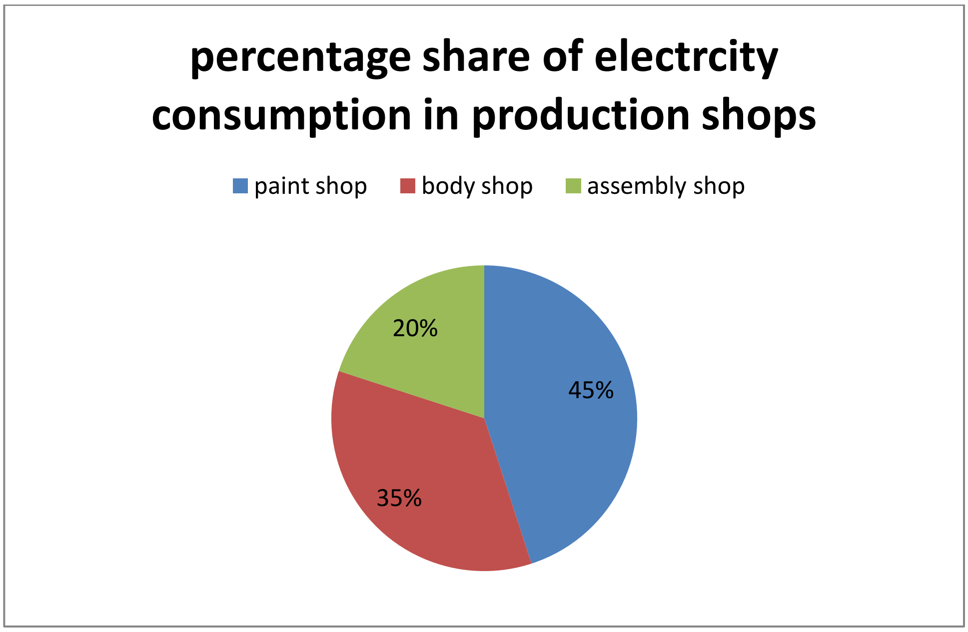

Figure26:- share of electricity consumption in production shops (source: - Eicher Motors Ltd)

4.2. 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 shows the automobile industry manufacturing process flow chart indicating he direction of material flow in all major production shops:-

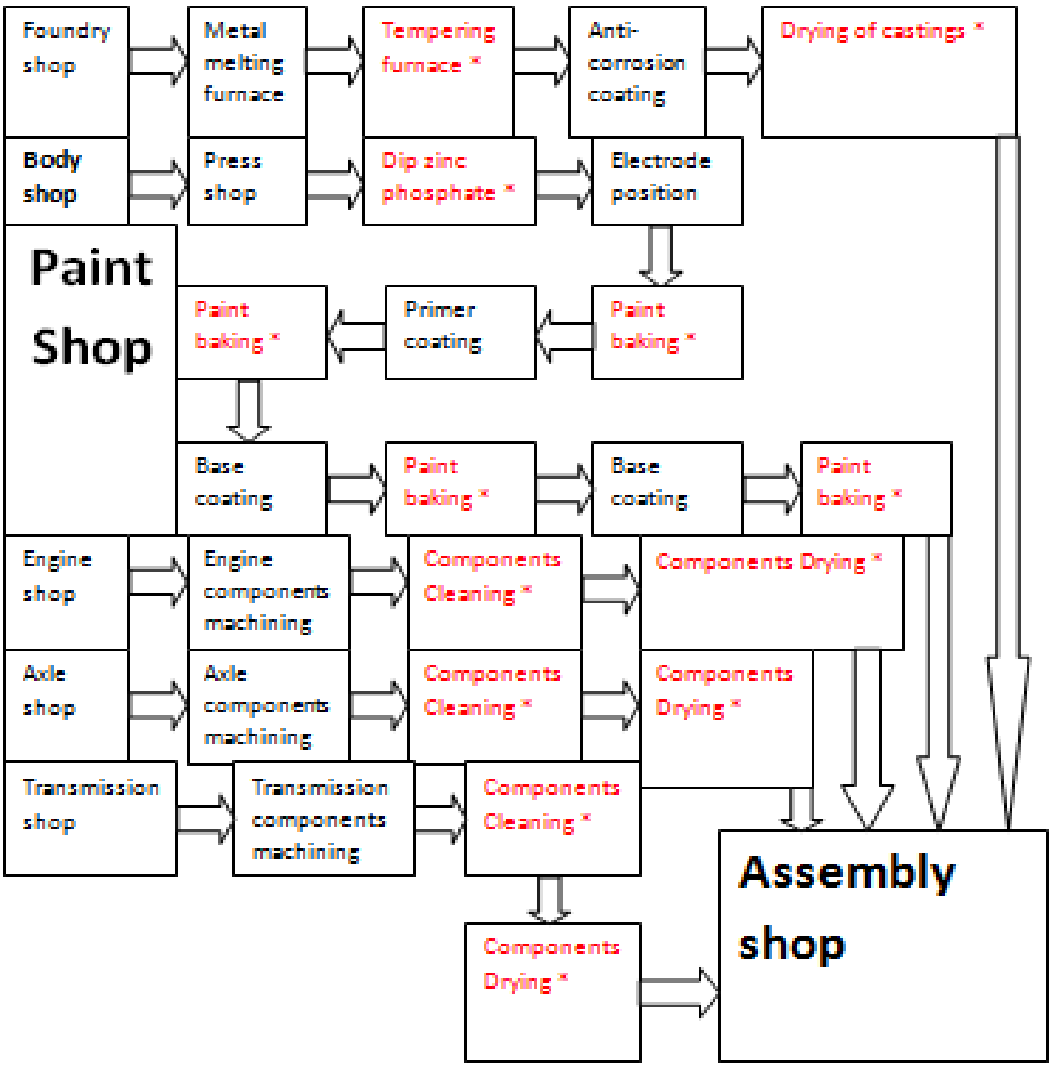

Figure27:- Automobile Manufacturing Process flow chart (source: - Eicher Motors Ltd)

4.3. MANUFACTURING PROCESSES REQUIRING PROCESS HEAT WITH THEIR TEMPERATURE RANGE

Some of the manufacturing process requires thermal energy at different temperature range. These manufacturing processes are shown in figure 27, marked with * require thermal energy at temperature range appropriate for that process. Different processes marked with * from different production shops are as follows:-

- **Tempering furnace**:- tempering and hardness are done of machining components to improve their wear resistance, strength and toughness. Low temperature tempering is done at temperature range of 150°C to 200°C of steel automobile components. Fuel source being used currently is natural gas and working medium is process hot air.
- **Drying of castings**:- castings manufactured in production shops are washed to remove impurities and then dried to improve overall lifetime performance of casted products by applying anti corrosion coatings. Fuel source being used currently is electricity and working medium is process hot air.
- **Dip zinc phosphating**:- standard 7 tank process or Dip Zinc phosphating process is used to make automobile components with good paint adhesion and corrosion resistance before it is sent to paint shop. All these processes are carried in tank which is heated by immersed electrical heaters and working medium is pressurized hot water. Following table shows all the 7 processes involved in phosphating along with their temperature required and dip time in seconds:-

Table 8:- 7 tank dip zinc phosphating process (source: - Eicher Motors Ltd)

Step Involved	Temperature Required (°C)	Dip time (sec)
Degrease	95	15
Cold water rinse	25	5
De rust	70	10
Cold water rinse	25	5
Zinc phosphate dip	80	5
Cold water rinse	25	5
Passivation	70	10

- **Paint baking process**:- paint is applied on automobile body in three coats i.e. base coat, primer coat and finish coat. Between each coat, paint is baked continuously in baking ovens where hot air is blown at 200°C. Currently natural gas is used to produce hot air for paint curing process.
- **Components cleaning**:- automobile components are cleaned off dust and grease by washing them in pressurized hot water in washing chambers. Hot water is produced at 90°C by electrical immersion heaters.

- **Components drying:-** components cleaned in components cleaning process are dried by hot air at 90°C in ovens before being sent to assembly shop for further operation. Hot air is produced by burning natural gas.

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:-

Table 8:- 7 tank dip zinc phosphating process (source: - Eicher Motors Ltd)

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

CHAPTER 5: 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.

5.1. PARABOLOID DISH SOLAR 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 **[23]**:-

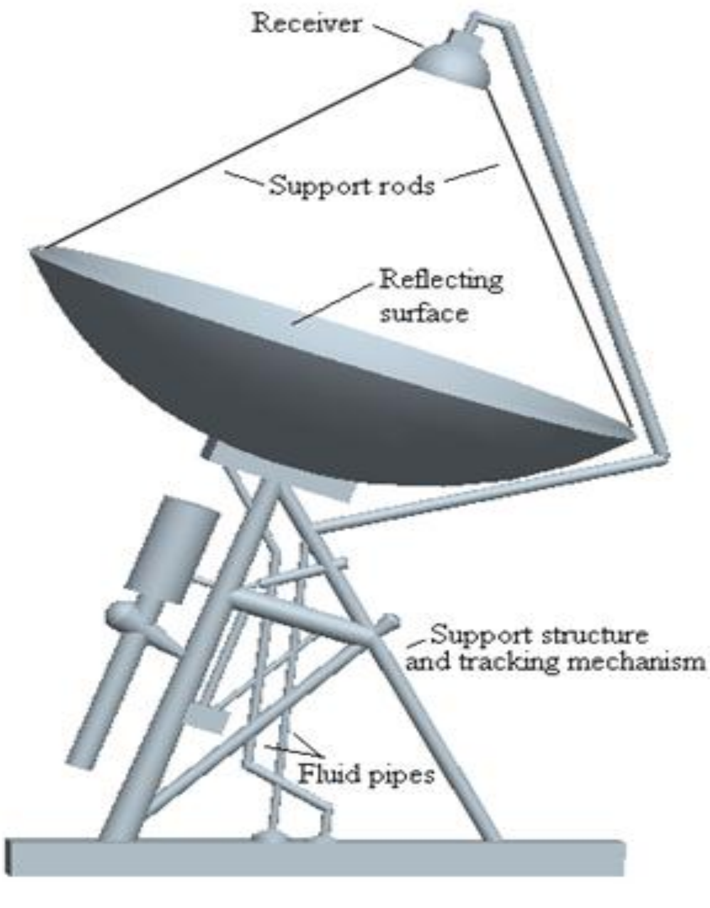

Figure28:- Paraboloid Dish solar collector components (source: - NREL)

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:-

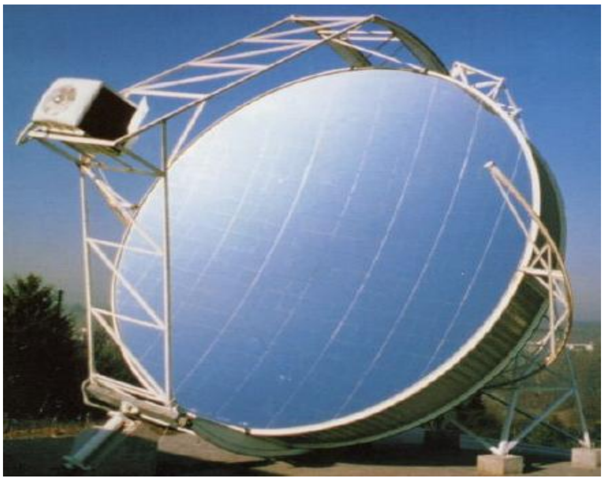

Figure29:- Collector of solar Paraboloid Dish (source: - NREL)

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:-

Figure30:- 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:-

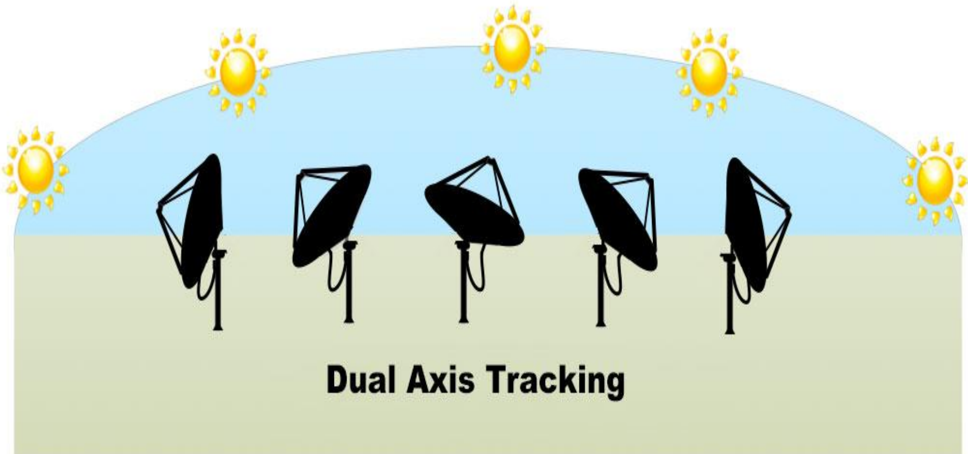

Figure31:- Azimuth- Elevation (Az-El) type Tracking for solar Paraboloid Dish (source: - NISE)

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:-

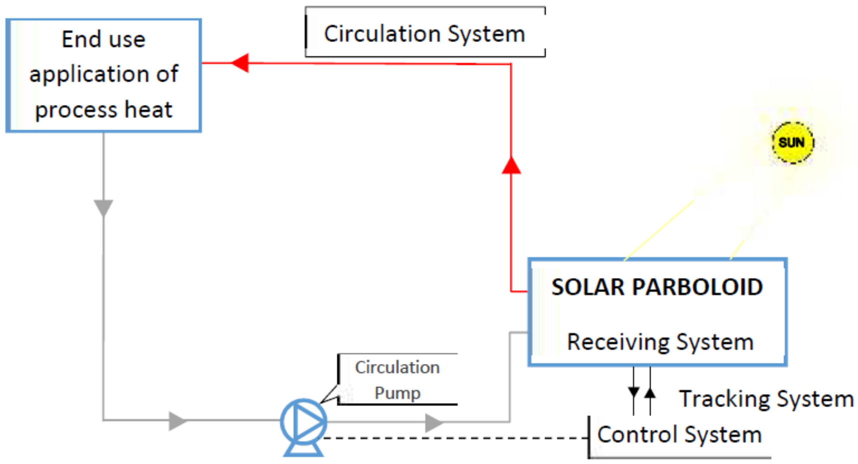

Figure32:- Circulation system and control system for solar Paraboloid Dish (source: - NISE)

5.2. 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 **[24]:-**

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

Where

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

A_{app} = area of concentrator aperture

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)

5.3. 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**

5.3.1 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:-

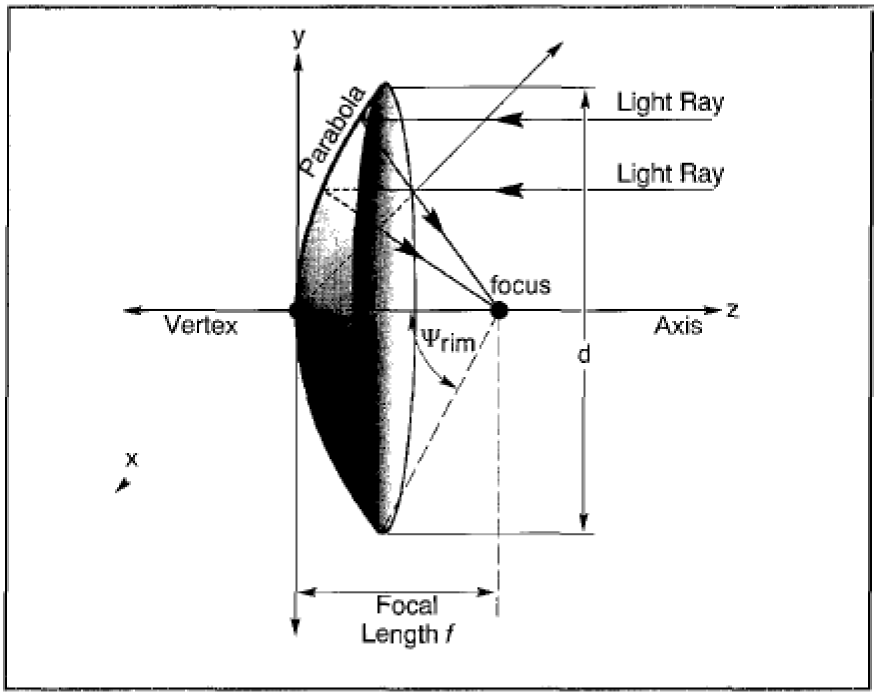

Figure33:- Paraboloid Dish with focal length, rim angle, diameter (source: - NREL)

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:-

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

5.3.2 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:-

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

5.4. 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 (η_{conc}), receiver thermal efficiency (η_{rec}) and overall system efficiency ($\eta_{overall}$). Following table gives the value of basic input parameters and design coefficients assumed for calculations of solar paraboloid dish:-

Table 9:- 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 **Φ**	0.9
Transmittance **τ**	0.9
Absorptance **α**	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 $\mathbf{T_{rec}}$ (°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 $\mathbf{I_{b,n}}$ (w/m^2)	1000
Ambient temperature $\mathbf{T_{amb}}$ (°C)	25
Stefan Boltzmann constant **σ** (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 **[25]**:-

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

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:-

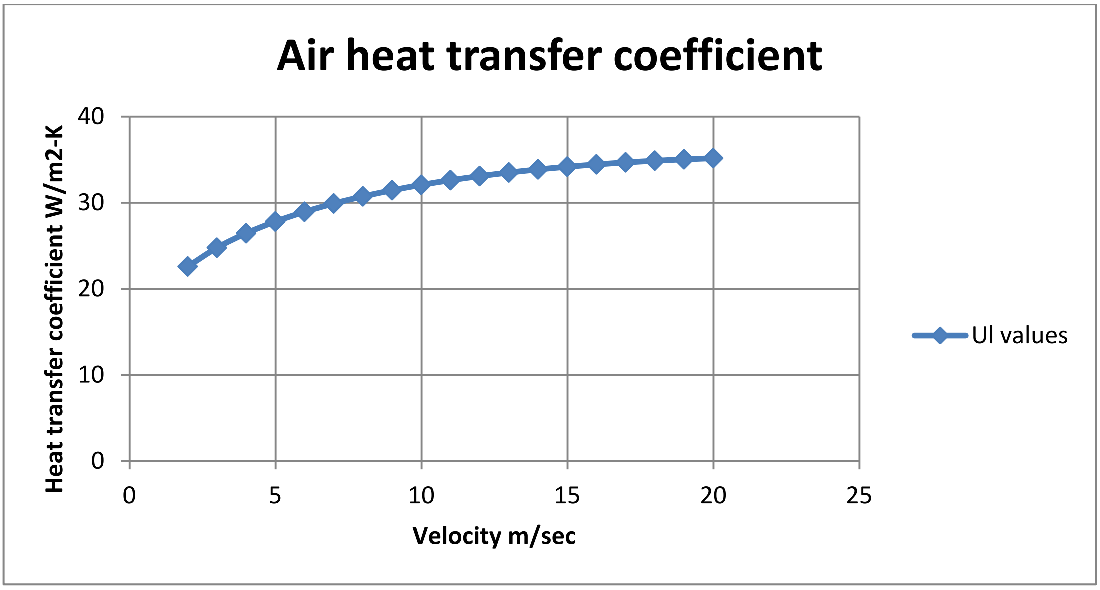

Figure 34:- overall heat transfer coefficient VS wind speed curve

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 10:- 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:-

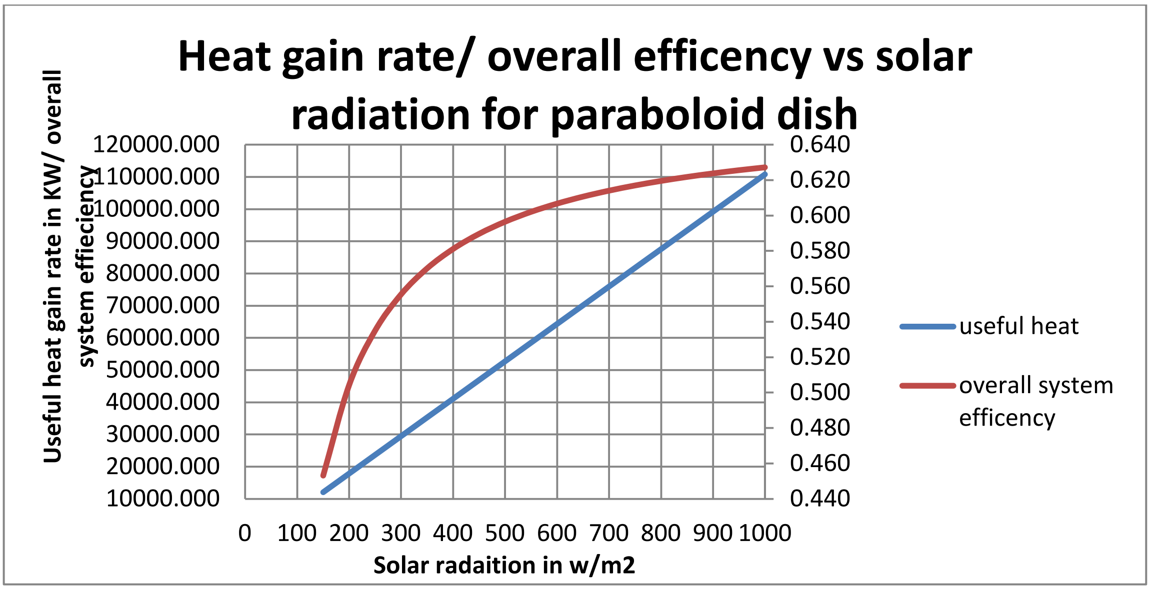

Figure 35:- overall system efficiency/ useful heat gain rate Vs solar radiation curve

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:-

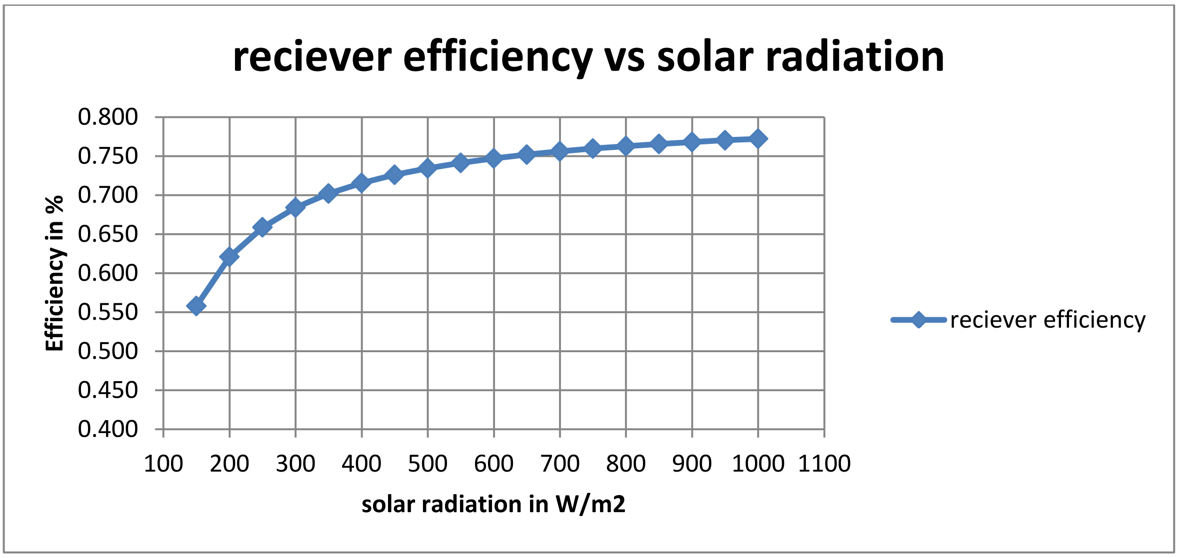

Figure 36:- Receiver thermal efficiency Vs solar radiation curve

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:-

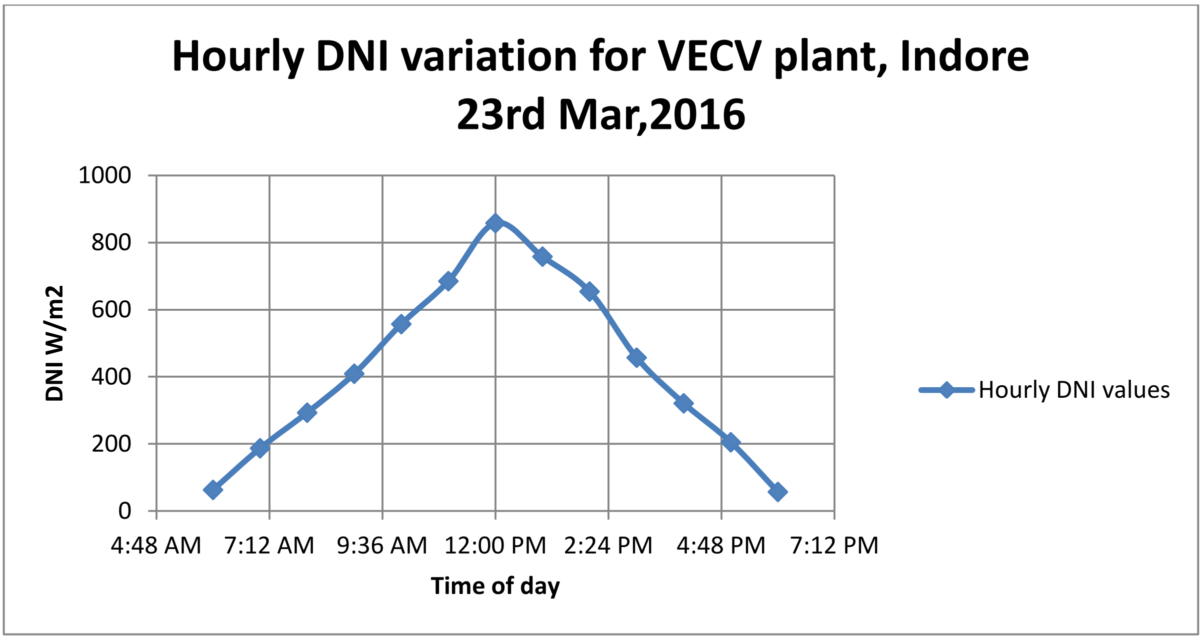

Figure 37:- Hourly DNI variation at VECV Plant, Indore (source:- VECV weather station)

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 10:- 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:-

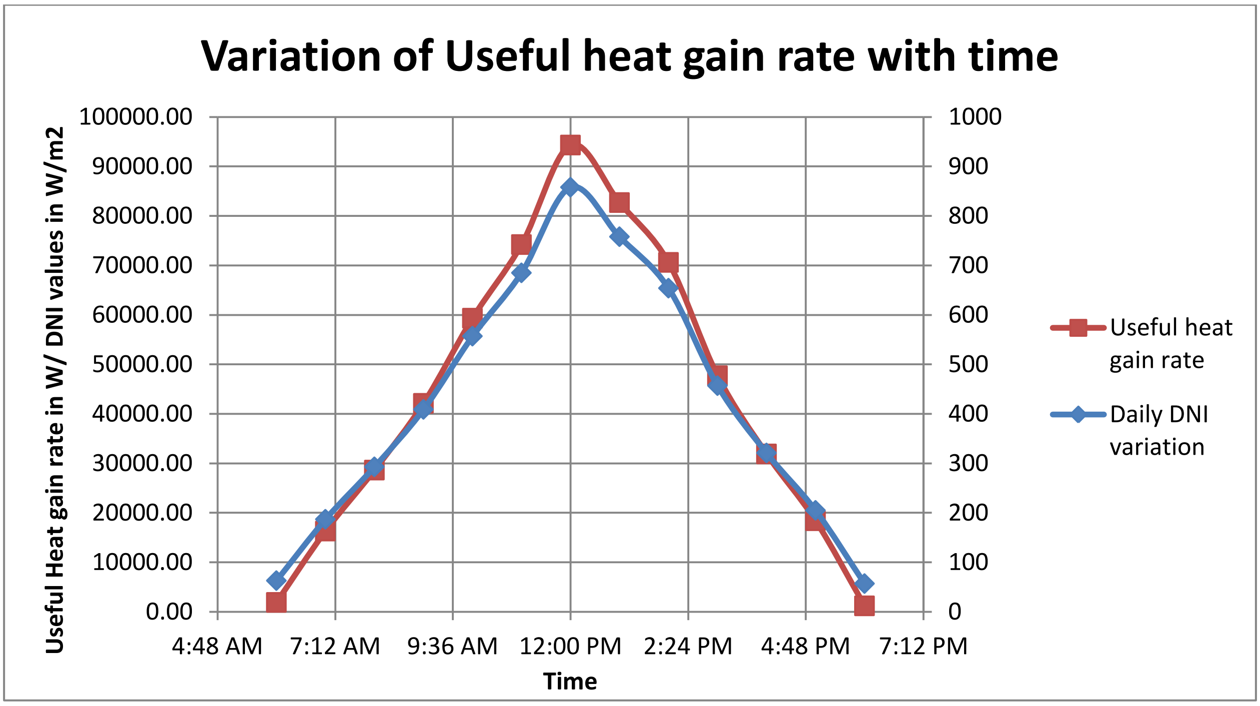

Figure 38:- Hourly Useful heat gain rate variation for 23rd Mar, 2016 at VECV Plant, Indore

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:-

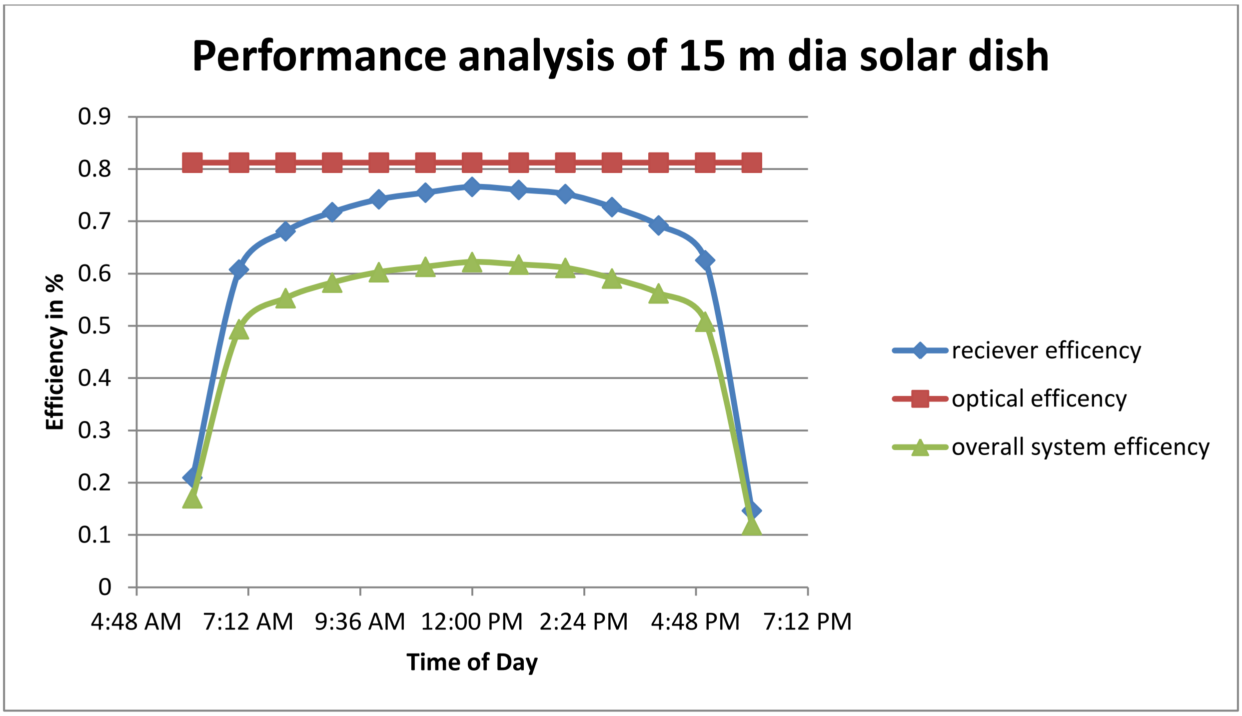

Figure 39:- Hourly Efficiency variation for 23rd Mar, 2016 at VECV Plant, Indore

CHAPTER 6: 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.

6.1. INTRODUCTION TO VECV MANUFCATURING FACILITY

Volvo Eicher Commercial Vehicles (VECV) Limited is a joint venture between the Sweden based Volvo Group and India based Eicher Motors Limited with headquarters at New Delhi. Started in July 2008, VECV comprises of four business verticals as follows **[26]**:-

- Eicher Trucks and Buses
- Volvo Trucks India
- Eicher Engineering Components
- VE Power train

Each of these business units is already well established and supported by a sizable customer base. The first truck was rolled out from VECV manufacturing facility at Pithampur, Indore, Madhya Pradesh in 1986. Trucks are present in the 5 Tons to 49 Tons category with VE series fuel efficient engines.

The state-of-the-art manufacturing plant at Pithampur, Indore has top level line manufacturing processes which includes cab robotic welding machine in body shop, CED paint shop with superior paint finish, integrated assembly shop facilities. The top coat paint finish is superior in terms of glossy appearance and corrosion resistance. The manufacturing facility has initial annual capacity of 33,000 automobiles which can be increased to 100,000 vehicles per annum in future. Total investment made for the plant set up was around Rs 375 crores. The Euro 6 based engine test facility has been set up for medium-duty automotive engine of 5 to 8 litre capacity engines.

Following products are rolled out of manufacturing facility at Indore, ranging from Tipper, light duty truck to heavy duty truck, Articulated tractor, etc as follows:-

- Eicher Terra 16
- Eicher 20.16
- Eicher 40.35

Following figure shows the various products ranges from VECV manufacturing facility as follows:-

Figure 40:- VECV product range at Indore Manufacturing facility (source:- VECV)

6.2. SITE LOCATION AND SOLAR RESOURCE

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:-

Latitude:- 22.614088° N

Longitude:- 75.673688° E

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 m^2 which is totally shade free area. Single 15 m diameter solar paraboloid dish concentrator has a total aperture area of 176 m^2 which will require total shade free area of 250 m^2. 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 m^2.

Also to keep one collector free from shadow of another solar collector, shadow analysis has been done on Google Sketch up software. Shadow analysis is done for 23rd December when shadows are the longest due to low altitude of the sun in the sky. Results for the shadow analysis shows that distance between one collector and another in a row is kept at least 25 m to prevent shading effect and between two rows, it is kept at 30 m distance.

The following figure 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 41:- Satellite image for VECV Manufacturing facility at Indore

Following figure shows the 10 number of solar collectors installed at site stated above along with shadow analysis for 23rd December as follows:-

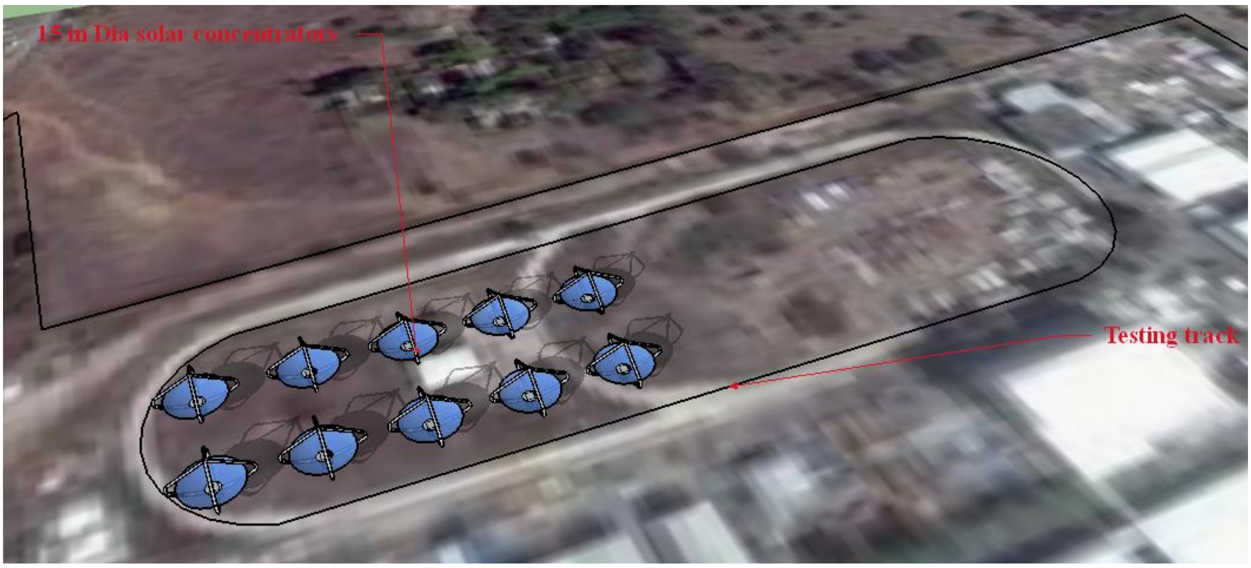

Figure 42:- Shadow analysis for 15 m diameter solar collector array

6.2.1. SOLAR RESOURCE AT VECV PLANT SITE

Direct Normal Irradiance (DNI) resource required for the working of concentrated solar thermal technology is taken from MNRE solar resource data base available on its website. Database is available for all latitudes and longitudes of major cities in India, data is selected for the above stated latitude and longitude. This monthly DNI data will be used to estimate annual generation potential for the solar collectors which can be used to calculate payback period for the system. Following figure gives the monthly average values of DNI at indore as follows **[27]**:-

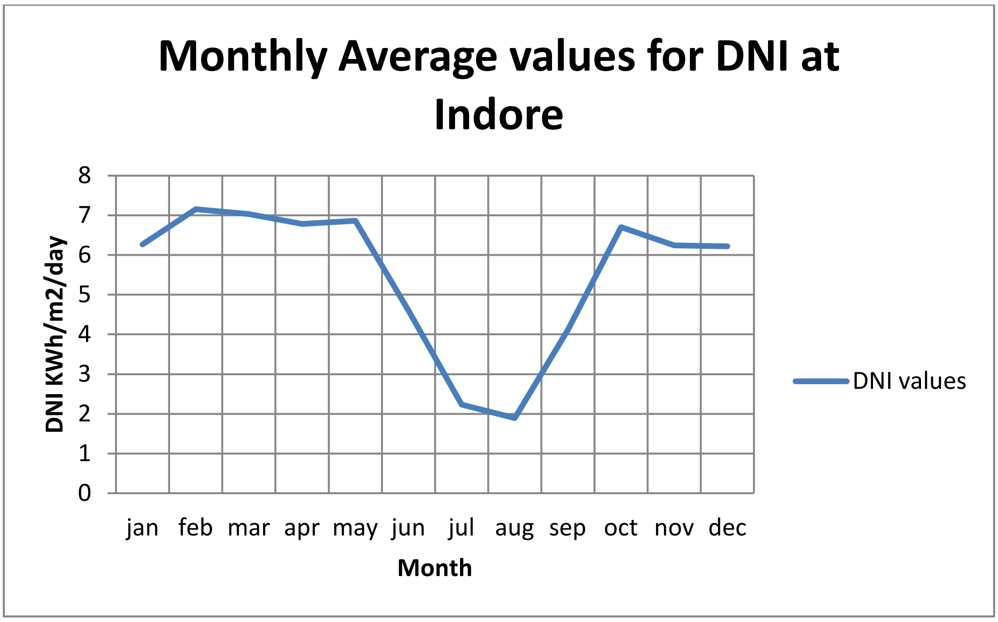

Figure 43:- Monthly Average DNI values for Indore (source:- MNRE)

Average annual value for DNI is 5.51 KWh/m^2/day for Indore with values highest for February at 7.15 KWh/m^2/day and lowest for august at 1.89 KWh/m^2/day due to monsoons in India. Hence system will work optimally from January to May, and then performance will dip from June to September, then again will perform optimally from October to December.

6.3. PROPOSED LAYOUT OF SIPH SYSTEM

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

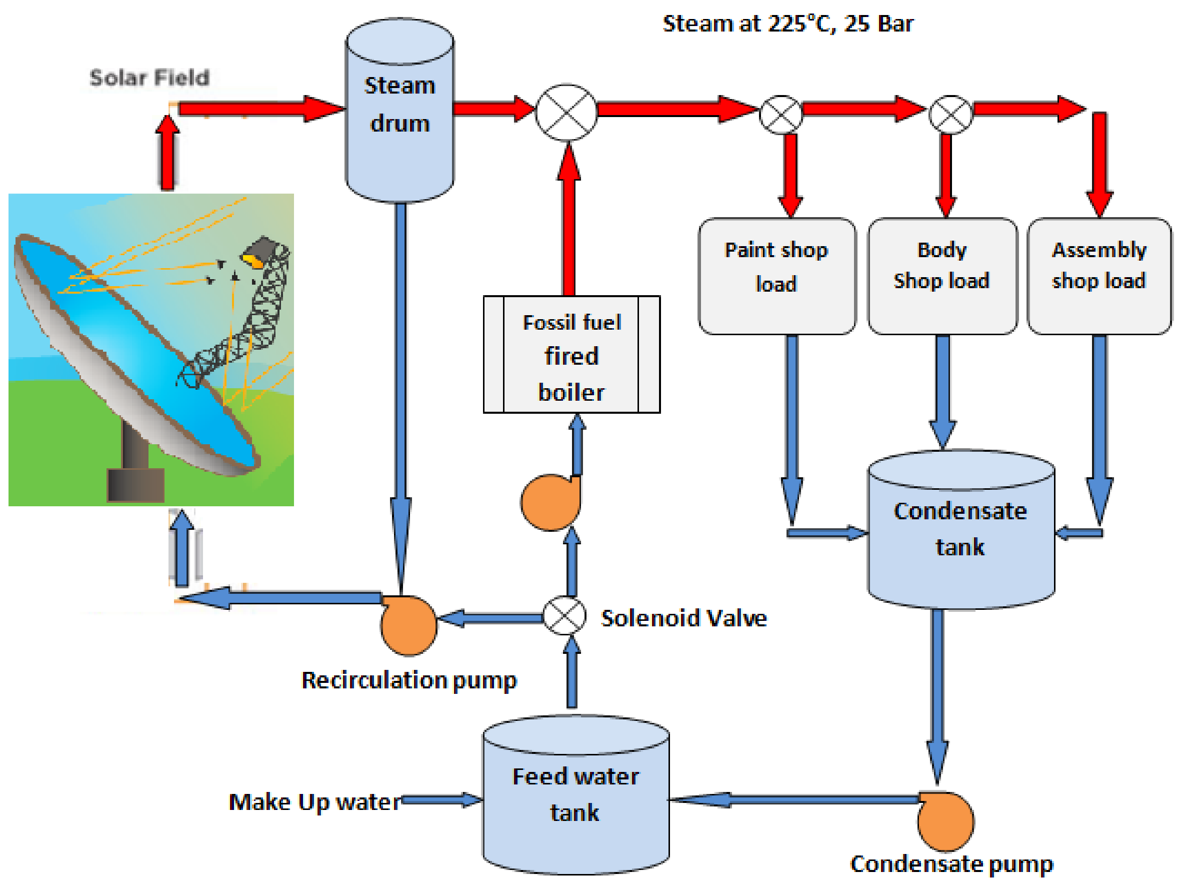

Figure 44:- Schematic P&I diagram for SIPH system at automobile industry

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.

15 m diameter solar paraboloid dish proposed 3D model has been prepared on Google sketch up along with major dimensions like concentrator dish diameter and focal length. Also major components of solar thermal collectors have been marked like cavity receiver, mounting support structure, reflecting concentrator surface and two axes tracking system mounted on a pedestal. 3D model has been added the physical properties of all the material used for different components like Aluminium frame, solar grade mirrors, galvanised iron etc to add realty to the model. Following figure shows the 3 dimensional model of Solar thermal collector to be used for automobile industry SIPH system as follows:-

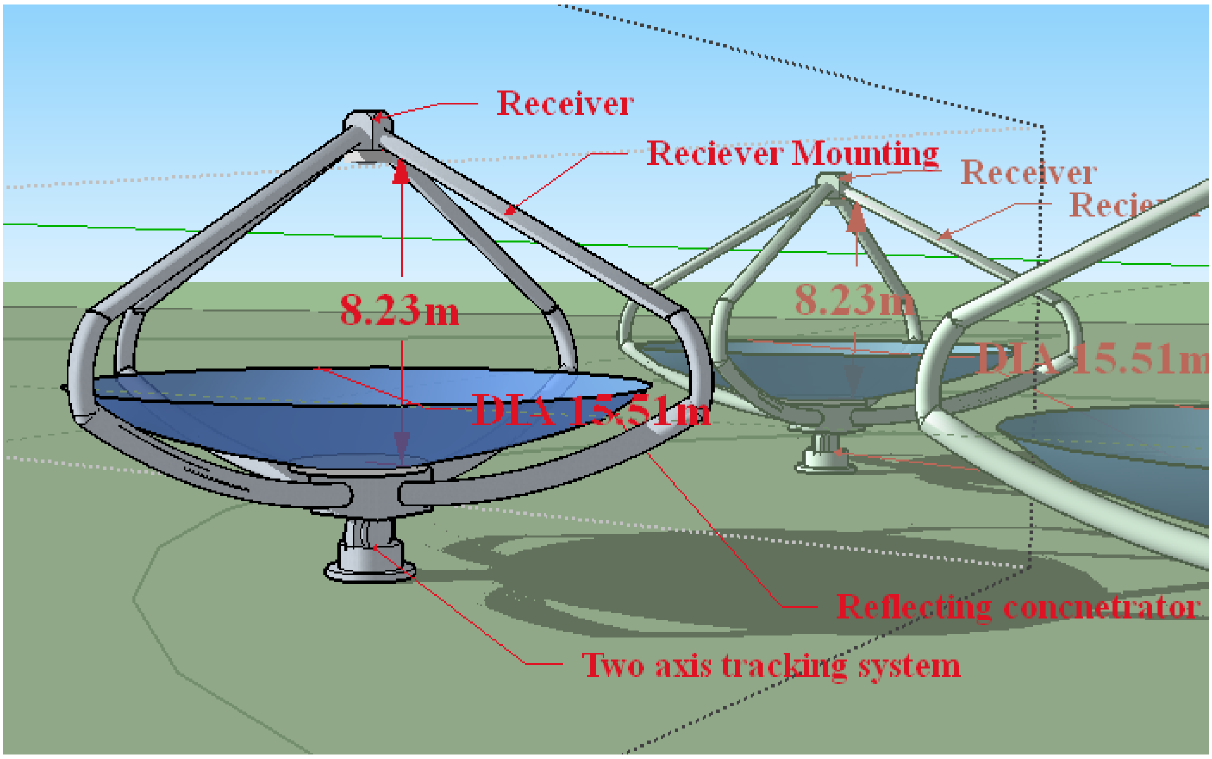

Figure 45:- 3D model for SIPH system solar collector at automobile industry

CHAPTER 7: 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.

7.1. TOTAL ENERGY REQUIREMENT OF INDUSTRY

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 shows the annual thermal energy required in KWh_{th} for the plant on monthly basis as follows:-

Table 11:- Design Calculation procedure for Annual energy estimation for VECV plant

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**

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.

7.2. ESTIMATION OF ENERGY GENERATION POTENTIAL OF SIPH SYSTEM

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 gives the design procedure for calculating annual energy estimation for solar paraboloid dish based SIPH system as follows:-

Table 12:- Design Calculation procedure for Annual energy generation for SIPH system

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**

Results of the following table are compiled in the form of the graph of monthly thermal units or KWh produced by one 15 m diameter dish. Following curve shows the graph for each month generation potential for solar thermal collector as follows:-

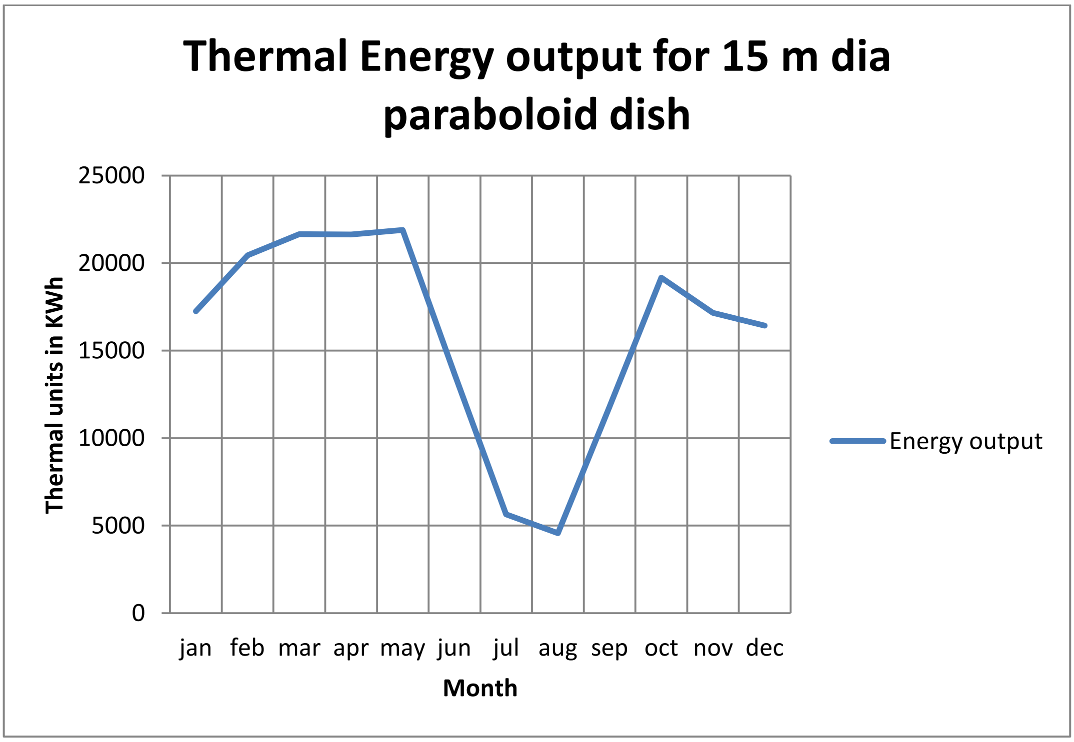

Figure 46:- Thermal energy generation for one 15 m diameter solar dish

Energy generation remains high for January to May, then dips from June to august and then rises from September to October to medium then falls low to November and December. This curve follows the same profile as DNI values varies for each month.

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.

Following figure shows the monthly solar fraction values for SIPH system at VECV plant, Indore as follows:-

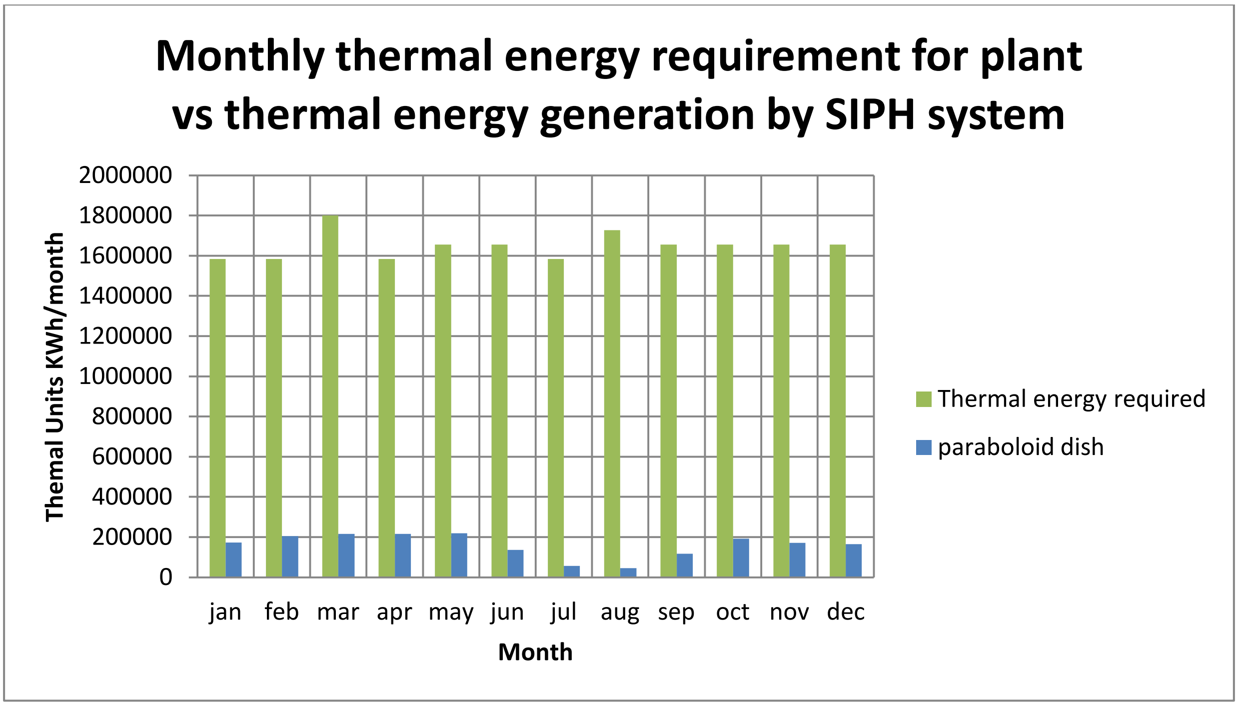

Figure 47:- Monthly Thermal energy requirement Vs generation for SIPH system at Indore

7.3. CALCULATIONS FOR PAYBACK PERIOD ESTIMATION

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.

Cost of currently used fossil fuels at VECV plant for thermal energy requirement is as follows:-

- **Electricity charges**:- **Rs 11/- per KWh** with taxes (Industrial connection at 11 KV from Madhya Pradesh Electricity Board)
- **Natural Gas charges**:- **Rs 5/- per KWH** with taxes (Industrial connection from Gas Authority of India limited)

As stated above break down for both sources of fuel is 59 % for electricity and 41 % for natural gas for energy demand fulfilment. Therefore Levelized cost of fuel depending on consumption percentage will be calculated as follows:-

Levelized Cost of fuel = 0.59 * Electricity charges + 0.41 * Natural Gas Charges

= 0.59 * 11 + 0.41 * 5

= Rs 8.54/- per KWh

This fuel cost of Rs 8.54/- per thermal unit will be used for calculation of payback period for the system. Following tables shows the calculation steps for the payback period estimation of Solar paraboloid dish based SIPH system at VECV plant , Indore as follows:-

Table 13:- 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**

CHAPTER 8: RESULTS, CONCLUSION AND RECOMMENDATIONS

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.

8.1. RESULTS OF THE PRESENT WORK

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 shows the results of the present work titled **Designing of Solar process hearting system for Indian automobile industry** as follows:-

Table 14:- 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%

8.2. CONCLUSIONS AND RECOMMENDATIONS

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:-

- Automobile industry is usually spread over hundred of acres of area with vast shade free rooftops available on production shed which make them viable for large collector areas.
- 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.
- 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.
- 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%.

However major challenges still exist against the growth of Concentrated solar heat (CSH) in industrial sector which can be addressed by the recommendation as listed below:-

- Government should promote local manufacturing of components required for concentrated solar technology like solar grade high reflective mirrors; microprocessor based tracking systems, etc under **Make in India** programme to meet growing demand for CST.
- Government should set targets for the CST annually like targets set for Photovoltaic or wind power and take commitments from various public and private sector companies at event like RE Invest. This will help to expand CST nationally.
- Government should make mandatory installations of CST for industries with area covered more than 50 acres to generate 10% of their thermal energy requirement from solar route or else pay fine for not complying with the rule.
- Government should promote new start up companies in the field of CST under **Stand Up India** programme by providing tax benefits, easy company registration process to expand CST nationally on the same line as of Photovoltaic.

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