A PROJECT REPORT MAJOR - II

On

SOLAR AIDED PROCESS HEAT APPLICATION IN CHEMICAL INDUSTRIES

Submitted in the partial fulfilment of the requirement of

Master of Technology

In

Renewable Energy Technology

Submitted By

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2K14/RET/11

UNDER THE GUIDANCE OF

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DECLARATION

I **Mohit Arora**, hereby certify that the work which is being presented in the major project –II entitled **"Solar Aided Process Heat Applications in Chemical Industry"** submitted in the partial fulfilment of the requirements for degree of M.Tech (Renewable Energy) at Delhi Technological University is an authentic record of my work carried under the supervision of **Dr. K. Manjunath (Assistant Professor)** & **Dr. R.S. Mishra (Professor)**. I have not submitted the matter embodied in this major project – II for the award of any other degree. Also it has not been directly copied from any source without giving its proper reference.

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CERTIFICATE

This is to certify that project entitled, **"Solar Aided Process Heat Applications in Chemical Industry"** is submitted by **Mohit Arora (Roll No. 2K14/RET/11)** to Delhi technological University, Delhi for the evaluation of M.Tech Major Project – II as per academic curriculum. It is a record of bonafide research work carried out by the student under our supervision and guidance, towards partial fulfilment of the requirement for the award of Master of Technology degree in thermal engineering.

The work is original as it has not been submitted earlier in part or full for any purpose before.

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ABSTRACT

The thermal energy requirement for a large number of processes in industries lies with a temperature range of 60°C-250°C, which constitutes major energy consumption in this sector, hence there is a huge potential for the implementation of solar aided industrial process heat systems. Different technologies of solar collector are available which can be selected based on the solar resource available at site and temperature range of the processes. Current work focuses on the thermal energy requirement in Chemical Industry in form of steam, hot air and hot thermic fluid. Non-evacuated tube parabolic trough collectors have been designed and analyzed for the chemical cluster in Ankleshwar, Gujarat. The site calculation is depicted by a particular case with roof – top installation of the system and a solar fraction of 22 % has been achieved. For the smooth integration of the solar collector system hydraulic scheme has been suggested by P&I diagram in the work. On the further evaluation, financial feasibility has been determined for the system with a payback period of 2.55 years & 25 % internal rate of return wrt. MNRE standards.

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Nomenclature

MNRE: Ministry of New and Renewable Energy

NREL: National Renewable Energy Laboratory

TERI: Tata Energy Research Institute

CST: Concentrated Solar Thermal

PTC: Parabolic trough Collector

IEA: International Energy Agency

UNDP: United Nation Development Program

CHAPTER: 1 INTRODUCTION

As per current scenario, Energy is the need of an hour. All the activities of the human and energy are inter-related, hence the energy consumption per capita is being considered as the index for Human development. The energy consumption across the globe has increased exponentially due to increase in the population. The major part of the energy generation is done by burning of Fossil fuels like Coal, Crude Oil and Natural gas which has contributed to environmental degradation in the form of extinction of species; melting of polar ice caps, increase in the average temperature, low quality air, fear of energy security and many more. Results of the over utilization of fossil fuels have lead the world to think and take over the alternate path for fulfilling their energy needs by using alternate sources of energy and making them the New Conventional sources of energy (Solar, Wind, Biomass, Tidal, Geo thermal etc). This sector is relatively new and requires large amount of money in setting up the plants and R&D as well.

Classification of the energy can be done in various ways, but as per the above context it is done majorly in two forms:-

- **Renewable Energy**: - The energy which can be utilized and replenished in the same form as extracted from nature. These are energies obtained from wind, sun, water & earth and are environment friendly i.e. do not pollute the environment.
- **Non Renewable Energy**: - The energy obtained from burning of Fossil fuels like coal, natural gas and crude oil which are exhaustible in nature and cannot be replenished at same rate of utilization.

Recent Climate Meet held in Paris December, 2015 oversaw the G-20 countries taking pledge towards safer environment by utilization of Renewable energy and energy efficiency. So the new ear has begun in which the RE will power all the process in one form or other.

1.1 Global Energy Scenario

Various International Organization like World Energy Council, International Energy Agency (IEA) have published reports – World Energy Scenarios, World Energy Outlook 2015 etc. which brings in light towards the current energy consumption pattern and recent development in the energy world. The Study and analysis of these trends will bring up the issues and problems related to the energy sector. Solution of these problems and issues can be found by different Renewable energy forms so that energy security and sustainability could be achieved via path of putting forward different energy policies.

1.1.1 Electricity Generation

A variety of sources are used for generation of electricity across the globe i.e. fossil fuels (Coal, Crude Oil, Natural Gas), Nuclear power and Renewable energy sources (Wind, Solar, Hydro, Tidal, Geothermal) etc. About 68% of the total electricity generation is from fossil fuels as per year 2014 which is almost equal to 16000 TWH.CO_2 emission caused by the fossil fuel burning for electricity generation amounts to 12 Gigatons. **[1]**

World Energy Council has given two different scenarios of electricity consumption by 2050 – **Jazz** (Based on affordability of energy) and **Symphony** (Based on Environmental sustainability achievement). In the former category the primary energy consumption will increase by 61 %, while of the latter side the increase is 27% as huge amount of investments is required to carry forward the electricity generation in environmental sustainable manner. **[2]**

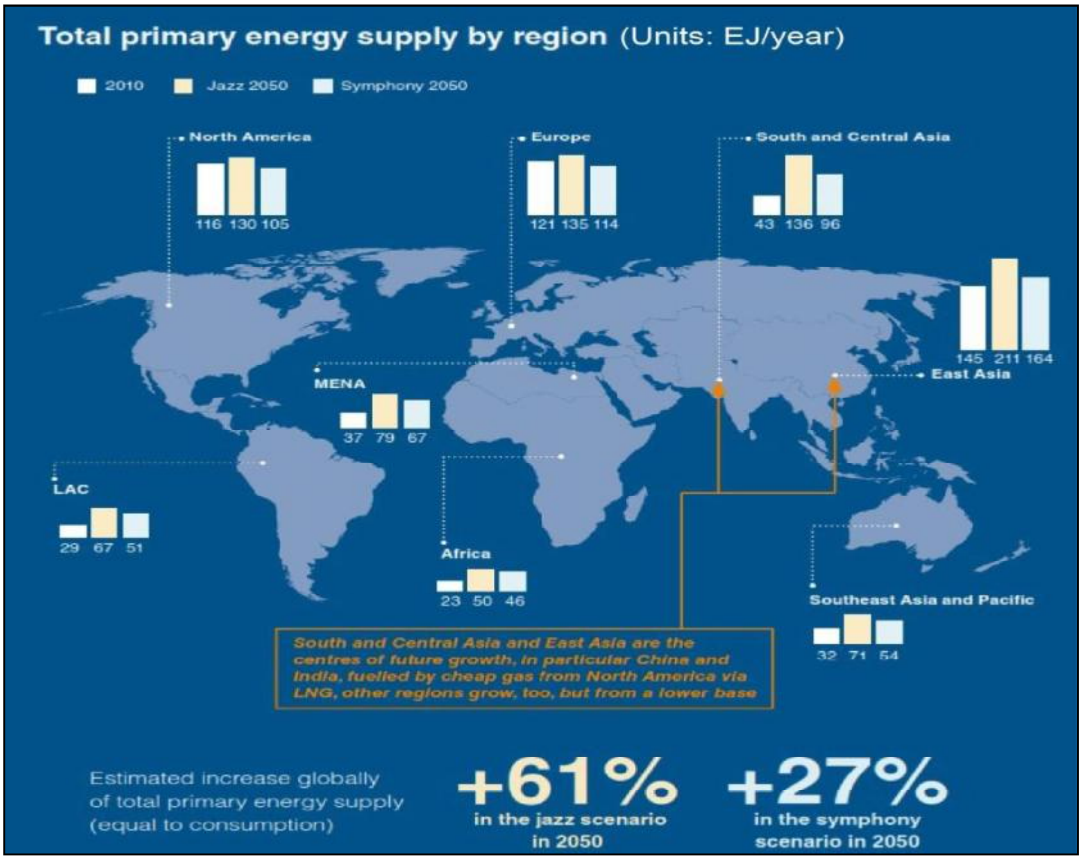

Figure: 1.1, World Map showing Increase in Energy Consumption up to 2050 around the world [2]

As per the goals of different countries announced worldwide, **IEA** in World Energy Outlook 2015 has estimated the electricity generation by different sources as summarized in the table below:-

Table: 1.1, Energy Generation from different sources in 2014 and 2040 (estimated) [1]

Different Sources	Electricity Generation by different sources (2014)		Electricity Generation by different sources (2040)	
	TWH	%	TWH	%
Coal	10000	42.55	11750	29.71
Oil	1200	5.1	800	2.02
Gas	4800	20.42	9000	22.75
Nuclear	2500	10.63	4500	11.37
Renewable	5000	21.27	13500	34.13

So from both scenarios, it is evident that the world energy generation is shifting its tides from the pool of fossil fuels towards the Renewable Energy stream line path. In the fossil fuel area the generation from Natural gas is going to increase, while the generation from Coal and Crude oil is contracting. In the race to clean up the air Nuclear power generation is also increasing.

$C0_2$ emissions have increased from 6 Gt in 1990 to 12.5 Gt in 2015, which are directly resulted from fossil fuels generation i.e. the Green house gas emissions have doubled in last 2 decades as of generation of electricity 11000 GWH (1990) to 23500 TWH (2015). The relationship of the C02 emissions and the electricity generation in terms of graph is given by IEA report below: - **[1 & 3]**

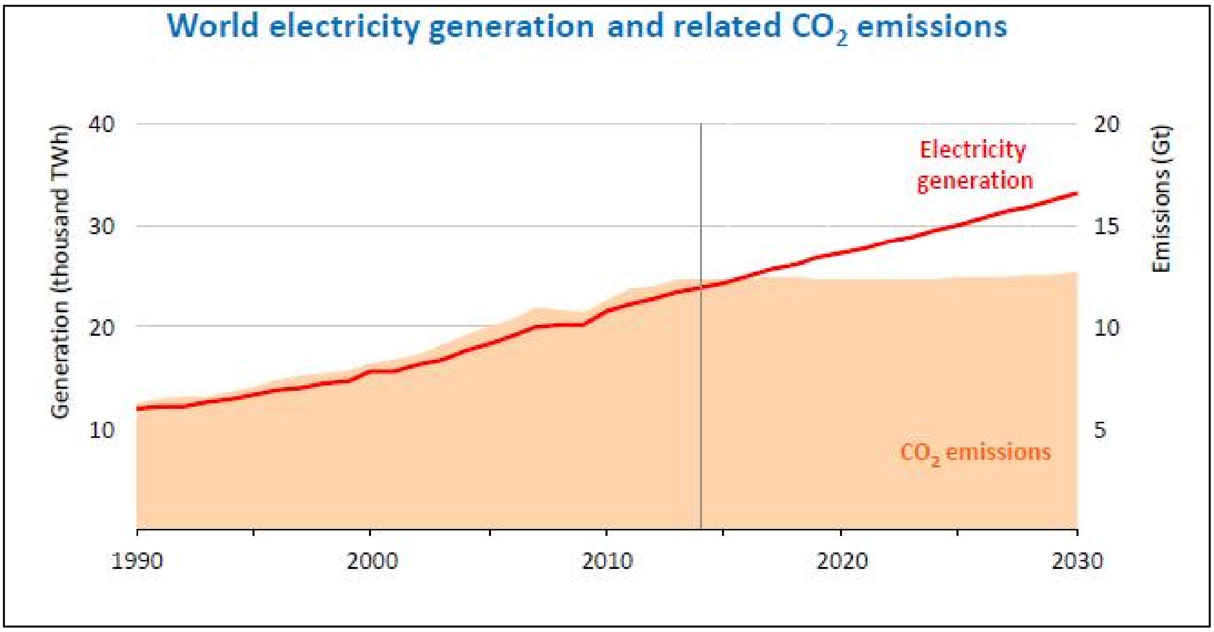

Figure: 1.2, World Electricity generation and related C02 emissions [1]

After the COP 21 meet in December, 2015 the world has pledged to move towards carbon free generation leading towards sustainable development. The graph exactly depicts the tremendous increase in the green house gas emissions from 1990 to 2015, however with new Energy generation the level of C02 emissions should remain fairly constant (12 Gt) while the electricity generation continuous to increase and expected to reach 39550 TWH by year 2040. The new generation sources of energy by which the C02 emission would remain nearly constant are Renewable (Solar, Hydro, Wind, Others), Gas and Nuclear based. Following chart gives the comparison of electricity generation by different sources for year 2014 and 2040 as per prediction by IEA: - **[1 & 3]**

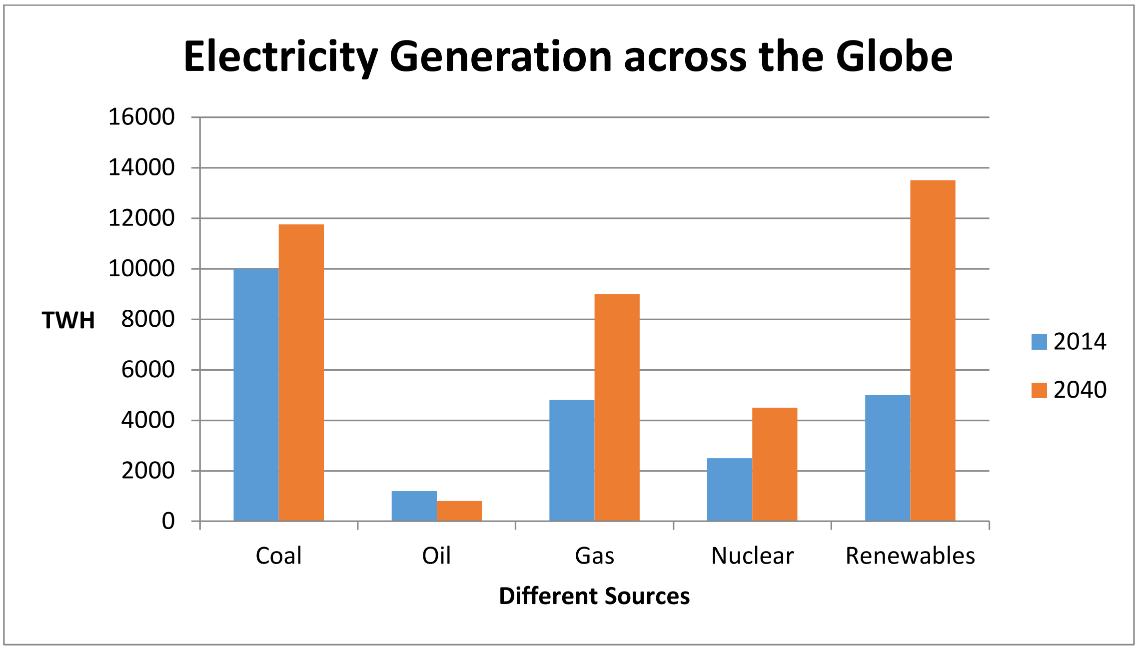

Figure: 1.3, Comparison source wise generation for year 2014 and 2040 [1]

1.1.2 Electricity Consumption

Figure: 1.4, World Map showing density of energy consumption for different countries [4]

The world generation and energy consumption show two different overview in some region while mention same in some region i.e. some countries have less generation of electricity but are still utilizing more as they are independent on the other countries and some have less population but still there energy intensity is very high due to quality standards of living. The above map shows the energy consumption pattern over the globe. The energy consumption in U.S and European countries are much larger than Asian countries as per the geographical area. In terms of total consumption China is world leader. **[4]**

1.2 India`s Energy Scenario

India accounts for only 6 % world primary energy consumption while on the other hand India has world`s 18 % population. The energy consumption of India has doubled from 2000 to 2015 but still has large potential and is expected to grow exponentially .About 240 million people has no access to electricity and per capita consumption is one-third of the global average. Up to 2040, India is going to contribute more than any country of the world in the projected rise for energy demand. The key energy driving trends include - Industrialization and Urbanization which will further ignite the energy demand around the country. Comparison between India and rest of the world in per capita consumption is shown below:-

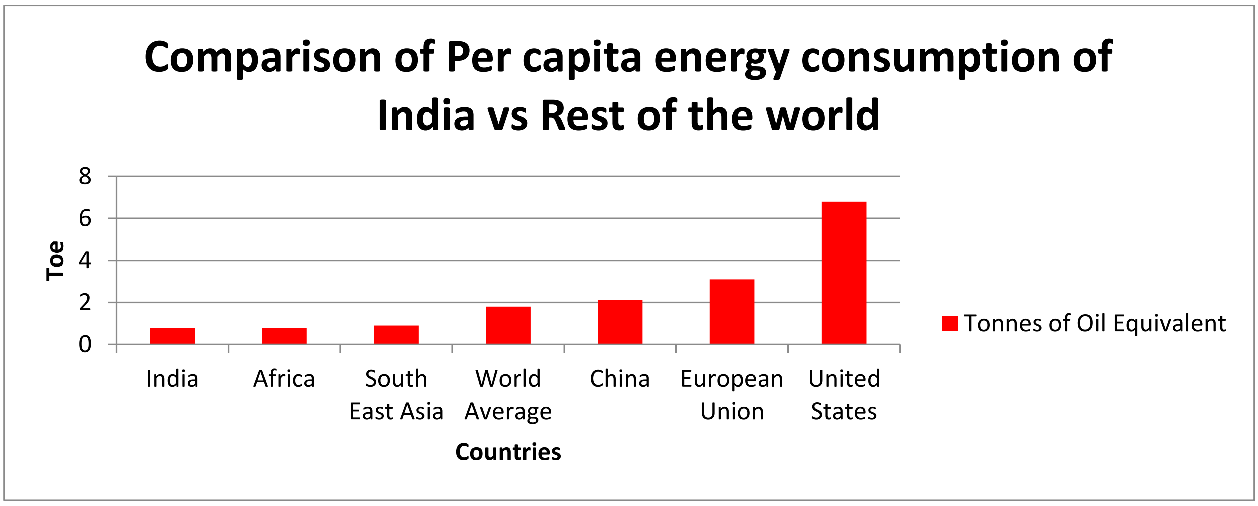

Figure: 1.5, Comparison of per Capita Energy consumption [5]

The Gross Domestic product and Primary energy consumption are inter-related. As the GDP of the country grew from 2000 Billion Dollars (1990) to 7000 billion dollars (2013) the primary energy demand grew from 300 Mtoe (1990) to 680 Mtoe (2013). In the year 2015, the energy demand of India grew equivalent to the GDP i.e. 7.5 %. It is represented by figure below:-

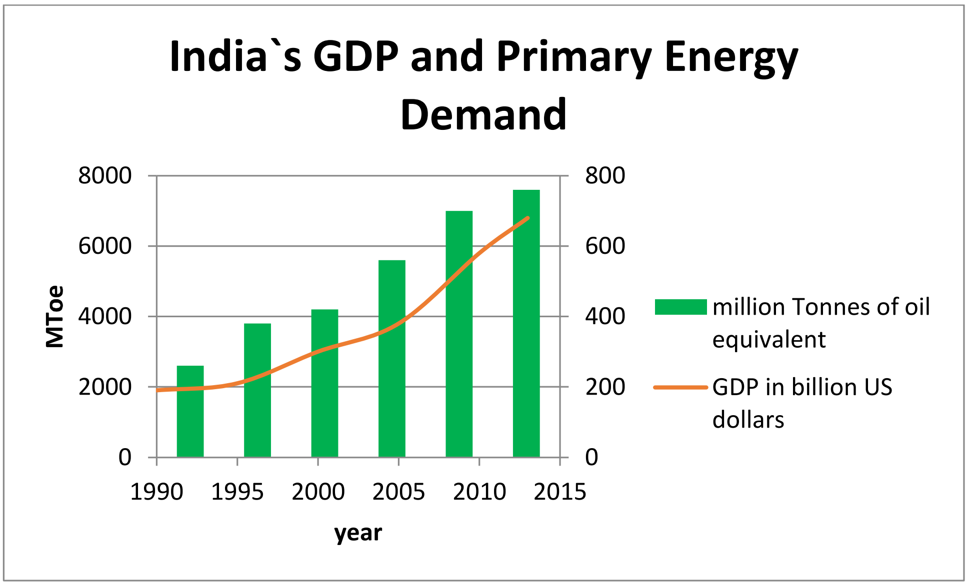

Figure: 1.6, Graph showing India`s Primary Energy Demand and GDP variation [5]

1.2.1 Primary Energy Demand in India according to Fuel

About 70-75 % of the Indian energy demand is met by Fossil Fuels; this increase is the result of coal usage instead of biomass. Coal accounts to about 44% of the total energy demand met in the year 2013 which is mainly due to tremendous increase in fleet of Coal based power generation and as Coking coal in steel industry.

Oil consumption in 2014 was 3.8 Million barrels/day out of which 40% was utilized in the transportation sector. Diesel contributes to 70% of the fuel market share. The share of LPG has swollen due to urbanization and subsidies by government of India. Natural gas got a small share of about 6% in the India energy market. The chart below mentions category wise demand by the year 2013. **[5]**

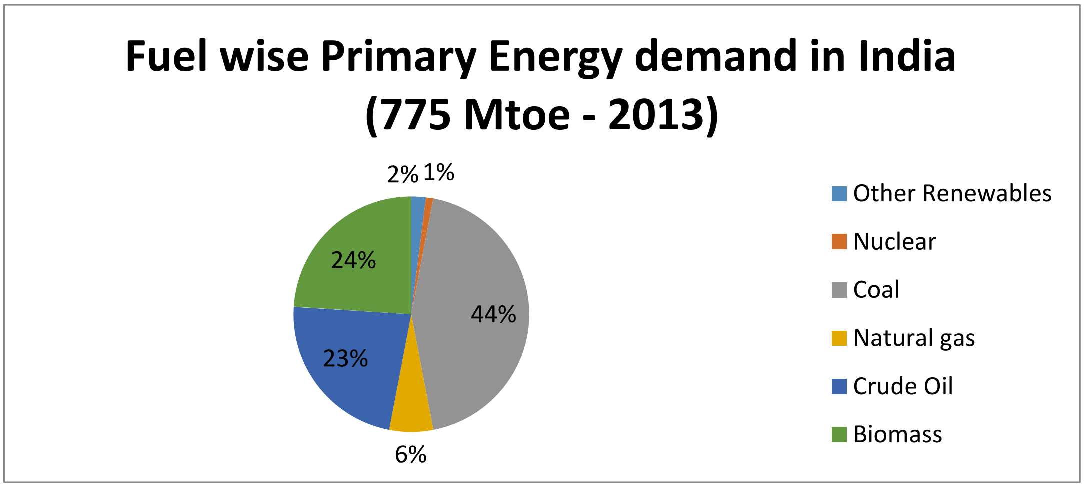

Figure 1.7, Pie Chart showing Primary Energy Demand met by different sources in 2013. [5]

1.2.2 Energy Demand by Selected End use sector according to fuel

Traditionally Building sector has dominated the energy demand including services & residential, but there has been more rapid increase in the energy demand in Industries and has overtaken buildings to be the leader by 2013. Energy demand in building sector has grown about 8 % in average from 2000 – 2013 due to increase in the appliance ownership like T.V, refrigerators, Air conditioners etc. Industrial energy demand has become twice in 2013 as of 2000 with large expansion in energy consumption sectors. Road transport accounts for 90 % of the total share of energy demand in the transport sector due to increase in passenger vehicles. Share of bio energy has decreased in the building sector and electricity & coal has become the replacing agent. **[5]**

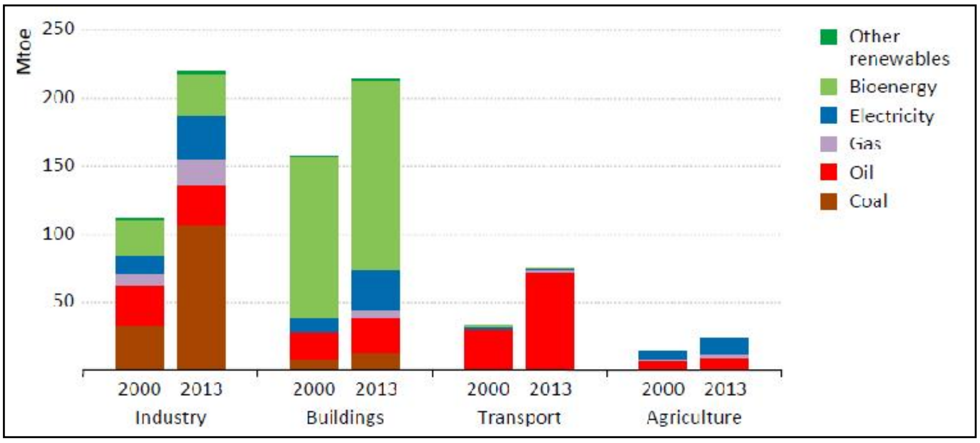

Figure: 1.8, Energy Consumption comparison in different sectors for year 2000 and 2013 [5]

1.2.3 Status of Fossil Fuel usage in India

India is one of the few countries of the world which heavly rely on the imports for meeting its energy demand in the form of Fossil fuels.These imports are major reason for India`s huge bills for crude oil & natural gas and economic trade deficit. The domestic production of these fossil fuels is much less in comparison to the consumption and demand within the country and thus raised the alarm of energy security in te country. The following graphs show the trend of increase towards imports in all the fossil fuel form 2000 to 2013:-

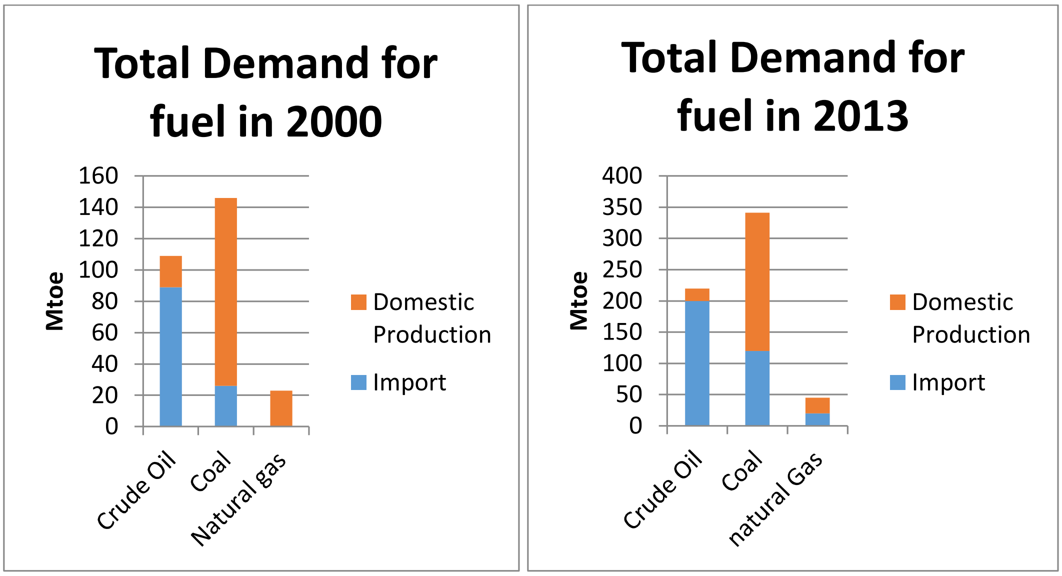

Figure: 1.9, Comparison of Demand of different types of fuel in 2000 and 2013 [5]

With the increase in the coal based power generation both the domestic production and Import both increased. While the increase in consumption of Natural gas has started the import .In case of Crude Oil the domestic production has not increased much as in comparison to the increased imports. **[5]**

1.2.4 Coal

India has got 12 % of the total world coal reserve and stands as 3 rd among countries having largest coal reserves. With current reserves India finds it difficult to meet the coal demand of the country because these deposits are having low calorific value and high ash content. In 2013, the domestic production of coal touched 340 Mtce and imported 140 Mtce to meet its demand. The imports accounted nearly 12 % of total world coal imports from Australia, Indonesia and South Africa. In order to decrease the imports of coal the Government of India announced plans for doubling the domestic production by 2020.Coal India, a public sector enterprise accounts for nearly 80 % of domestic production.

In recent years, the difficulty in expanding production of coal has got a number of factors including delays in land acquisition, environmental permits, infrastructure constraints, rehabilitation and resettlement issues etc. Land degradation, erosion, deforestation and acid water runoff are some of the common environmental problems caused due to coal mining. The coal reserves in the country are situated in eastern and central parts; hence the coal needs to be transported via railways or trucks to different parts across India and on the other hand increases the cost of generation of electricity. **[5]**

1.2.5 Natural Gas

In the India energy domestic mix Natural gas has only 6 % of share. Major onshore gas producing fields are in Assam (North-East), Gujarat (West), Tamil Nadu & Andhra Pradesh (South) and Offshore field is East coast of Krishna- Godavari basin. GAIL is main stream player in the Indian gas industry and a large number of distribution companies are there to provide the connection to consumers along with GAIL. In 2013 the production of the conventional gas reached 34 bcm. India has a large potential of unconventional Coal bed Methane and Shale gas. In this area private players have started gaining momentum and are in first stage of development. **[5]**

1.2.6 Crude Oil

For fulfilment of primary energy demand India is mainly dependent on import of crude oil. India has a domestic production capacity of 90,000 barrels/day, while the consumer demand is 3.8 Million barrels/day refined output.

India has got oil reserves of about 5.7 billion barrel which are much less in comparison to the current demand. The most of the oil reserves of India are in Rajasthan, Offshore areas of Maharashtra & Gujarat and Arakan Basin, Assam.

India has recently announced the strategic aim to decrease the imports up to 10 % by year2022. Another policy for encouraging the new exploration blocks in deep off shore region by companies; the Government of India have increased the incentives for natural gas and crude oil. **[5]**

1.2.7 Hydro Power

The current installed capacity of hydro power is 45 GW out of which 90 % is large hydro and 10 % accounts for small hydro. It is estimated that only about 33% of the total hydro capacity has been harnessed and rest is yet to be developed in Northern and North-Eastern parts of the country. About 14 GW of the capacity is under construction, which was delayed due to major issues like Public opposition, technical or environmental problems. Apart from non carbon generating electric source some of the advantages of hydro power plant are Water management for flood control, Drinking and irrigation purposes. In last decade, the growth of further projects have become stalled due to high upfront costs for large hydro projects with long term loans and financing issues. So in order to overcome this, Government of India has brought focus towards Small hydro power plants with capacity less than 25 MW. The total installed capacity of Small hydro as per March,2016 has reached 4 GW.**[5]**

1.2.8 Bio energy

It accounts to nearly 25 % of the total energy consumption of India with majority use in rural households for cooking. The major issue involved with usage if biomass is indoor pollution which causes adverse effect on human health especially ladies. Bagasse based cogeneration systems of about 8 GW capacities are currently installed and are electrifying grid as of March, 2016. To popularize the usage of different Bio energy forms like Biomass Gasifiers, Bio fuels Government of India has launched `National Bio Energy Mission`. A target for 20 % of Bio fuel blending with conventional fuel have been set up under the above said mission. **[5]**

1.2.9 Wind and Solar Energy

In 2015, government of India organized RE invest meet in which it raised the targets set earlier to 175 GW of total Renewable Energy capacity. The major parts of this target are Solar and Wind energy capacities of 100 GW and 60 GW respectively. As of 2016, India is currently 4th largest wind power producer across the globe with an installed capacity of 26 GW and in Solar the installed capacities have crossed over 6.5 GW. Gujarat, Rajasthan, Tamil Nadu are renewable energy states having a large potential of both Wind and Solar energy generation. The current cost of installation of Wind and Solar plants per MW is about 6 Crores and Feed in Tariff of Rs 5/ unit has reached.**[5]**

1.2.10 Nuclear Energy

India has an installed capacity of 6 GW nuclear power plants with 21 plants at 7 sites spread across the country. About 4 GW is under construction at 6 sites which will soon become operational. The operation of the plants went low up to 40 % plant load factor in 2008 but after nuclear supplier group agreement situation eased out. In 2013 the average PLF was about 80 %. Although the current share of the nuclear energy in the Indian energy mix is about 3 %, but Government of India has ambitious plans to increase the nuclear plants. India has got limited Uranium reserves but thorium reserves are available in large quantity. With Civil Nuclear Liability Act, 2010 India has failed to attract investment in this sector, but in 2015 the Insurance pool suggestion for talking up the liability has got the attention and has broken the deadlock for the US companies operation in nuclear sector of India.**[5]**

1.3 Industrial Process Heat Demand

Industrial Process Heat is defined as the thermal energy utilized in different processes to carry out manufacturing at desired conditions. In general this form of energy is currently supplied by burning of Coal & Natural gas or electricity. The application of process heat in different industries in done following modes:-

- Hot Air: - It is used for drying or dehydration application in Industrial process. It is generally supplied by hot air generators
- Hot Water :- It is used for various applications and are generated by steam from Boiler in heat exchangers
- Heated Thermic fluid:- It is used for dryer or jacket heating where Hot Air cannot be used and are generally generated by thermic fluid heaters
- Process steam: - it is used for high temperature heating and mixing operations' and Boiler fired by coal or natural gas are generally used.**[6]**

Large amount of energy is spent on the Industrial heat generation in many countries of the world. India uses 189 million tons of crude oil annually **[7]**, of which 40 % is used in the industry and 60 – 70% of this is used in majority applications of heating below 250°C. Indian industries require about 34 % of total primary energy requirement of the country to meet their own needs. It is estimated that about 30% of this total energy demand of industries could be met through Solar heating systems directly or indirectly which could save large amount of Coal, furnace oil, LDO or Diesel .**[8]**

India has got structural dependence on imports to meet it's nearly 77% of annual energy demand. With sound technological base and abundance of solar radiation altogether has created a favourable environment for solar energy exploitation in India. **[8]**

Based on study, research and interaction with Industrial counterparts, Industrial associations, Energy servicing companies and Energy Auditors, the potential areas for Integration of solar thermal collectors can be classified in following areas:-

- Potential for Hot Air generation
- Potential for Boiler Feed water heating
- Potential for process cooling and comfort cooling through VAM
- Potential for process heating**[9]**

From a number of studies on industrial heat demands, favourable conditions have been identified for integration of solar collector technology in several industrial sectors in the form of steam, heated thermic fluid, hot water or hot air. Some of the important processes and their temperature requirement range are outlined in the table below:-

Table: 1.2, Temperature ranges for different Industrial processes, [10 & 11]

Industrial Sectors	Processes	Temperature required (°C)
Dairy	Pasteurization	60-80
	Sterilization	100-120
	Drying	120-180
	Concentrates	60-80
	Boiler feed Water	60-90
	Washing & Cleaning	60-80
Tinned food	Sterilization	110-120
	Pasteurization	60-80
	Cooking	60-90
	Bleaching	60-80
	Washing	60-80
Textile	Bleaching, Mercerizing	60-90
	Drying, Degreasing	100-130
	Dyeing, Sizing	70-90
	Fixing	160-180
	Wrapping	90
Paper & pulp	Cooking, drying	60-80
	Boiler feed water	60-90
	Bleaching	130-150
	Chipping & Debarking	80
	Pulping	80-100
	Washing	80-100
Flours and by products	Sterilization	60-80
Chemical	Steam	150
	Hot Air	150-200
	Process heat	120-180
	Washing and Cleaning	60-90
Meat	Washing	60-90
	Cooking	90-100
Beverages	Washing, Sterilization	60-80
	Pasteurization	60-70
Bricks and Blocks	Curing	60-140
Plastics	Preparation	120-140
	Distillation	140-150
	Separation	200-220
	Extension	140-160
	Drying	180-200
	Blending	120-140

Pharmaceutical	Boiler feed Water Hot Air Sterilization Washing & Cleaning	60-90 70 140-160 60-90
Electroplating	Hot Water	60-90
Beer	Boiler make up water Brewing Process heat	60-90 60-70 80-110

1.4 Solar Industrial process heating system

SIPH systems are the systems which utilize the appropriate solar thermal collector technology along with thermal storage (if required), heat exchanger (optional) and hydraulic circuit consisting of valves, pumps and fluid flow piping's.

Various factors affect the techno-economic feasibility of any SIPH system, some of them are:-

- Adequate quantity of Heat must be supplied.
- Heat supplied must be of Good quality.
- Solar collectors must transfer heat directly to the process for which heat is required.
- There must be profitable utilization of Solar Energy.**[6]**

However it is advisable to have fossil fuel fired boiler as a backup, as solar energy is an intermittent source of energy, hence the output of the collectors would be varying according to the availability of sunlight. Different modes when integrated with solar collectors can be generated in the following manner:-

- **SIPH system for Hot Water**
  In industries large amount of hot water is required in the temperature range of 50-100°C for different processes like Cooking, Bleaching, Mixing, Dyeing etc. The hot water can also be utilized for feeding the boiler. This hot water requirement could be easily met by the flat plate or evacuated tube collectors. **[6]**

  It consists of Flat plate /evacuated tube collector for receiving solar energy and provides output nearly 80°C. The output generated from the system can be used directly or can be stored in the storage tank for later usage. However, the system can function with or without the storage system. Circulating Pump is used to maintain the flow in the system and all the actions are initiated by controller in accordance to temperature feedback. **[12]**

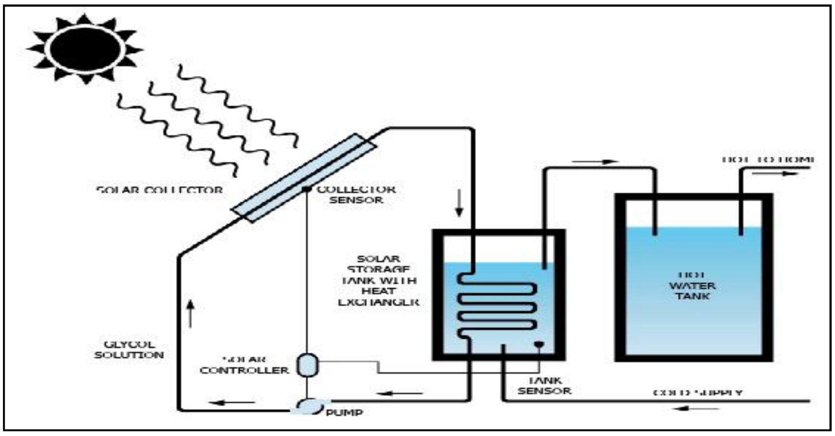

Figure: 1.10, Hot Water SIPH system [12]

- **SIPH system for Hot Air**

  The hot air is usually generated from solar dryers or flat plate/ evacuated tube collectors using air as working fluid. The system is almost similar to that of the hot water generating systems. For backup hot air generators fired by natural gas are utilized in case of non sunny day. The system consists of:-

  1. Array of conventional flat plate collectors
  2. Storage of stones or Rock bed for supplying heat during non sunshine hours
  3. Air ducts for connection between drying centre, solar collectors and storage system.
  4. Heat Exchanger(if any other fluid is being operated in the solar collectors)**[6]**

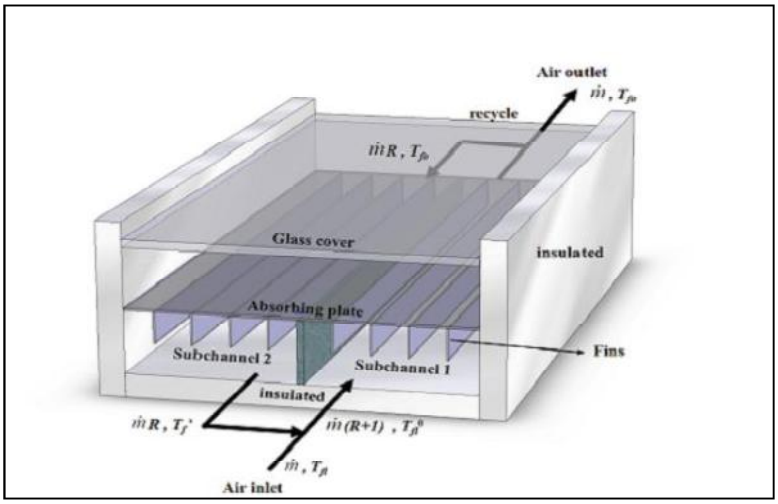

Figure: 1.11, Solar Air Collector system [13]

Air is drawn by forced circulation in larger system by air pumps or by difference in density gradient for smaller systems. As the air moves upwards the temperature of the air increases and its density decreases and is transported via duct to the drying chamber or storage. Fins are used to increase the heat transfer area. **[13]**

- **SIPH system for Process Steam**
  Steam is the main form of industrial process heat and accounts to more than 60 % of industrial processes. A large number of concentrating collectors are connected in array for steam generation and is supplied directly to the process via pipelines. The quality and quantity of the steam generation depends upon the system design. Steam up to 250 °C is used industrial processes can be generated by different ways:-

  1. Direct generation of steam by concentrating collectors

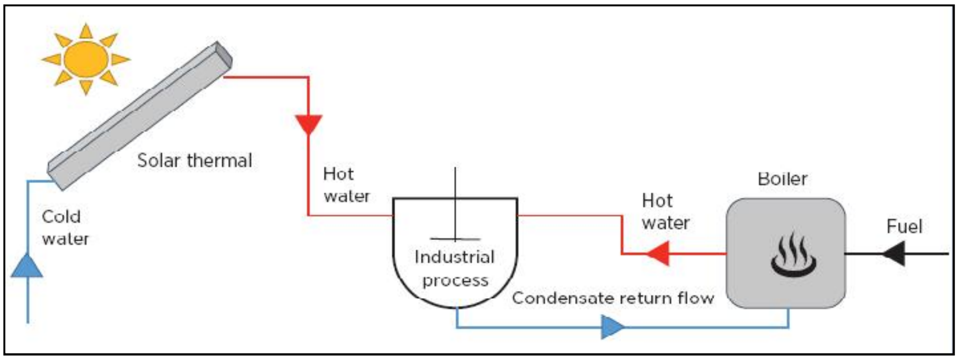

Figure: 1.12, direct generation of Steam/Hot Water by Solar Thermal Collectors [14]

  2. Pre heating of water by solar collectors and then feeding it to Boiler for further increase in temperature to get saturated steam.

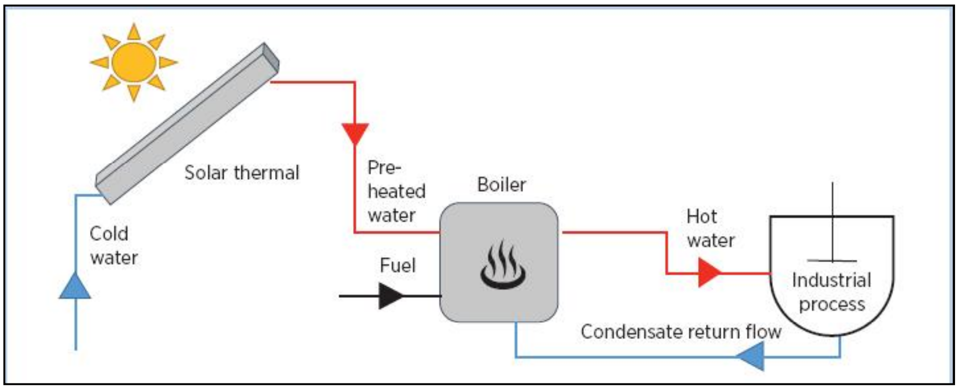

Figure: 1.13, preheating of feed water for Boiler [14]

  3. Steam production by high temperature water circulation through flash chamber.

Integration of Solar collector system with conventional system requires control strategies and storage to manage the system during non sunshine hours. The accurate estimation of demand and supply that that could be generated by the system are the fulcrums for effective working of these types of system. Some of the characteristics of SIPH systems are:-

1. Good utilization of solar equipment is only possible if utilized year around
2. The temperature ranges are well suited for operation of Solar thermal collectors
3. Lack of awareness and knowledge about these types of systems have hampered the growth of this particular sector
4. Economies of scale make it commercially viable to use these types of systems

5. It can decrease the amount of usage of fossil fuels thereby decreasing the carbon emissions. **[6]**

1.5 Potential of SIPH system in India

ABPS Infra mapped industry segments and their clusters for MNRE in 2011.Focuss of this task was to map out the Industrial segments which require different types of process heat either in the form of hot air ,water or steam. The tabular column mentions the location and different industrial segments spread across the country:-**[9]**

Table: 1 .3, Different Industrial Cluster across India [9]

Industry	Clusters Covered
Textile	Tripur/ Maharashtra/ MP
Paper & Pulp	Muzaffarnagar / Vapi
Food Processing	Sangli / Kochi / Aurangabad
Auto Component	Coimbatore / Pune / Gurgao n
Chemicals, fertilizer, pharmaceuticals	Baroda/ Dehradun
Rural Industries	Raipur
Sugar	North Karnataka / Sangli

Industrial process heat generation has accounted nearly about 40% of the total primary energy demand of the country. India has come in par with the developed nations of the world like United States, European Union etc. The energy is being majorly supplied by the Natural gas, Crude Oil & Coal or by electricity. The pattern of energy consumption in India is shown in the pie chart below:-**[6]**

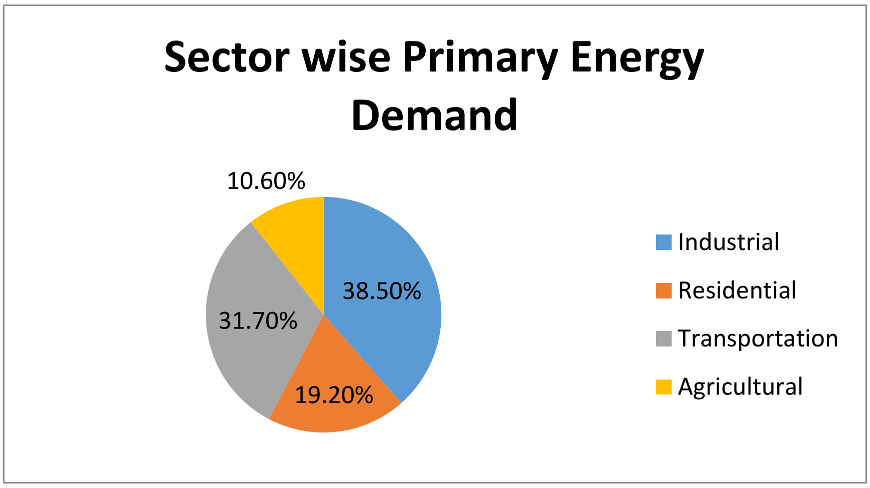

Figure: 1.14, Pie Chart representing Sector wise Primary Energy Demand [6]

Energy supplies by different sources in the Industrial sector are given by following pie chart:-

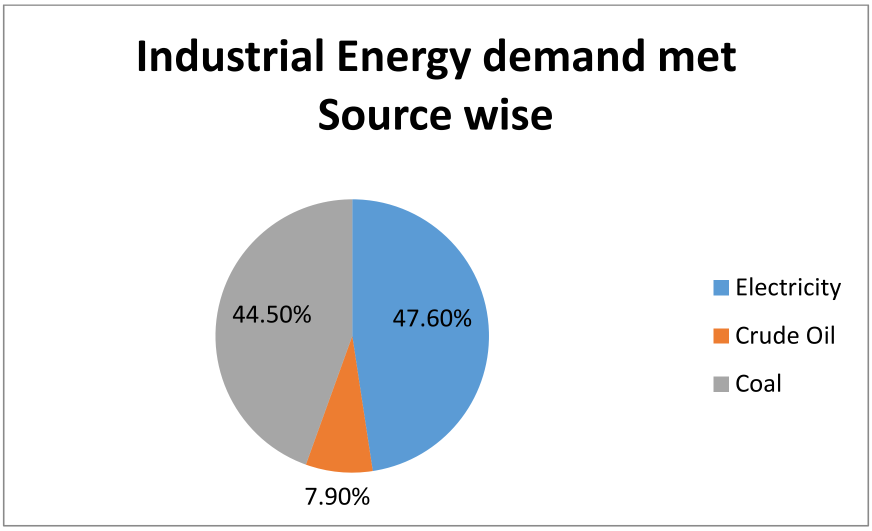

Figure: 1.15, Industrial Energy demand met by different sources [6]

1.6 Successful SIPH system - Case Studies in India

With the initiatives from MNRE, the solar thermal collector systems are gaining popularity and have got successful implementation in some of the industries which have justified its technical and financial viability. Some of the case studies have been discussed below:-

- Steam pressing using Scheffler dishes
- Preheating of feed water for boiler using NICC
- Washing by Arun dishes

Steam Pressing using Scheffler Dishes

Scheffler dish based systems are installed at **Purple Creations** for meeting steam requirement for pressing application. The dishes are connected in series and parallel arrangement to generate steam at 150°C.The each dishes is having 16 m^2 area and output capacity of each module is 6 KW_{th}. During sunshine hours the steam generated is used for their pressing needs. The system has got automatic tracking from east to west to focus sunlight on the receiver. The layout of the system installed is shown below: - [15]

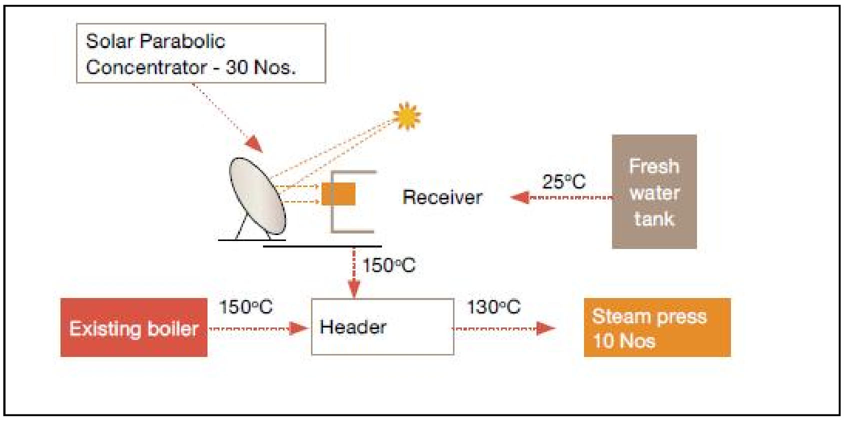

Figure: 1.16, Layout of system installed at Purple Creation [15]

Techno-Economic details of the system installed at Purple creations are summarized in the table below:-

Table 1.4, Details of system Installed at Purple Creations [15]

Parameters	Specification
Aperture Area of single Dish	16 m^2
Installation area required for 1 Dish	35 m^2
No. Of Dishes	30
Total shade free area required	1050 m^2
Weight of 1 Dish	400 kg
Weight of total system	12,000 Kg
Tracking	Single axis Automatic tracking
Heat Delivered	30,000-35,000 Kcal/day
Fuel Savings	15,000 Kg per annum (LPG)
Days of system operation	275
Cost fuel saved (LPG)	Rs. 900/-
Annual savings	Rs. 10,80,000 /-
Cost of Total system	Rs. 90,00,000 /-
MNRE subsidy @ Rs 5400/ m^2	Rs. 25,92,000 /-
Project Cost	Rs. 64,08,000 /-
Pay Back Period	4.8 Years

Preheating of Feed Water for Boiler using NICC

At ITC factory, Bangalore a Non Imaging collector based system has been installed by Thermax. The system has been installed in the open porch near the conventional boiler set up with total aperture area of 680 m^2. The single module has an output capacity of 0.9-1.1 KW_{th} and delivers a temperature up to 120°C.It delivers water at temperature at 95 °C for feeding the boiler. 200 numbers of modules have been installed at the site which helps ITC to save 45,000 litres of furnace oil annually. The layout of the system installed at ITC factory is given below:-[16]

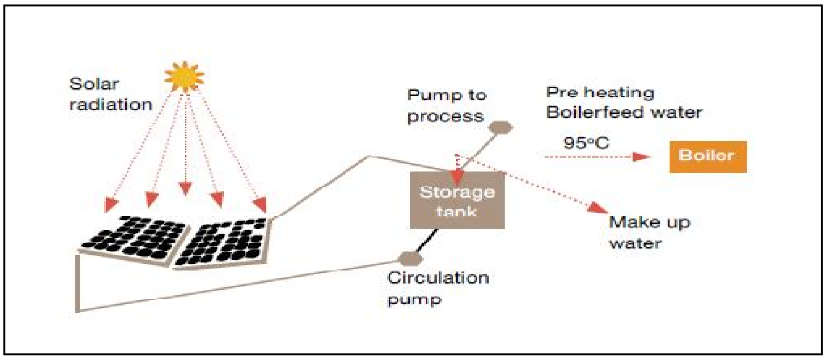

Figure: 1.17, Layout of system installed at ITC, Bangalore [16]

Techno-Economic Details of the system installed at ITC Factory, Bangalore is summarized below:-

Table: 1.5, Details of system installed at ITC Factory, Bangalore

Parameters	Specifications
Number of Modules of NICC	200
Aperture area of module	3.4 m^2
Total Aperture area	680 m^2
Shade free area required for each module	4.5 m^2
Total Shade Free area	900 m^2
Weight of one Module	54 Kg
Weight of the Total system	10,800 Kg
Tracking	None
Heat Delivered	7600 Kcal/day
Days of Operation	275
Cost of fuel Saved	Rs. 55/ Litre
Amount of Fuel saved	45,000 Litres of Furnace Oil
Annual Savings	Rs. 23,00,000 /-
Total cost of System Installed	Rs. 1,40,00,000/-
MNRE Subsidy @ Rs.3600 /m^2	Rs. 24,48,000 /-
Project cost	Rs. 1,15,52,000 /-
Pay Back Period	3.7 years

Washing by Arun Dishes

Mahindra has installed one Arun dish for running washing machines for engine components at its Chakan plant. The system generated pressurized hot water at 120° C for degreasing various engine components and block. The dish has innovative Fresnel parboiled mirrors and utilizes two axes tracking system for collection of solar radiations .It is capable of delivering 25 bar steam at 400°C.Layout of the system is shown below:- [17]

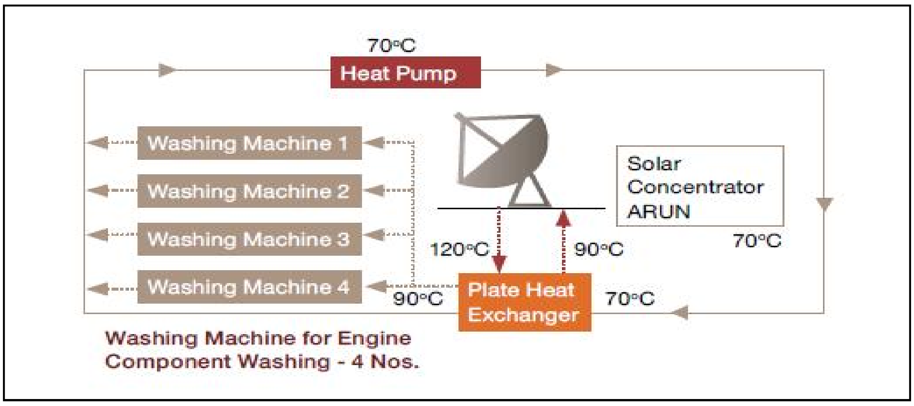

Figure: 1.18, layout of system installed at Mahindra, Chakan [17]

Techno-Economic specification of the system installed at Mahindra plant is summarized below:-

Table: 1.6, Details of system installed at Mahindra, Chakan Plant [17]

Parameters	Specifications
No. Of Dishes	1
Total Aperture Area	169 m2
Total Shade Free Area required	180 m2
Total Weight	18,000 Kg
Tracking	Dual Axis tracking
Heat Delivered	7,00,000 Kcal / Day
Amount of Fuel Savings	2,00,000 KWh per annum (Electricity)
Annual savings	Rs. 21,60,000 /-
Total cost of the system	Rs. 39,00,000 /-
MNRE Subsidy @ Rs.6000 /m^2	Rs. 10,14,000 /-
Project cost	Rs. 28,86,000 /-
Pay Back Period	2.1 years

1.7 Ministry of New and Renewable Energy

The Ministry of New and Renewable Energy (MNRE) is the Nodal agency of Government of India for all the matters and information related to new and renewable energy. The aim of the ministry is to help India meet its energy requirement by different forms of renewable energy. The brief history of MNRE is described in the following points:-

1. Commission for Additional Sources of Energy (CASE),1981
2. Department of Non-Conventional Energy Resources (DNES),1982
3. Ministry of Non-Conventional Energy Resources (MNES),1992
4. Ministry of New and Renewable Energy (MNRE),2006

With growing concerns about country`s energy security, the role and significance of different forms of renewable energy has increased and has become the aim of the government to exploit these forms of energy to lead the path for sustainable development. The main drivers for the research in this sector was the two oil shocks by OPEC countries to the world in the 1970s and which led to the development of CASE and which revolutionized to the present day MNRE. The various missions of MNRE are:-

1. Energy Availability and Access
2. Energy Affordability
3. Energy Equity
4. Energy Security

5. Increase in Clean power share

MNRE facilitates the Research & Development, Manufacturing & Deployment of systems or devices for promoting utilization of Renewable energy through:-

1. Policy Initiatives
2. Technology Mapping and Bench Marking
3. Laying out standards for specification and performance parameters
4. Deployment strategies and feedback from customers & manufacturers.

MNRE has the national goal to fulfil the Energy security of India. **[18]**

1.7.1 Initiatives taken by MNRE to support Concentrated Solar thermal technologies

MNRE along with UNDP-GEF has taken a large number of initiatives for increasing the installations of solar thermal technology in India. Some of them are:-

- 30 % MNRE Subsidy in accordance to bench mark costs along with 80 % accelerated depreciation.
- UNDP – GEF subsidy (15 % of MNRE bench mark cost) in addition to MNRE subsidy for new demonstration projects.
- Technical Capacity Development by setting up Standards ,test facilities and studies for potential identification in various sectors
- Enhanced Awareness and capacity building by awareness seminars and training workshops at different training centres for users, installers and manufacturer.**[19]**

1.7.2 Installation cost for various CST technologies

The investment required for CST technologies is generally higher, however with support from MNRE the payback period generally lays between 2-5 years for various technologies. As per the current market scenario, most of the systems installed are retrofitted ones along with the already installed conventional system. The current market prices are nearly 20% above the bench mark cost of MNRE and nearly 30-35 % above in high altitude regions. The MNRE bench mark cost for various collector technologies is summarized in table below:-**[19]**

Table: 1.7, Bench mark cost for different technologies [19]

Type of Technology	**Installation Cost in Rs. per m2 (approx) in plains**
Fixed receiver elliptical dish(Single Axis Tracked) i.e. **Scheffler Dishes**	Rs. 16,000
Fixed receiver elliptical dish (Dual Axis tracking) i.e. **Scheffler Dishes**	Rs. 18,000
Parabolic Trough Collector (**PTC**) with Non-Evacuated Tube Receiver	Rs. 16,000
Parabolic Trough Collector (**PTC**) with Evacuated tube Collector	Rs. 18,000

Single Axis tracked Linear Fresnel Technology (**LFR**)	Rs. 18,000
Fresnel Reflector based Dish(Dual Axis Tracked) i.e. Arun Dishes	Rs. 20,000
Paraboloid Dish(Dual Axis tracked) with moving Focus	Rs. 20,000

1.7.3 Capital subsidy for various CST Technologies

For promoting the installation of CST Technologies, the MNRE provides 30 % subsidy of the bench mark cost. For making the installation of these systems more lucrative & financially viable and lowering the payback period MNRE offers capital subsidy in Rs per m^2 for different technologies. For special category of states (North Eastern States, Uttrakhand, J&K etc.) And non electrified villages the subsidy offered is up to 60% .In addition to subsidy, the **IREDA** (Indian Renewable Energy Development agency) offers soft loan on balance cost of the system after deducting subsidy @ 5 % per annum. The subsidy pattern for setting up CST technologies is summarized in the table below: - **[20]**

Table; 1.8, Capital Subsidy available by MNRE for different Technologies [20]

Type of Technology	**Capital Subsidy (In Rs./m^2) or 30% of the project cost whichever is less**
Evacuated tube collectors (**ETC**)	Rs. 3,000 /-
FPC (Flat plate Collectors) with Liquid as Working fluid	Rs. 3,300/-
FPC (Flat plate Collectors) with air as Working Fluid	Rs. 2,400/-
Solar Collector system for direct heating Applications	Rs. 3,600/-
Non- Imaging Concentrators (**NICC**)	Rs. 3,600 /-
Concentrators with Manual Tracking	Rs. 2,100 /-
Concentrators with Single Axis Tracking	Rs. 5,400 /-
Concentrators with Double Axis Tracking	Rs. 6,000 /-

CHAPTER: 2 LITERATURE REVIEW

2.1 Review of previous work

Kalogirou [10] studied the temperature requirement for different industrial process heat applications ranging between 60°C to 250°C. According to the requirement of the particular industry, different type's solar collectors of medium to high temperature range were discussed. TRNSYS simulations have been done for estimating operational efficiency in the Mediterranean Climate for different Solar Thermal Collector technologies. Commercial viability of these systems has been studied in accordance to the Initial Cost and fuel prices. In the study the systems were analysed wrt. Life cycle savings, thermal energy output and resulting heat prices for different collector technologies and temperature ranges. It was found that none of these costs were stable and it will become more viable as these technologies become cheaper and fuel subsidies are removed. The optimization procedure was suggested in the paper for the selection of the most appropriate technology in each case.

Bhave [21] estimated the amount of oil being utilized by the industry for thermal energy generation and how it could be substituted by the Solar concentrating collectors which would help in reducing the oil imports. Authors have mentioned number of case studies where solar thermal energy has proven its technical feasibility and are economically viable.

S.C. Kuashik et al [22] performed the exergetic analysis of the concentrating collectors and optimized it with the inlet fluid temperature. In the analysis, it was found that some components are varying due to solar intensity and some due to mass flow rate. At lower values of the solar intensity the exergetic efficiency first increases and then decreases when the concentration ratio is increased.

C Ramos et al. [23] carried out the study to identify the potential in the small textile and food industry in Mexico where most of the thermal energy was being supplied by Liquefied gas, Natural gas and Diesel. Author considered Parabolic Trough Collector as an alternative for thermal energy generation. The methodology followed for potential assessment included statistical information from NBE, questionnaires and personal interviews. CST is not economically viable option; hence the small installation of parabolic troughs up to 100 m2 could be productive.

Abdel-Dayem et al. [24] performed the feasibility study for identification of solar energy potential in textile industry. The research work mentions two categories – preheating of boiler feed water and directly feeding the hot water generated from the solar thermal systems. Comparative analysis between two categories based on economics can be used to determine the optimal system. The optimality check based on the flow rate and collector area founded that second category is more efficient and economic.

Hui-Hong et al. [25] proposed use of Low grade solar heat for heating the feed water in the boiler instead of the mid steam extraction in order to improve the overall thermal efficiency of a Coal fired thermal power plant resulting in the hybrid power generation as the output increases by 17.1 MWe. Exergy analysis of the complete system has been developed using Energy Utilization Diagram. The partial repowering of the thermal power plant has got an edge over lone energy generation by the parabolic trough plant.

A. Frein et al. [26] summarized the design steps and analysis for solar thermal integration for the 1000 m2 dyeing industry in Tunisia. Static model based on assumed water & energy consumption and performance of heat recovery systems have been utilized for analysis. The study has been evaluated in different modes – process circuit pressurized tank, using Heat Exchangers, primary circuit solar tank and direct heating of hot water. Energetic performance indicators indicated good amount of savings in the form of fossil fuels and reduction in the carbon dioxide emissions. The study helps in selection of the optimized solution for type and sizing of solar plant. Due to low cost fossil fuel (subsidized) availability the system is not appealing to the industrial consumers.

Patrik Frey et al. [27] has installed a process heat system using parabolic trough collector in Southern Germany. Detailed monitoring systems have been installed in the system to measure real time data. The average COP_{ele} has been found to be 10.7 for the plant. The system provides hot water for different production processes. The collectors have been installed with an East-West Axis and provide an average thermal output of 70 KW. Water/Glycol mixture has been used as circulating fluid in the circuit and heat exchangers have been utilized for the energy transfer from solar collectors to the energy consumption points.

Ricardo Silva et al. [28] utilized the parabolic trough technology for the preservation of Vegetables in food processing industry in Southern Spain for thermal treatment and canning. In the analysis of the system, along with solar field thermal storage and a Boiler have been also considered. E-W and N-S orientation of the solar field have been studied and the N-S orientation produces higher solar output. During the summer months in which solar energy is available in excess, there is a low demand of energy hence the excess energy is being wasted. While in winter months when the solar availability is less and thermal input required is higher, the overall system output decreases. Major part of the demand could be met by small thermal field but the necessity of the thermal storage during prolonged period could lead to significant amount of thermal losses, if proper insulation is not provided. Idle mode for longer duration makes it mandatory for utilization of thermal energy storage. The utilization of heat exchangers increases the thermal efficiency of the system by decreasing the inlet temperature and increasing the storage density.

S.C. Kaushik et al [29] presented first and second law analysis based on energy and exergy for solar thermal power plant using parabolic trough collector. Exergy analysis shows there is maximum loss at collector-receiver assembly and Energy analysis shows maximum loss is at condenser of the Rankine heat engine. Irreversibility of the components has also been evaluated, so that the deviation between real and ideal efficiency curves.

Martin Haagen et al. [30] installed a SIPH system in Jordan for meeting the heat demand of the RAM pharma company. Author used Linear Fresnel technology of 18 modules for direct steam generation. As the fuel prices and availability of Solar Isolation are high, the economic viability of solar collector systems can be justified. Fresnel collectors with a thermal output of 222 KW and 396 m2 area have been installed on the roof top of the company which would help in reducing the diesel consumption. About 65% of total energy required in the pharmacy industry is in Heating and Air conditioning. Steam drum have been utilized for providing the constant steam output in almost all conditions.

Marco Calderoni et al. [31] evaluated technical-economic feasibility for three different industrial processes in Tunisia for the textile industries. The pay-back period evaluation, IRR, NPV and social benefit analysis have been done for the systems. The author has utilized two different types of technologies – ETC and PTC in accordance to the industry requirement. The hydraulic schemes for solar thermal systems have been suggested by the author for different cases. However, due to highly subsidised fuel available in Tunisia solar thermal technologies are not economically appealing. The case of public utility being a potential investor in the solar thermal sector have also been evaluated and found to be beneficial for the end user.

Christan Zahler et al. [32] has installed a pilot project for sustainable automobile manufacturing at Durr campus. The temperature range involved in this process is about 200°C,so Fresnel collector were utilized for thermal energy generation in the convection ovens for drying purpose. Six modules of Fresnel collector with an area of 132 m2 have been used to provide an output of 180°C along with a traditional boiler for backup have been used in case of intermittent supply. Air heat exchanger is utilized as final convertor for the generation of Hot air. With an adequate buffer storage volume about 50% of solar fraction of the total thermal requirement could be achieved. Pay-back time is generally less than 5 years.

Jose Antino et al. [33] evaluated the viability for integration of solar thermal system with current fossil fuel fired boiler at a Dairy plant in Spain. Different scenarios have been considered to determine the potential of the system and integration of solar thermal technology. The methodology involves utilization solar energy for milk fermentation, complete reuse of hot water after pasteurization etc. Mathematical modelling has been done to evaluate the performance of the solar collector field and in terms of fraction of energy which is being substituted by this system as of conventional requirement. According to the solar radiation availability, vacuum type tube collectors were preferred as the option for the system. The most appropriate collector network would be parallel. In winters due to low availability of solar radiation, the productivity of the system is found to be very poor, while form April to October substantial amount of excess thermal energy output is being generated.

Jose Antinio et al. [34] considered the viability for integration of solar thermal system with a heat pump, into conventional system at canned fish industry, Basque country. Pinch analysis has been employed to study the current scenario and the different cases for potential identification of the most suitable case. With deployment of collector area of 500 m2, the solar fraction of about 11.5% could be achieved. Due to nature of solar radiation availability, heat –pipe evacuated tube is found to be best technology for solar adsorption. With the utilization of internal heat pump with solar subsystem higher level of efficiency could be achieved and results in lower consumption of natural gas.

R. Silva et al. [35] used memetic algorithm for the optimization of parabolic trough collectors and performed thermo-economic analysis. For the optimal design point identification levelized cost of energy and pay-back time are compared. Different optimization cases are performed to evaluate the effect of fuel prices, demand, operating conditions and solar field orientation on the design. Optimization design based on short term criteria leads to high solar collector efficiencies and smaller solar fractions.

R. Silva et al. [36] in present work developed a tri-dimensional complex model of parabolic trough collector & cross verified with the experimental data. SolTrace have been utilized to calculate the concentration ratio on the absorber outer surface. For an industrial demand of 100 KW about 67% of solar fraction could be achieved with an optimized mass flow rate of 0.22 kg/s m2 with an overall efficiency of 44%.

Franz Mauthner et al. [37] described that a large amount of thermal energy is required for the manufacturing of malt and beer which is currently being produced by fossil fuels which could be met by integration of the current system with the flat plat or evacuated tube collectors. Different applications have been successfully demonstrated for temperatures below 80°C.Pressurised hot water generated from solar collectors are stored in the large vessels for usage. Thermal output obtained is 1570 MWh from the solar water heating system and contribute to 30 % of the total energy requirement for mashing. Canned beer pasteurization takes place at 85°C and hot air with temperature range of 75-80° C is required for drying of green malt. The temperature ranges from 25°C - 105° C for different process.

Sebastian Schramm et al. [38] studied the use of solar tanks. It involved a typical load profile and simulations were performed to obtain the dimensions of solar tank volume. Depending upon the process temperature and load profile, a tank less or large volume tank necessity is evaluated. Analysis was done in four cases involving solar process heat application. Two out of four showcased severe errors and opportunity for large optimizing potential. In accordance to the results obtained, with different scenarios the solar yield maximizes from 250 to 450 KWh/m2 per year with buffer storage volume (60-100 m3).With a dynamic tank volume used as solar buffer, the solar yield increase by 25%.

Thiago P Lima et al. [39] evaluated the potential available in Brazil due to high level of solar insulation which could be utilized for thermal energy generation in industries. Techno – economic feasibility of Flat plate collector were done as it could be a good option for this purpose, most of the energy needs could be met form it. Case of laundry has been studied for solar water heating purpose. Optimization was done based on following parameters – Flow rate of water, tilt angle of collectors, required collector area and size of water storage tanks. Economic feasibility based on the life time savings by usage of solar water heaters are made in comparison to natural gas burners and results obtained suggest it as viable option.

Martin et al. [40] suggested that design and selection of the system should be done by keeping in mind the hydraulic and thermal objectives to be met. On the hydraulic side the fluid should move in the specified limits of pressure drop and on thermal by achieving the desired temperature. The overall arrangement of the solar collectors is said to be network of heat exchangers connected in series, parallel or series- parallel according to the requirement. For a system involving large number of collectors forced circulation is made by a pump. Thermal length required to achieve heat load is called thermal space, while hydraulic space represents length required to meet specified pressure drop. The thermal and hydraulic lengths provide the concept of design space and the required combination of collectors could be obtained.

S. Ushak et al. [41] analysed the performance of flat plate collector system for providing the heat input to copper electro winning process. The system has generation capacity of 540 MWh/year and to provide continuous heat output thermal storage of water at 95°C. The performance analysis was carried out for 4 months at Northern Region, Chile. The global performance of the plant is about 60%. Reduction in the fuel consumption and $C0_2$ emissions caused by thermal heat input from solar collector has been also studied.

Ashish Sharma et al. [42] carried out potential assessment for heat requirement in paper mills to be substituted by different solar collectors. In this work author collected the data for feedstock input required by the different sized paper mills, existing cogeneration system, annual production and specific thermal heat input required for different processes. The annual process heat requirement for paper mill industry is found to be about 93 PJ.

Monica Borunda et al. [43] presented a study which involved the usage of the thermal heat input generated via. Parabolic trough collector for electric power generation using ORC (organic Rankine cycle) and heat input for different industrial process & charging the thermal storage in textile industry. The performance evaluation of the system was done according to real conditions on TRNSYS. Promising results obtained reflects that system can be utilized for thermal and electric generation simultaneously in medium temperature industry.

Rizwan Masood et al. [44] studied the usage of parabolic trough technology for industrial feasibility in the local environment Ipoh, Malaysia. Comparison with other solar thermal technology is also presented in this paper. Various potential applications for heat input have been identified in accordance to the industries. SAM been used for thermal analysis of PTC. Temperature profiles have been obtained for all months of the year. The peak output temperature of the Fluid (Therminol VP -1) reaches 240°C and the average thermal output obtained is 60 KWh per day.

Soteris Kalogirou et al. [45] developed a programming model for prediction of the stream generation fro Parabolic Trough field. Size of the inventory and the flash vessel determines the energy spent in the beginning of the day for raising the temperature of the water to saturation temperature. Program for the optimization of flash vessel has also been presented in the work. 48.9 % of the total amount of solar radiation incident is utilized for the generation and rest are the thermal losses.

S.C. Kaushik et al. [46] gave the concept for usage of solar concentrator along with Natural gas fired boilers for feed water heating and low pressure steam generation. The performance analysis was carried out for Linear Fresnel reflector by varying the concentration ratio and inlet fluid temperature. There was 10 % increase power generation capacity when solar concentrators are used for feed water heating and low pressure steam generation. Exergetic analysis is more effective than the energy analysis for solar energy utilization calculation for the above purposes.

2.2 Research Gap identified

After going through the previous work mentioned in the literature review, it can be summarized that more research work has been focused on:-

- Solar collector design
- Energy – exergy analysis of the system
- Optimization of these systems
- Potential determination for the process heat applications in different industry etc.

Less consideration has been given to:-

- The site suitability & validation of the collector system for process heat applications,
- Smooth integration of the SIPH systems by retrofitting techniques,
- Justification for economic viability of these systems.
- Only one or two researchers have focussed on the SIPH system related to chemical manufacturing, hence this industry has been chosen.

2.3 Scope and Objectives

Main aim of the present work is to reduce the dependence on fossil fuels by partially substituting the thermal energy generation by using the solar industrial process heat system. There will be considerable reduction in green house gas emissions and would lead to eco-friendly and sustainable manufacturing of Chemicals. Following objectives are to be met for successful integration of SIPH system in Chemical Industry: -

- To study and analyse the manufacturing process of the Chemical Industry, find out the processes utilizing thermal energy in different forms, their temperature range, amount of energy required/ hour and their current sources of generation.
- Selection of suitable technology from different concentrated solar thermal technology in accordance to the temperature range and solar resource available.
- Designing and Performance evaluation of the CST technology selected.
- Estimation of the generation potential of the CST technology according to site.
- Integration of the SIPH system designed to current system by Site analysis and P & I diagram.
- Evaluation of the effectiveness of the SIPH system by determining solar fraction.
- Determine the financial viability of the project by calculating the Payback period, IRR and performing Cash Flow Analysis.

CHAPTER: 3 SOLAR THERMAL TECHNOLOGIES

Most readily available source of energy on our planet is Solar Energy. Sun is a hot gas ball and due continuous nuclear reactions a large amount of energy is generated which radiated in the form of radiations which we receive at earth's surface. There are two components of solar radiations – heat and light.

Earth receives 1, 74, 000 TW of solar radiation at upper atmosphere. About 30 % is reflected back and rest is absorbed inside the earth's atmosphere. Solar energy has the potential to meet all the energy requirements of the world. Main advantages associated with solar energy are that it is available in large quantity and the energy generation & consumption is eco-friendly. With current issues of increasing problems of Global warming and for sustainable future the solar energy is a solution for all the problems. **[47]**

Solar energy can be utilized directly or indirectly, depending upon the requirement of the humans. In general it can be used in the following manner:-

1. Direct Utilization
   - Solar thermal (Concentrating or Non-Concentrating)
   - Solar PV (Concentrating or Non-concentrating)
2. Indirect Utilization
   - Wind Power
   - Hydro Power
   - Biomass Energy
   - OTEC etc.

3.1 Availability of Solar Energy in India

With about 300 clear sunshine days, India receives a 5,000 trillion KWh per year which much larger in comparison to the current energy consumption and can certainly fulfil the energy needs of the country. To estimate the potential of all parts of the country effectively, Ministry of New and Renewable Energy has started a project to set up a large number solar radiation resource assessment (SRRA) stations with NIWE (National Institute of Wind Energy) as partner for implementation. This resource assessment is essential for the successful implementation of solar energy project in order to achieve the Government of India target of 1,00,000 MW of solar energy by 2022 under JNNSM (Jawaharlal Nehru National Solar Mission).Under JNNSM, the 60 GW is to be achieved through installation in mega and ultra – mega solar parks and rest of 40 GW is to come up from decentralized grid connected or off grid systems.

The data which is being collected at all the 121 stations installed in 4 Union territories and 29 states will be used for the projects which are under implementation and future projects.**[48]** Different instruments are installed at the resource assessment site and are:-

- Global Pyranometer (to measure Global radiation)
- Diffuse Pyranometer (to measure diffused radiation)
- Pryheliometer (to measure Direct normal incident radiation)

- Wind vane and Anemometer (to measure the wind speed and direction)
- Humidity Sensor
- Temperature Sensor
- Tracking System
- Power system(for providing power to data logging and various instruments of the system)
- Rain fall measurement system
- Tower (for mounting of instruments)

A typical solar resource assessment station installed is shown below:-

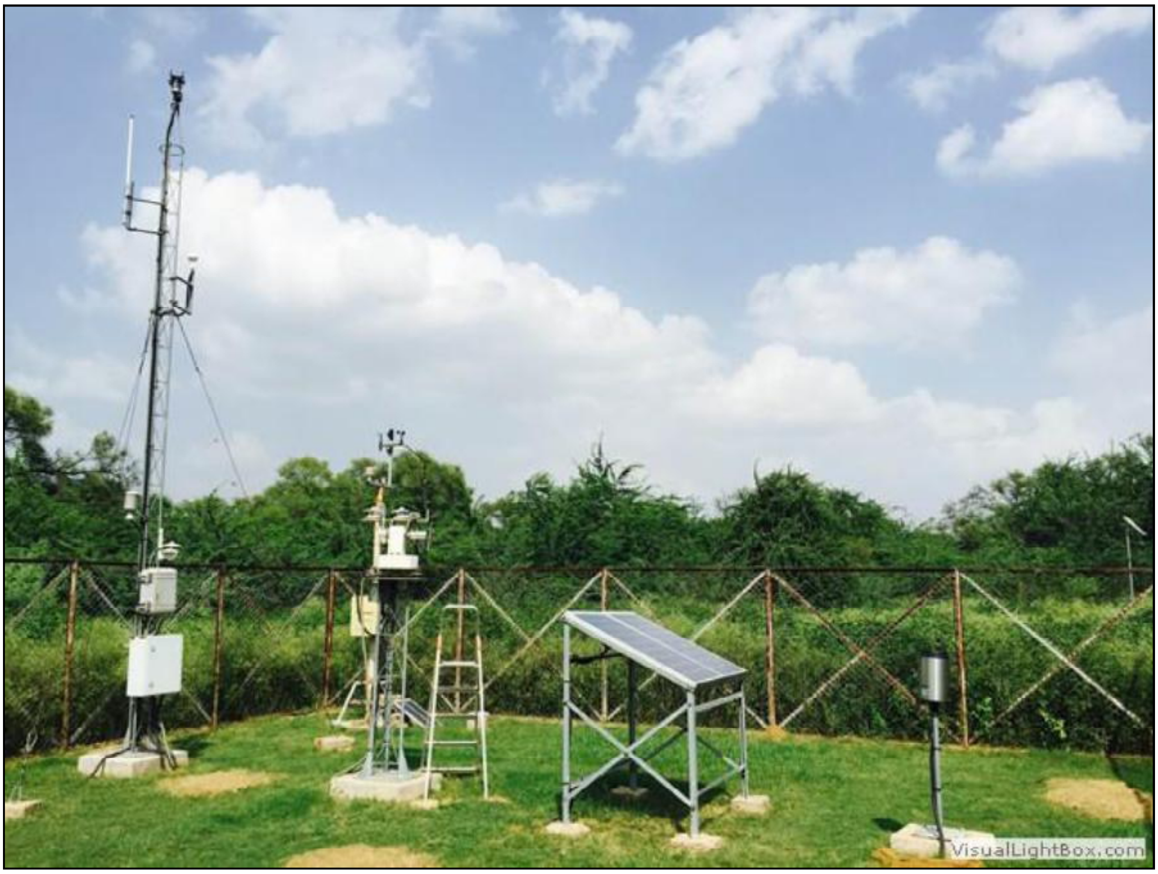

Figure: 3.1, a typical Solar Radiation Resource Assessment (SRRA) Station [49]

The solar radiation received at earth surface when fall on these systems, all the data which is generated from the system are data logged in the storage installed and can be taken from the site or connected to internet for the data transmission to the suitable place. At the site fencing is provide so that installation are safe and maintenance is being done as per the requirement.

The SRRA stations installed across the country are connected to the central GPRS network and all the data of the solar radiations is available from NIWE. Data collection over the years will be reliable and help in forming a Solar Atlas for the country which can be used in the forecasting and management of Renewable energy generation for effective grid management. **[48]**

3.1.1 Direct Normal Irradiance (DNI)

It is the amount of radiation received on unit surface area that is normal to the direction parallel rays of solar radiation. DNI is collected for the designing of concentrator technology. Pryheliometer is the instrument used for measuring of DNI and has a tracking system integrated with it, so that it always follow the sun and surface remains normal to the solar radiation. National Institute of Solar Energy in collaboration with NREL has made a showing the DNI potential across the country. The map is shown below:-

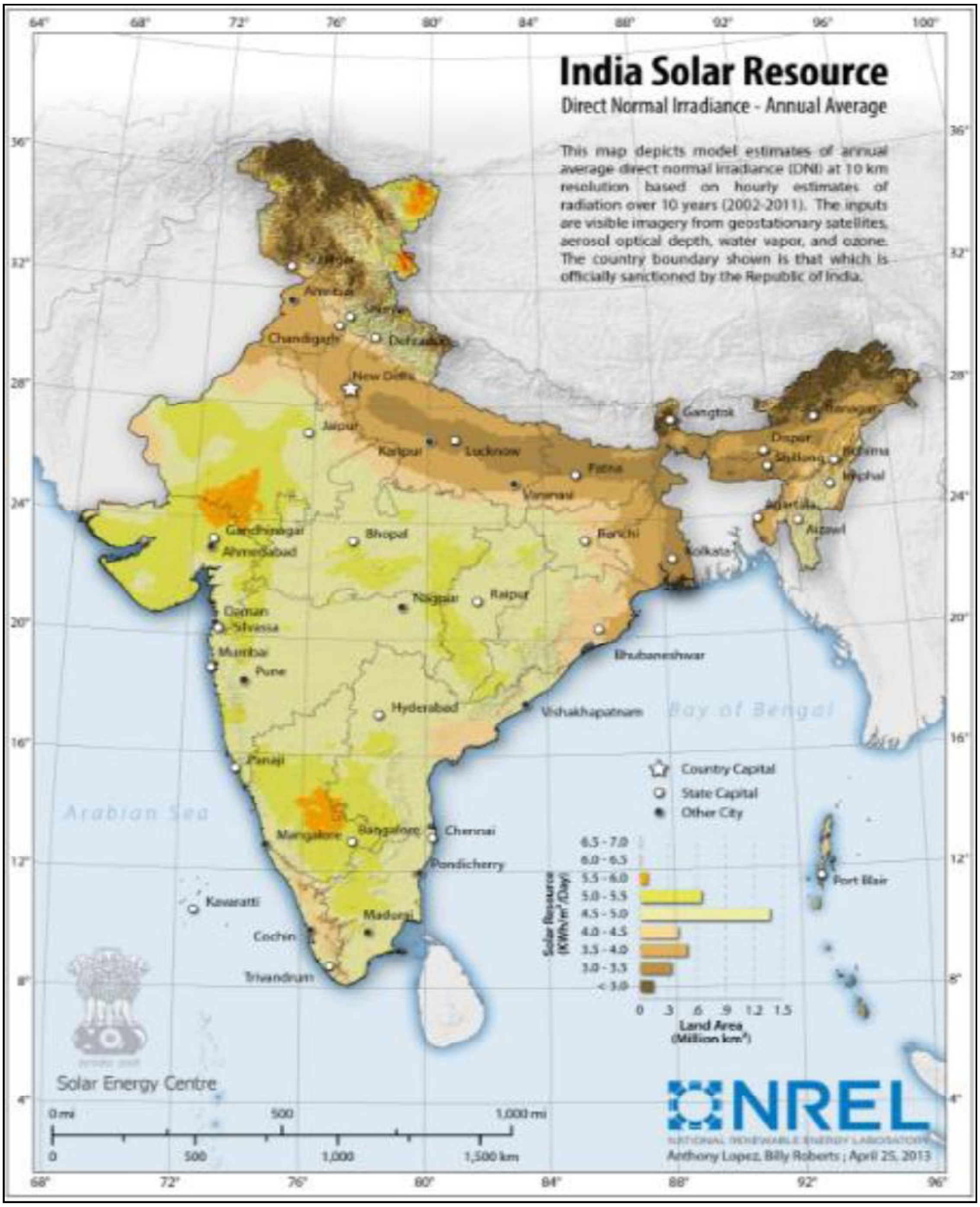

Figure: 3.2, Map showing Average DNI across India [50]

3.1.2 Global Horizontal Irradiance (GHI)

GHI is the sum of Beam and Diffused solar radiation received at the earth`s surface. Diffused radiation is that part of radiation which is received at the surface after scattering from the atmosphere. It is generally used in the designing of non concentrated solar thermal and solar photovoltaic technology. It is measured by Pyranometer, which is installed in SAAR station. National Institute of Solar Energy (NISE) in collaboration with NREL has released the GHI map of India which can be utilized by different organization. The map shown below is based on average for a year:-

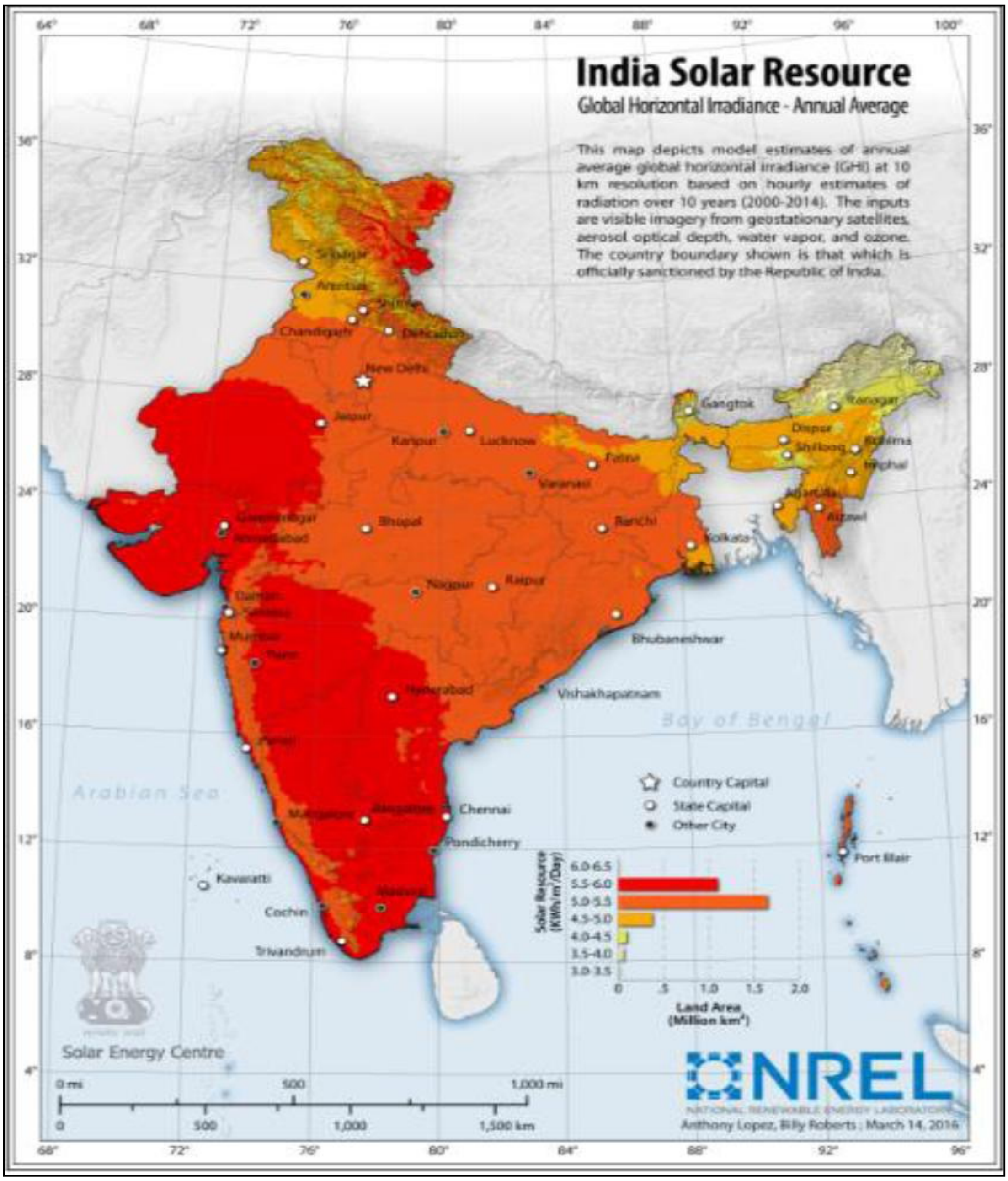

Figure: 3.3, Map showing average GHI all across India [50]

3.2 Different types of Solar Thermal Collectors

Solar Thermal Collectors are the heat exchangers which transform the energy of solar radiation to the internal heat energy of the fluid. The heat transfer fluid is usually air, water or oil which extracts energy from the collector system depending upon the mass flow rate. The solar energy collected is utilized directly in the process for heating or cooling applications or is sent to thermal storage tank, so that it can be utilized during non sunshine hours.

Solar thermal collectors are generally classified as- Stationary Collectors and Non- Stationary Collectors. Stationary collectors are the one which have got same amount of area for intercepting and absorbing solar radiation, While Non Stationary or Tracking type of Solar collectors usually follow the suns path, intercept the solar radiations using their reflective surface and focus the beam radiations on the receiver.

Many types of Solar collectors are available in the market, some of them summarized in the table below:-

Table: 3.1, Different types of solar thermal Collectors [10]

Motion	Type of Collector	Type of Absorber	Concentration ratio	Indicative temperature range
Stationary	Flat Plate Collector	Flat	1	30-70 °C
	Evacuated Tube Collector	Tubular	1	50-100 °C
	Compound Parabolic Collector	Tubular	1-5	70-150 °C
Single Axis Tracking	Linear Fresnel Technology	Tubular	10-40	60-250 °C
	Parabolic Trough Technology	Tubular	10-45	60-300 °C
	Scheffler Reflector	Point	20-40	60-200 °C
Dual Axis Tracking	Paraboloid Dish	Point	100-1000	500-1200 °C
	Fresnel Reflector based Dish	Point	100-1000	500-1200 °C

The selection of the solar thermal technology depends upon the following factors: -

- Output Temperature of heat transfer fluid
- Mass Flow rate required
- Solar radiation availability
- Utilization purpose of the system
- Tracking or Non –Tracking requirement
- Capital cost involved
- Availability of the type of system selected

3.2.1 Flat Plate Collectors

These are the most common type of solar collector used. As the solar radiation fall on the collector surface, the transparent sheet or cover allows maximum part to go through it and these radiations are absorbed on the blackened absorber surface and which is transferred to the heat transfer fluid which acts as transport medium for the usage or storage. Beneath the absorber plate a good amount of insulation is provided between the casing and plate which prevents thermal losses of the system, thereby increasing the overall system efficiency.

The operation of the collector system mainly depends up on the way absorbing tubes are connected to the riser tubes. Riser tubes could be welded or made an integral unit of the system with absorber tubes. With the availability if highly selective coatings the standard flat plate collectors could achieve a stagnation temperature up to 200°C.Flat plate collectors are stationary and do not need to track the sun. A good efficient collector normal reaches up to 100°C.The flat plate collectors are installed in such a way that it is oriented towards the equator i.e. facing south in the northern hemisphere and facing north in the southern hemisphere. The tilt angle of the collector is equal to the latitude of the location with an angular variation of 10-15° depending upon the seasons.

The water is the most common fluid used and after getting heat is stored in the storage tank located above a certain height above the collector. The heat occurs based on the Thermosyphon principle. According to thermosyphon principle, the cold water flows down to the absorber tube and as it temperature increases the density of the water decreases and start rising upwards reaches the header tank. The water which is being heated up is supplied to the inlet outlet naturally, it works on Natural circulation due to density difference and however for the larger systems the forced circulation is being used. **[51]**

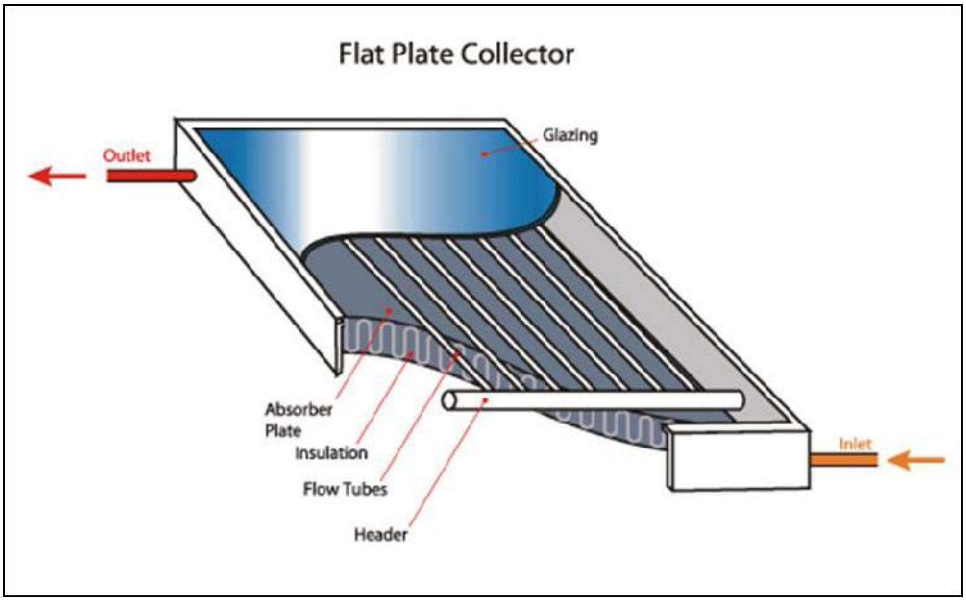

Figure: 3.4, Flat Plate collector [52]

3.2.2 Evacuated Tube collectors

It consists of the heating pipes which are sealed inside a vacuum tube. A larger number of variable evacuated tube collectors are available in the market. The working principles of the evacuated tube collectors are almost similar to the flat plate collectors. The heat tubes are having special coating over its surface and absorb the radiations which enter the vacuum tubes, which are further transferred to the heat transfer fluid. The main advantage of the vacuum tubes is that it reduces the conduction and convection losses, so that higher temperatures could be achieved. Like Flat plate collectors, they absorb both diffuse and beam radiation. There efficiencies are higher at low angle of incidences, which is another advantage over the conventional flat plate collector. **[51]**

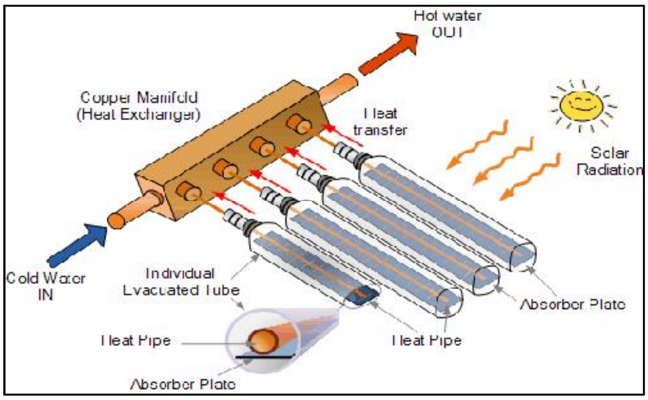

Figure: 3.5, Evacuated tube collector [53]

3.2.3 Compound Parabolic Collector

These are stationary collectors with a concentration ratio ranging from 1-5 and acceptance half angle of 30°C.These are non imaging collectors which are oriented with longitudinal axis either in East-West or North south direction and aperture tilted towards equator. This collector track the sun with help of the reflective surface placed below the heat tubes and construction is such that it focuses all the sunlight falling on the reflective surface on the heat tubes. This phenomenon increases the output temperature of the heat transfer fluid and overall system efficiency. **[51]**

Figure: 3.6, Compound Parabolic Collector [54]

3.2.4 Parabolic Trough Collectors

Parabolic trough collectors are the one in which the solar radiations falling on the reflective surface (Parabolic shaped) are focussed on the receiver tube passing through the focal point. The reflective surface is generally made of curved glass, small glass strips or highly reflective metal .The absorber tube is coated with selective coating and is surrounded by glass tube. The space between the glass tube and absorber tube is either filled with air or is made vacuum.

Parabolic trough is one most mature technology in the solar concentrators and is used for both process heat application and solar thermal electricity generation. Single axis tracking system is used to follow the sun path. The parabolic trough collectors can go up to 400°C.The convection losses are reduced by the glass cover. **[51]**

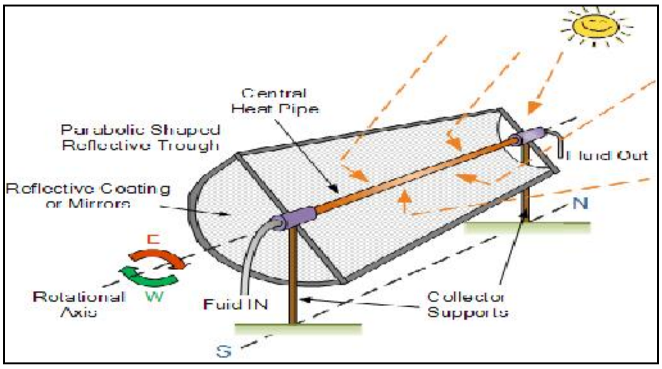

Figure: 3.7, parabolic trough collector [55]

3.2.5 Linear Fresnel Collector

LFR technology utilizes an array of linear mirror strips, which focuses the solar radiations on an elevated receiver mounted with help of side supports. In this the reflective mirrors move are having different angular motion in order to focus the solar radiations on the receiver. The receiver tubes are stationary and are cased from the top surface with proper insulations or secondary reflective surface and glass cover are used to allow the solar radiations to reach the absorber tube. The absorber tube has a selective coating to increase the absorptivity. The reflective mirror system is mounted close to the ground, which reduces the structural requirement. **[51]**

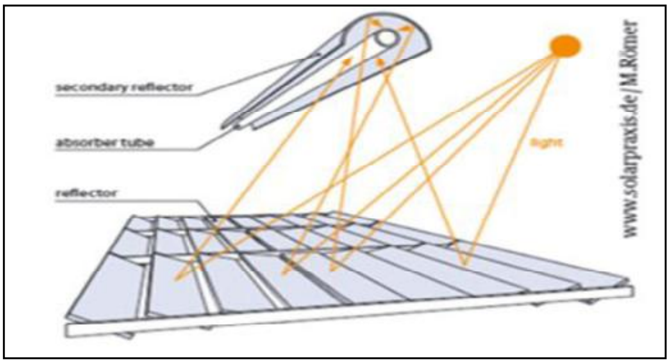

Figure: 3.8, Linear Fresnel Technology [56]

3.2.6 Scheffler Reflector

It was basically developed for cooking application such that receiver is always fixed while the reflector is tracking the sun. The shape of the reflector is designed from lateral cut section of the parabola and is formed by small strips of glass mirrors. The axis of rotation of the reflector is formed by line passing through the focus and perpendicular to the axis. It could achieve a temperature up to 200°C in the receiver.

Figure: 3.9, Scheffler Reflector [57]

3.2.7 Paraboloid Dish

It is a point focus collector which has two axis tracking system to track the sun throughout the day. The reflector is a parabolic dish which is formed by highly reflective mirrors and focuses the solar radiation on a point focus, which transfers heat to the heat transfer fluid. The heat can be transformed to thermal energy or electrical energy depending up on the type of application. The Paraboloid dishes could achieve a temperature of about 1500°C.The receiver is installed at the focus of the dish and keeps on moving along the dish. **[51]**

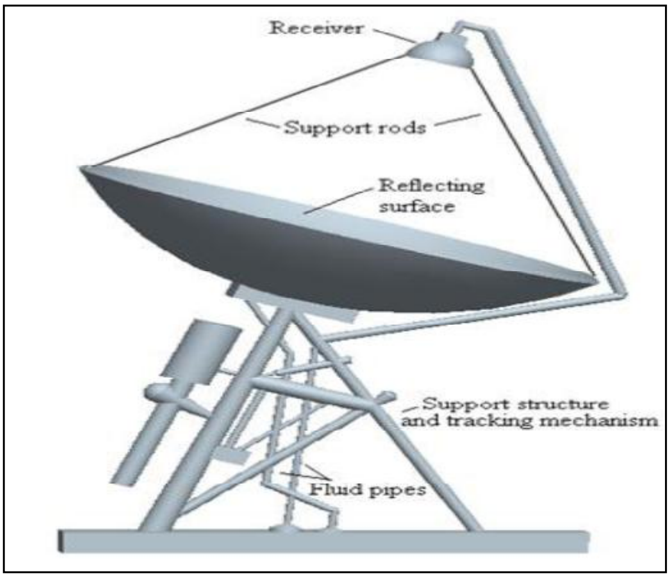

Figure: 3.10, Paraboloid Dish [58]

3.3 Requirement of Heat Storage

The intermittent and variable natures of solar energy are the main challenges which come in the way of solar energy utilization. It leads to the mismatch between the time of collection of solar energy and its need for the application involved. This results in the requirement of storage system. According to the purpose of utilization, thermal energy storage is classified as:-

- **Buffer Storage** (It is used when the time of collection matches with energy requirement and it helps is overcoming mismatch between both)
- **Diurnal Storage** (It is used when the load requirement is throughout the day and the collection is done in sunshine hours)
- **Annual Storage** (It is the storage which is used to collect the solar thermal input during summer season and could be utilized throughout the year)**[59]**

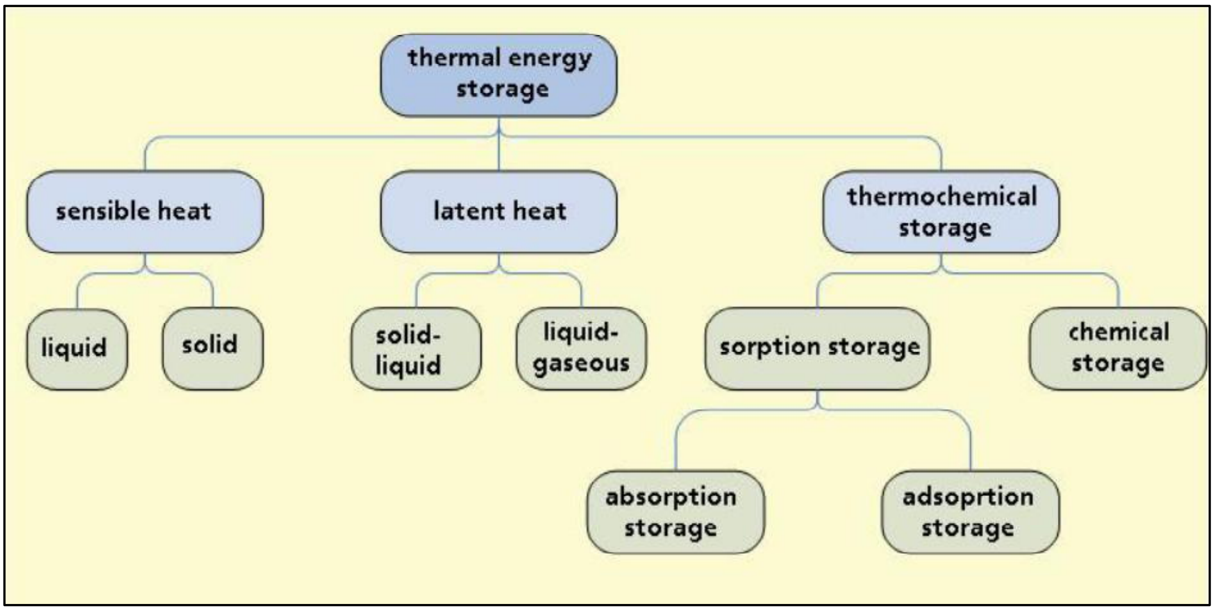

Figure: 3.11, Classification of thermal energy storage [60]

The thermal energy can be classified as Sensible Heat and Latent Heat. **Sensible Heat storage** is one in which the temperature of the storage increase, while the **Latent heat storage** involves the phase change of the material. Common types of Sensible heat storage are Hot Water in insulated tank; Rock bed storage and Latent heat storage are various types of Organic and inorganic salts. Another type of storage used in recent years is **Thermo-Chemical storage.** These are type of storage in which addition of heat leads to an endothermic reaction and when heat is needed the reverse reaction takes place releasing the heat. **[59]**

CHAPTER: 4 STUDY OF CHEMICAL MANUFACTURING PROCESS

4.1 Introduction to Indian Chemical Industry

Chemical Industry in India is very key component and contributes to about 7% of India`s GDP. Indian Chemical industry stands 12 Th in the world and 3 rd largest in Asia in terms of volume of production. Indian chemical industry has got an annual growth of about014% by which it is expected to reach USD 350 billion by 2021.Some of the major advantage of Indian Chemical industry are:-

- Robust Demand (domestic as well as for export)
- Attractive Opportunities
- Increasing Investment
- Policy Support

Total production of Indian Chemical industry reached 8,839 MT (Metric Tonnes) in the year 2014.The Table representing product wise classification of Indian Chemical Industry and Pie chart giving the breakout by different types of Chemicals are shown below:-**[61]**

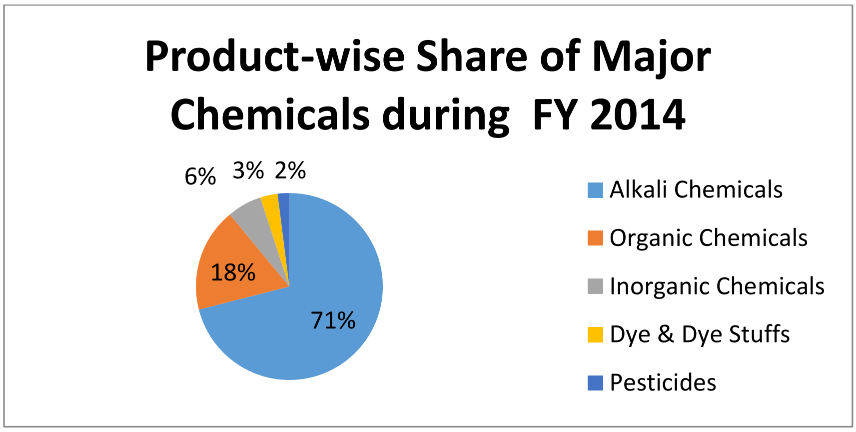

Figure: 4.1, Product wise share of Major Chemical during 2014 [61]

Table: 4.1, Product wise Classification of Indian Chemical Industry [61]

Alkali chemicals	Inorganic chemicals	Organic chemicals	Pesticides & insecticides	Dyes & dyestuffs
• Soda ash • Caustic soda • Liquid • Chlorine	• Aluminum flouride • Calcium carbide • Carbon black • Potassium chlorate • Titanium dioxide • Red phosphorus	• Acetic acid • Acetone • Phenol • Methanol • Ortho Nitro Chlorobenzene (ONCB) • Isobutyl • Para Nitrochlorobenzene (PNCB) • Ethyl	• Dichlorodiphenyltri-chloroethane (DDT) • Malathion • Parathion • Ethicon • Endosulphan • Phosalone • Phorate • Acephate • Fenvalerate	• Azo dyes • Disperse dyes • Fast colour bases • Ingrain dyes • Napthols • Vat dyes • Reactive dyes • Pigment Emulsion • Sulphur dyes • Other dyes

Chemical clusters are spread around the country, the map showing below represents the location of chemical clusters:-

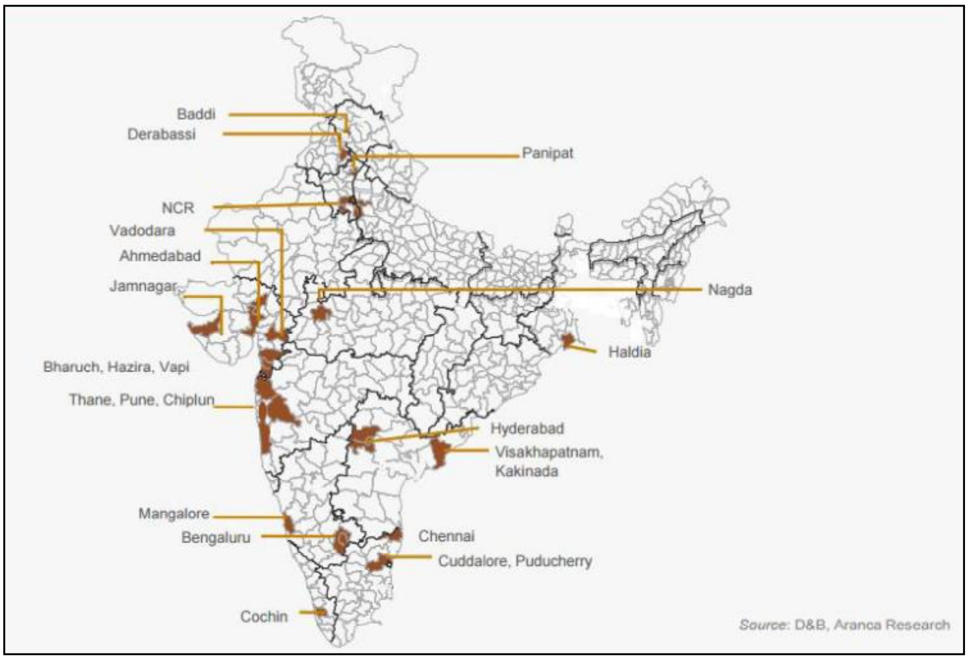

Figure: 4.2, Map showing the location of Chemical Clusters in India [61]

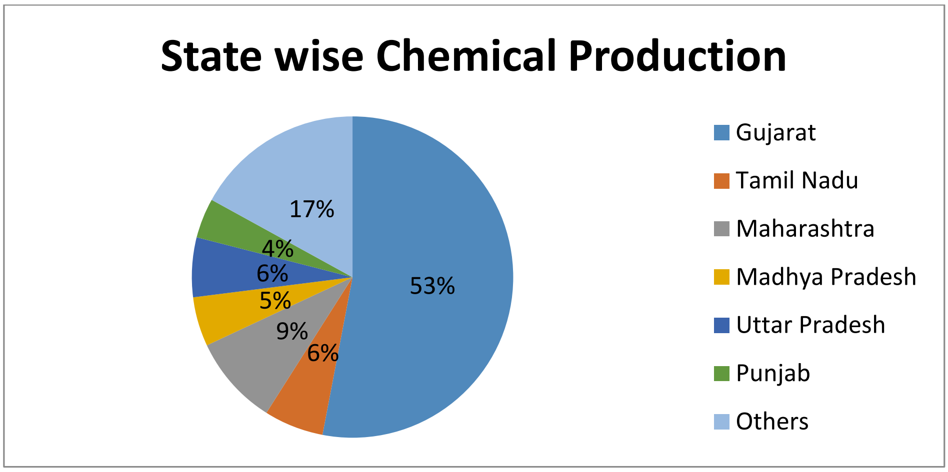

Figure: 4.3, State Wise Chemical Production [62]

One of the major contributors for chemical production is Gujarat. In both fields of basic and petrochemical as well, the state of Gujarat accounts for more than 50% of the total chemical production as compared to the different parts of the country. **Ahmadabad** and **Ankleshwar** are two major chemical clusters accounting for 50% of the total Gujarat production. There are a large number of industries which are end product users of chemicals. Some of them are:-

- Clothing
- Soaps and Detergents
- Plastics

- Paints
- Transport and Automobile
- Leather and Footwear.
- Food and Agro Chemicals
- Drugs and Diagnostics
- Perfume and Flavour etc. **[63]**

Some of the **major companies** in the **Indian chemical Sector** are:-

- Aditya Birla Group
- Gujarat Alkali`s and Chemicals
- DCM Shri Ram Consolidated
- Ranbaxy
- Cipla
- Cadila Pharmaceuticals
- Reliance Industries
- Haldia Petro Chemicals
- GAIL
- IOCL
- United Phosphorous
- Rallis
- Excel Industries
- Asian Paints
- Nerolac
- Hoechst
- Clariant
- Coates
- Hindustan Inks etc. **[62]**

4.2 Production Equipments and Technologies used for Manufacturing

A variety of products are manufactured by chemical industries like dyes, paints, pigments, agrochemicals etc in MSME`s. However the technology and equipment involved in the manufacturing of chemicals are quite similar. Process equipments generally used are:-

1. **Steam Boiler**: For steam generation both IBR and Non – IBR Boilers are used in chemical cluster. Wood and Natural gas are the major types of fuel used for steam generation. Primary use of this steam is direct insertion in the reactor and jacket heating. The capacity of the Boiler varies from one unit to another depending upon the requirement of the plant. Boilers with capacity range of 300kg/h to 3000 kg/h are used in MSMEs. The generation & utilization temperature and steam depends upon requirement. Generally steam generation pressure ranges from 7-10 Kg/cm2.

2. **Thermic Fluid Heater**: It is generally used for indirect heating in Jacket and dryers. For firing thermic fluid heaters Natural gas is used. The temperature of thermic fluid in heater ranges from 180-200°C and heat capacity varies in accordance to requirement. Heat Capacity generally lies between 1-4 Lakh Kcal/Hour.

3. **Reaction Vessels**: These are used for dissolving materials for chemicals units. They are generally made up of stainless steel and their capacities vary from 1-10 Kilo Litre as per requirement of the plant.

4. **Hot Air Generator**: To generate hot air for dryers these generators are used. Hot Air with temperature about 180-200°C is pushed into dryers via fans. Hot Air is used to remove moisture from material placed in dryers. In the cluster, the heating range of hot Air generator ranges from 1-2 Lakh Kcal/Hour.

5. **Centrifuge**: It is used for separating suspended solid particles in the liquid slurry, which are generally intermediate products using sedimentation principle. The vessel is rotated and given centripetal acceleration which causes denser particles to separate out in the radial direction.

6. **Press Filter**: Using hydraulic presses with filter installed solid particles are separated out from liquid chemicals. The solid generated as intermediate is removed from the press. Compressed air with a pressure of 5 $kg/cm^2$is used to remove interstitial water from the pores of filter cake. 50-60% of the moisture content is removed using filter press.

7. **Air Compressors**: Conventional reciprocating compressors are used to produce compressed air ranging from 5-7 Kg/cm^2.The compressed air has got a wide range of applications in chemical industry.

8. **Dryers**: These are used to evaporate the liquid content from solids. The moisture filled product is placed inside the chamber and is heated to the desired temperature for removing moisture. Different types of Dryers are available- Fluidized bed dryer, Tray dryer etc. Boiler, Thermic fluid heater or Hot Air Generator either can be used depending upon the type of dryer.

9. **Chilling System**: It consists of evaporator and condenser pumps, compressor and cooling tower. These systems are used for jacket cooling and are having a range of 5-50 TR. Centrifugal and Reciprocating chillers are generally used.

10. **Circulation pumps**: These are generally used for variety of purposes like circulation of boiler feed water, thermic oil, cooling water, chilled water and process water.

11. **Electric Motor**: it is used to run equipment like Pumps, Agitator, Fans, Dryers, and Centrifuge etc. The ratings of the motors used vary according to the power required and duration of operation. **[63]**

4.3 Manufacturing Process

Manufacturing process generally varies from one industry to another depending upon the product being manufactured by them. A typical manufacturing sequence is mentioned along with energy sources and process equipment involved in the process chart below:-

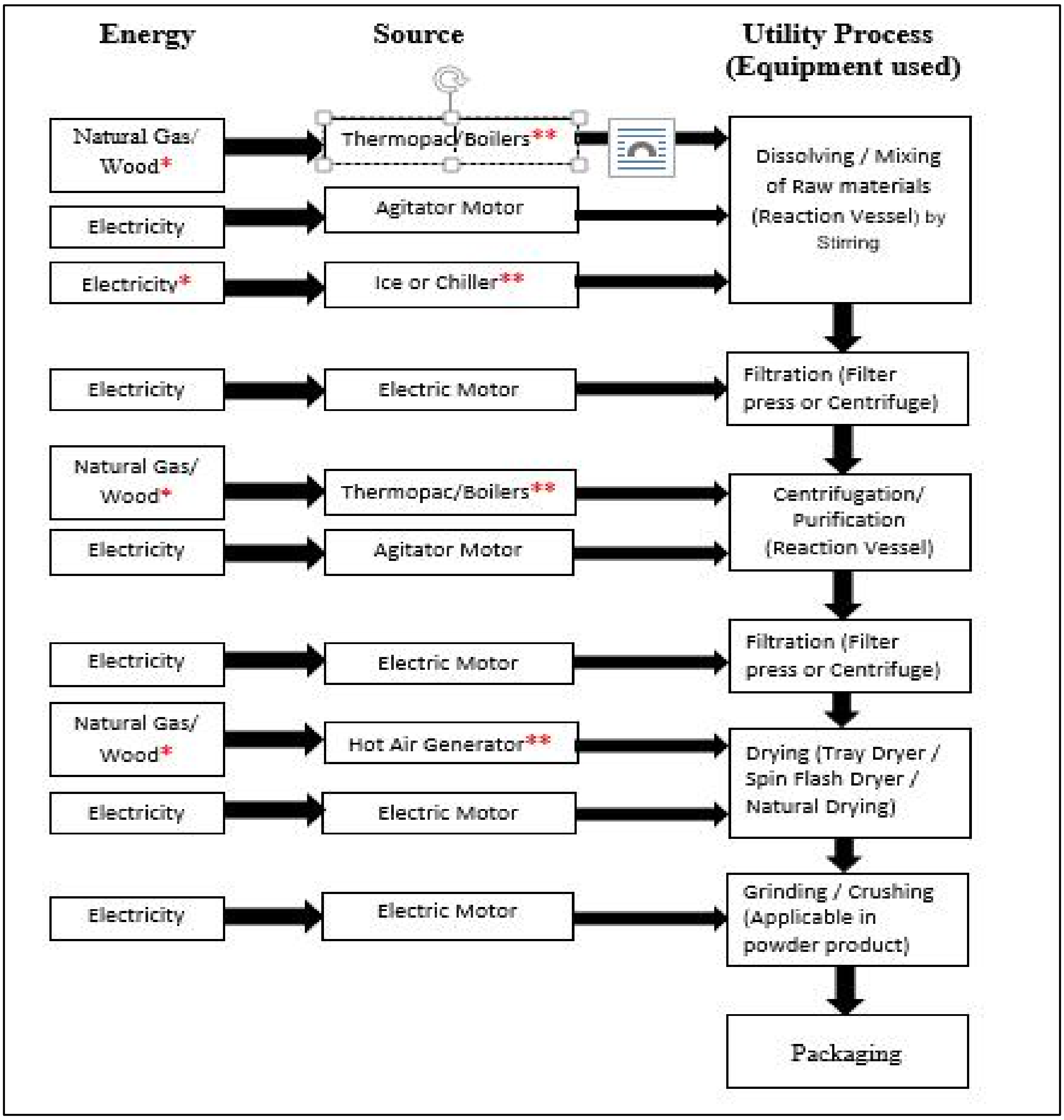

Figure: 4.4, Flow Chart representing a typical manufacturing sequence of a chemical [63]

Note: * - Represents the energy form that can be replaced by steam

** - Represents the sources that can be replaced by solar collector

The steps involved in the manufacturing are described below:-

- In the first step raw materials are mixed in the reaction vessel with appropriate proportions, the centrifuge is used for mixing and the adequate temperature conditions are provided by jacket heating or cooling as per requirement from boiler/ thermic fluid heater or Chiller.
- In this step primary filtration of solid particles is done by centrifuge or filter press and solid intermediate which is generated is separated out.
- In this step, the purification of the intermediate is done by addition of acids or bases in order to neutralize it; the mixture is continuously run by agitator system. The required temperature conditions are met by jacket heating or cooling as per requirement.
- Now secondary filtration takes place and rest of the solids left after purification are removed.
- In this step, hot air or steam is used in the dryers for removal moisture to obtain the desired product.
- Crushing of the solid type of the product takes place to the required size in pulveriser
- Final product is packed as per the safety standards. **[63]**

4.4 Energy Consumption pattern of MSME Industry in Ankleshwar Chemical Cluster

Both thermal and electrical energy are required for the manufacturing of the chemicals. Various sources are used for fulfilling the energy demand. Some of the energy sources used are:-

1. Piped Natural gas
2. Firewood
3. Coal (only in very few units)
4. Electricity
5. LDO,HSD (used rarely - only for DG sets) **[63]**

Annual Energy consumption of industries is represented by following table and pie chart for **Ankleshwar** district, which indicates Natural gas, is the main source of energy, followed by Electricity in the chemical cluster. The usage of firewood has become negligible:-

Table: 4.2, Annual Energy Consumption by chemical industries in Ankleshwar district [63]

Source	Annual Energy Consumption (Toe)	Annual Energy Consumption (Respective Units)
Electricity	82706	715 Million units/year
Fire Wood	1040	381.9 Million SCM/year
Natural Gas	324677	3250 Tonnes

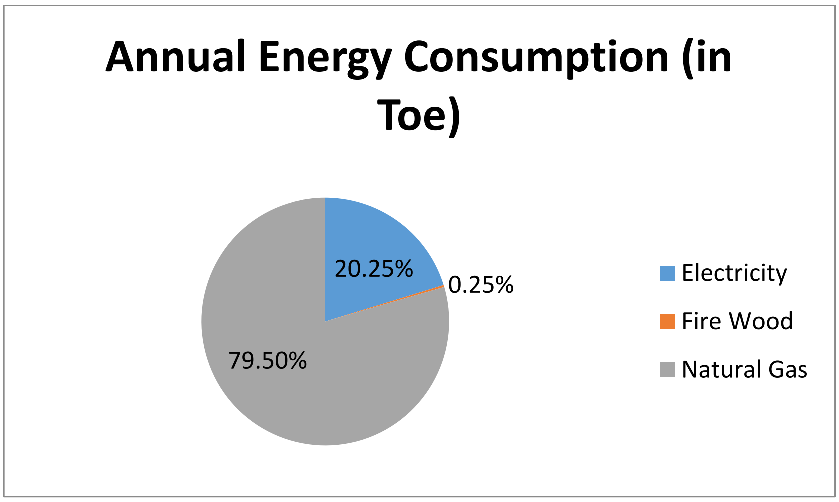

Figure: 4.5, Pie chart representing the annual energy consumption (toe) [60]

Costs of the various sources of energy are represented in the table below:-

Table: 4.3, Cost of different energy sources [63]

Source	Units	Cost	Supplier
Natural Gas	Rs. / SCM	31.94 (Quota Price)	GGCL
Electricity	Rs. / KWh	4.35 + Fixed charges	DGVCL
Wood	Rs. / Kg	4	Local Suppliers

4.5 Scope for Solar thermal Collector Integration in a Chemical industry

The different processes have been studied which involved the usage of various energy sources and can be replaced by the usage of Solar thermal technology. These processes are:-

- Hot Air for drying
- Steam required for Jacket heating and Direct Mixing in the vessels
- Hot thermic fluid for Jacket Heating
- Jacket Cooling
- Steam/ Hot Water for washing and rinsing after every batch. **[63]**

The total energy requirement in general can be summarized in the following table which is to be supplied by Solar Collectors:-

Table: 4.4, Energy requirement for equipments that can be replaced by Solar Collectors [63]

Equipment Used	Conditioning Required	Quantity
Steam Boilers	150°C	300 – 3000 Kg/ Hour
Thermic fluid heaters	180°C - 200°C	1 - 4 Lakh Kcal/Batch
Hot Air Generator	150°C - 200°C	1 – 2 Lakh Kcal/Batch
Chiller	5 – 50 TR	26 -36 Hours/Batch

CHAPTER: 5 PARABOLIC TROUGH COLLECTOR (NON-EVACUATED) AND ITS INTEGRATION

5.1 Basic Terminology

The amount of energy which is incident on the absorber is increased by concentrating the solar radiations using the reflective aperture, which results in the higher concentration but they need a tracking mechanism to follow the sun path. Some important characteristic parameters are:-

1. **Aperture (W)**: - The area through which solar radiation passes.
2. **Absorber Area (A_{abs})**: - The area of the absorber surface which receives solar radiation.
3. **Acceptance Angle (2θa)**: - It is the angle which defines the angular limit through which if the incident rays deviate from normal to aperture plane but still reaches the receiver / absorber.
4. **Concentration ratio (C)**: - It is the ratio of Effective aperture area to the receiver area.
5. **Intercept Factor (ϒ)**: - It is the ratio of the amount of energy received by the absorber and amount of energy reflected by aperture.
6. **Optical Efficiency (η_o)**: - It is ratio of the energy absorbed by the receiver to the amount of energy falling on the aperture. It includes geometric imperfection losses, mirror absorption loss, reflection losses, tracking losses etc. **[64]**

Thermal Analysis

Basic thermal analysis used for determining the useful heat gain at absorber is given by the following equation: -

$$Q_u = A_{aper} \times S - Q_l \quad (1)$$

Where Q_u is Rate of useful Heat gain

A_{aper} is effective aperture area

S is absorbed solar radiation per unit aperture area

Q_l is rate of heat loss from receiver / absorber and Q_l is given by:-

$$Q_l = U_l \times A_{abs} (T_{pm} - T_a) \quad (2)$$

Where U_l is Overall loss coefficient

A_{abs} is absorber area

T_{pm} is average temperature of the absorber surface

T_a is temperature of the surrounding air **[64]**

5.2 Non Evacuated tube Parabolic Trough Collector

The basic elements of a Parabolic Trough Collector are:-

1. Absorber Tube through which liquid to be heated flows
2. Concentric transparent cover
3. Curved Mirror/ Glass as Reflectors
4. Support Structure

The elements 1 & 2 constitute the Receiver, while 3 & 4 constitute to form Concentrator. Concentration ratio of PTC ranges from 5-80, Aperture area from 1 to 60 m^2 and Rim angle 70° to 120°.

The absorber tube is usually made up of Copper or Stainless steel and is coated with a selective coating or heat resistant black paint. Glass cover is concentric to the absorber tube and is surrounded by radial gap of 1-2 cm. For the high-performance collectors space between absorber tube and glass cover is evacuated. For smaller collectors, glass cover is replaced by plastic or glass sheet. In general, the reflective surface is curved back silvered surface. Coating is done for the protection of the reflector surface from environmental conditions. The design of supporting structure is made of aluminium for making it light weighted. The structural design is important as it influences shape and orientation of the collector. The structure should be such that it must have proper movement for tracking.

There are five modes in which the tacking is possible: -

Mode I: - The focal axis is E-W and horizontal. The trough is rotated about E-W axis and the adjustment is done once everyday such that the beam is normal to the aperture plane at solar noon of the day

Mode II: - The focal axis is E-W and horizontal. The trough is rotated continuously about the horizontal E-W axis such that solar beam makes minimum angle of incidence with aperture plane.

Mode III: - The focal axis is N-S and horizontal. The trough is rotated continuously about the horizontal N-S axis such that solar beam makes minimum angle of incidence with aperture plane.

Mode IV: - The focal axis is N-S and inclination at a fixed angle is provided which is equal to the latitude. This orientation is often referred as Polar Mount.

Mode V: - The Focal axis is N-S and inclined. The trough is rotated about an axis which is parallel to the focal axis and a horizontal axis perpendicular to the former axis and is adjusted continuously such that solar beam is falling normal to the plane of aperture at all times. **[64]**

5.3 Performance Analysis

Basic thermal equation mentioned above provides only the amount of heat gained in the receiver; however which is totally dependent on the various parameters of the concentrator & receiver and some other factors such as DNI, Wind speed, Ambient temperature etc. which have to be analysed. The heat gain is also depended up on the losses from receiver i.e. conduction, convection and radiation.

Let us consider some basic parameters for analysis consider the basic dimensions of the collector as Aperture W and Length L. The absorber tube has got an outer and inner diameter D_o and D_i respectively and its concentric glass cover has inner and outer diameter as D_{ci} and D_{co}. The heat transfer fluid has a specific heat Cp, mass flow rate m, an inlet temperature T_{fi} and outlet temperature T_{fo}.

The beam radiation falling normally over the aperture surface is given by $I_b\ r_b$.

The analysis is done by an energy balance on an elementary part *dx* of the absorber tube, which is at *x* distance from the inlet and results for a steady state in the following equation:-

$$dq_u = [I_b\ r_b\ (W-Do)\ \rho\Upsilon\ (\varsigma\alpha)_b + I_b\ r_b\ Do\ (\varsigma\alpha)_b - U_l \pi\ Do\ (T_p - T_a)]\ dx \qquad \textbf{(3)}$$

Where dq_u = Useful heat gain rate for a length *dx,*

ρ = specular reflectivity of the concentrator surface

Υ = intercept factor

$(\varsigma\alpha)_b$ = average value of transmissivity & absorptivity product for beam radiation

U_l = overall loss coefficient

T_p = local temperature of absorber tube

T_a = ambient temperature

I st term of the equation represents the incident beam radiation absorbed after reflection.

II nd term of the equation represents the incident beam radiation absorbed which falls on it directly.

III rd term represents the losses by convection and reradiation. **[64]**

By further simplification and integration over the length of the collector, L the above equation for useful rate of heat gain can be rewritten as:-

$$Q_u = F_R\ (W-Do)\ L\ [S-\frac{\mathbf{U}l}{\mathbf{C}}(T_{fi} - T_a)] \qquad \textbf{(4)}$$

Where, Absorbed Flux, $S = I_b\ r_b\ \rho\ \Upsilon\ (\varsigma\alpha)_b + I_b\ r_b\ (\varsigma\alpha)_b\ [\frac{Do}{W-Do}]$ **(5)**

Heat Removal Factor, $F_R = \frac{\text{m Cp}}{\pi\ \text{Do Ul}\ L}[1 - \exp\{-\ \frac{F'\ \pi\ \text{Do Ul}\ L}{m\ Cp}\}]$ **(6)**

Collector Efficiency Factor, $F' = \frac{1}{Ul[\frac{1}{Ul}+\frac{Do}{Di\,hf}]}$ **(7)**

5.3.1 Heat Transfer Coefficient and Overall Loss Coefficient

Overall Loss coefficient is calculated based on convection and reradiation loss and is given by: -

$$\frac{q_l}{L} = h_{p\text{-}c}\,(T_{pm} - T_c)\,\pi\,Do + \frac{\sigma\,\pi\,Do\,(Tpm^4 - Tc^4)}{\{\frac{1}{\varepsilon p}+\frac{Do}{Dci}\left(\frac{1}{\varepsilon c}-1\right)\}} \quad (8)$$

$$= h_w\,(T_c - T_a)\,\pi\,D_{co} + \sigma\,\pi\,D_{co}\,\mathcal{E}_c\,(T_c^4 - T_{sky}^4) \quad (9)$$

Where $\frac{q_l}{L}$ = heat loss rate per unit length

$H_{p\text{-}c}$ = convective heat transfer coefficient between glass cover and absorber tube.

H_w = Outside heat transfer coefficient between glass cover and outside air.

Tc = Temperature attained by the cover.

Tpm = Average temperature of absorber tube.

$$h_{p-c} = \frac{2\pi k_{eff}}{D_o \ln(D_{ci}/D_o)} \quad (10)$$

H_w is calculated using Nusselt number equation $Nu = C_1\,Re^n$, where C1 and n are constants, whose values are dependent on Reynolds number. **[64]**

5.4 Designing of Parabolic Trough Collector

5.4.1 Collector Size Selection

As the parabolic trough system was designed for steam generation for the location in Gujarat, the collector considered were having following parameters:-

Table: 5.1, Table representing dimensions of different collectors

Type	Length (m)	Aperture (m)	Aperture Area (m^2)
Collector I	50	5	250
Collector II	4.22	1.6	6.76
Collector III	25	1.2	30
Collector IV	1.93	1.07	2.1

The collector used were analysed with mass flow rate in proportion to their sizes and on the two parameters: -

- The generation of thermal output by the collectors per unit area
- The space utilization at the roof of the chemical industry taken into consideration.

The results from the first and second parameter analysis are given below and final selection is done based on both the parameters:-

- According to the secondary parameter considered the size of the collector is chosen based on the roof of the chemical industry, which has a lot of the air outlets, some equipments exhaust pipes and Roof is not long enough at many places ruling out the collector I and III, so only collector II and IV are left.
- The graph shown below represents the thermal output obtained across the year at Ankleshwar, Gujarat. The comparison for the collectors clearly indicates that the increasing order of Collector generation is III < I < IV < II , which results as Collector II is best choice as it has more thermal output available according to the location and thus overall generation would be more than others.

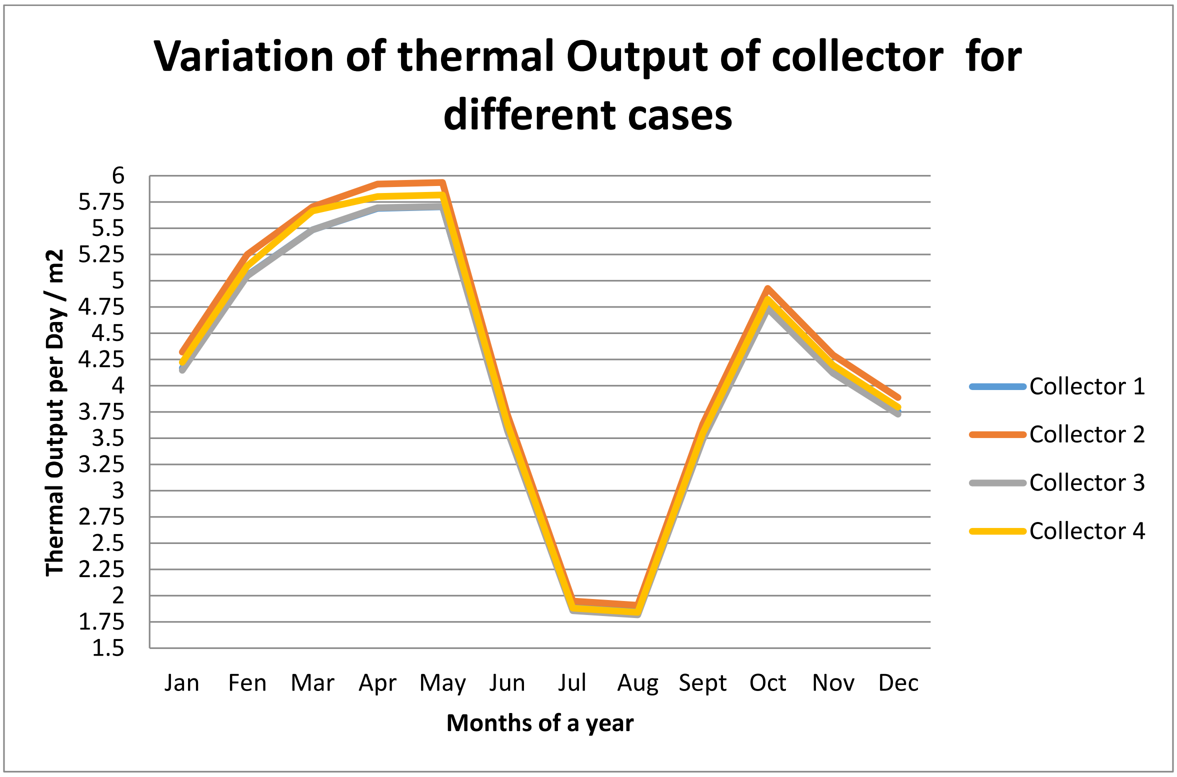

Figure: 5.1, Graph representing the thermal output comparison for different collectors

For the detailed thermal output data, please refer the tabular column in the appendix

Hence only **Collector II** has been used for the further analysis.

5.4.2 Detailed Calculation and Design for Collector II

Before going into the calculation part, the parameters of the concentrator and absorber tube of **Collector II** are mentioned in the tabular column below:-

Table: 5.2, Table representing Design parameters and values of the collector

Design Parameter	Design values	Units
Length, **L**	4.22	m
Aperture ,**W**	1.6	m
Aperture Area, A_{aper}	6.76	m^2
Inner Diameter of the Absorber Tube, D_i	0.066	m
Outer Diameter of the Absorber Tube, D_o	0.07	m
Inner Diameter of the Glass Cover, D_{ci}	0.115	m
Outer Diameter of the Glass Cover, D_{co}	0.12	m
Rim Angle, θ_r	70	Degree
Focal Length, **f**	0.57	m
Specular Reflectivity of the Concentrator Surface, **ρ**	0.935	-
Intercept Factor, **ϒ**	0.95	-
Absorptivity-Transmissivity product, $(\varsigma\alpha)_b$	0.924	-
Mean temperature of the Absorber tube, **Tpm**	210	° C
Temperature of Cover, **Tc**	72.5	° C
Ambient Temperature, **Ta**	25	° C
Sky Temperature, T_{sky}	19	° C
Emissivity of Glass Cover, ε_c	0.86	-
Emissivity of Absorber Tube, ε_p	0.65	-
Mass Flow Rate, **m**	0.2	Kg/s
Stefan Boltzmann Constant, **σ**	5.67 x 10^ -8	W/m-k
Heat transfer coefficient b/w absorber tube and glass cover, **Hp-c**	8.308	W/m2-K
Heat transfer coefficient inside the absorber tube, H_f	238.5797	W/m2-K
Heat transfer coefficient b/w glass cover and outside air, **Hw**	23.651	W/m2-K
Overall Heat loss coefficient, U_L	13.635	
Wind Speed, **v**	4.5	m/s
Solar Direct Normal Incidence radiation for rated design, I_b	1000	W/m2
Average Cosine Factor for rated design	0.913	-
Optical Efficiency , η_o	0.7505	-

For the design parameters mentioned above, the parameters are dependent on the material used for the construction, geometry,and other environmental conditions .

The following table gives the procedure used for the calaculation gives the procedure followed for calculation of the varous perfromance parameters like Thermal Efficiecny, Overall Efficiency,Average Thermal Output per day,Absorbed Flux etc.

Table : 5.3,Calculation Procedure for designing of Parabolic Trough Collector

S.No	Terms	Units									
1	Heat Removal Factor,Fr	-	1.052607	1.052607	1.052607	1.052607	1.052607	1.052607	1.052607	1.052607	1.052607
2	Aperture,W	m	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
3	Outside Diameter of the Absorber Tube,Do	m	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
4	Absorbed Flux,S (Ib,rb)	W/m2	236.3805	315.174	325	393.9675	472.761	551.5545	630.348	709.1415	787.935
5	Length of Collector,L	m	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22
6	Overall Loss Coefficient,Ul	W/m2-K	13.635	13.635	13.635	13.635	13.635	13.635	13.635	13.635	13.635
7	Concentration Ratio	-	6.957345	6.957345	6.957345	6.957345	6.957345	6.957345	6.957345	6.957345	6.957345
8	Temperature of Inlet Fluid in the Tube,Tfi	K	343.16	343.16	343.16	343.16	343.16	343.16	343.16	343.16	343.16
9	Ambient Temperature,Ta	K	298.15	298.15	298.15	298.15	298.15	298.15	298.15	298.15	298.15
10	Useful Heat Gain	WH/day	1007.002	1542.503	1609.283	2078.004	2613.506	3149.007	3684.508	4220.009	4755.511
11	Per day Kwh Thermal Output	KWH/day	1.007002	1.542503	1.609283	2.078004	2.613506	3.149007	3.684508	4.220009	4.755511
12	Unshaded Aperature Area Fraction		0.925	0.925	0.925	0.925	0.925	0.925	0.925	0.925	0.925
13	Intercept Factor,Y		0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
14	Mirror Reflectance		0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.935
15	Cos θ		0.9135	0.9135	0.9135	0.9135	0.9135	0.9135	0.9135	0.9135	0.9135
16	Ib (Solar Radiation)	W/ m2	300	400	405	500	600	700	800	900	1000
17	ηo		0.75056	0.75056	0.75056	0.75056	0.75056	0.75056	0.75056	0.75056	0.75056
18	ηthermal		-0.262	-0.00886	0.000513	0.143022	0.244279	0.316605	0.370849	0.413039	0.446791
			0	0	0.00051	0.14302	0.24428	0.3166	0.37085	0.41304	0.44679
19	ηoverall		0	0	0.000383	0.107345	0.183347	0.237627	0.278345	0.310011	0.335343

From the results obtained from the tabular column, the variation of the different factors with the beam radiation has been plotted below:-

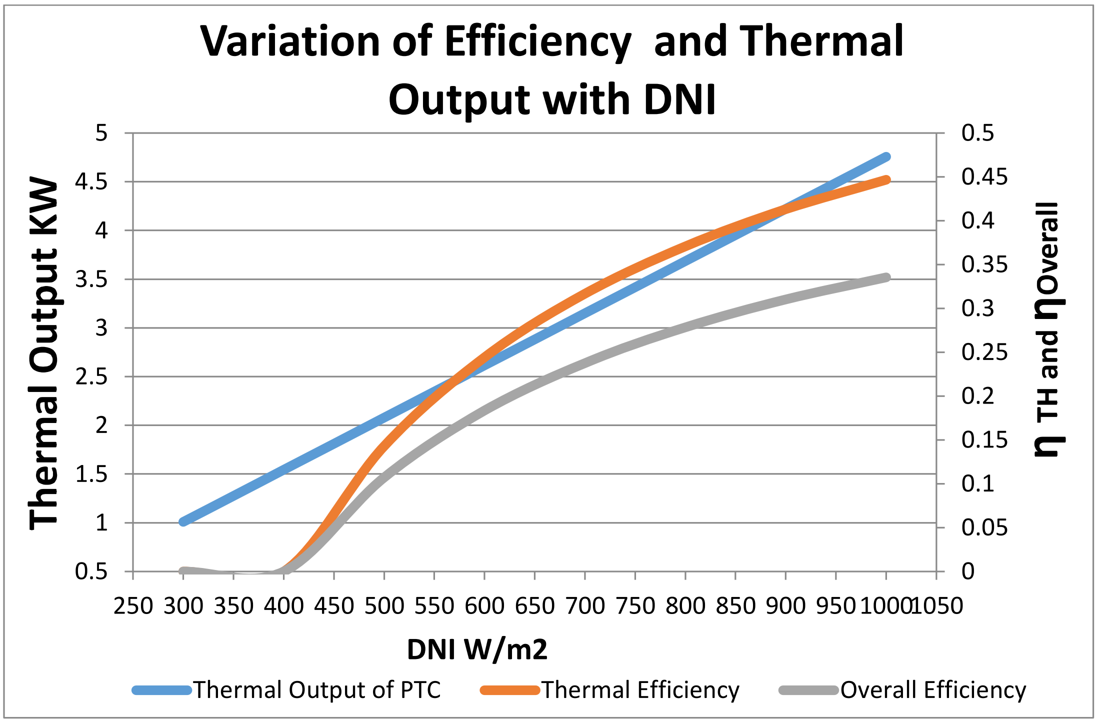

Figure: 5.2, Variation of parameters with DNI

From the above graph it is clear that the thermal output of the parabolic trough collector increases continuously with the increase in the DNI and at standard design point 1000 W/m^2 it reaches gives a thermal output of 4.75 KWh. On the other hand the thermal efficiency is found to be negative up to 400 W/m2 because the thermal losses due to convection and radiation of the absorber tube is higher than the thermal gains of the absorber tube, hence the thermal efficiency and overall efficiency become positive at DNI of 405 W/m^2 (Threshold) after exceeding which it rises continuously and at 1000 W/m2 thermal efficiency and overall efficiency of the system are found to be 44.67 % and 33.53%.

Variation of the Heat Transfer Coefficients with different parameters

The output of the parabolic trough collector varies according to a large number of factors; the heat transfer coefficients are changed and affect the overall output of the system resulted due to these variations by changes in the overall loss coefficient. Some of the critical parameters are Wind Velocity, Mass flow Rate and Mean tube temperature. Variation with these parameters has been studied below:-

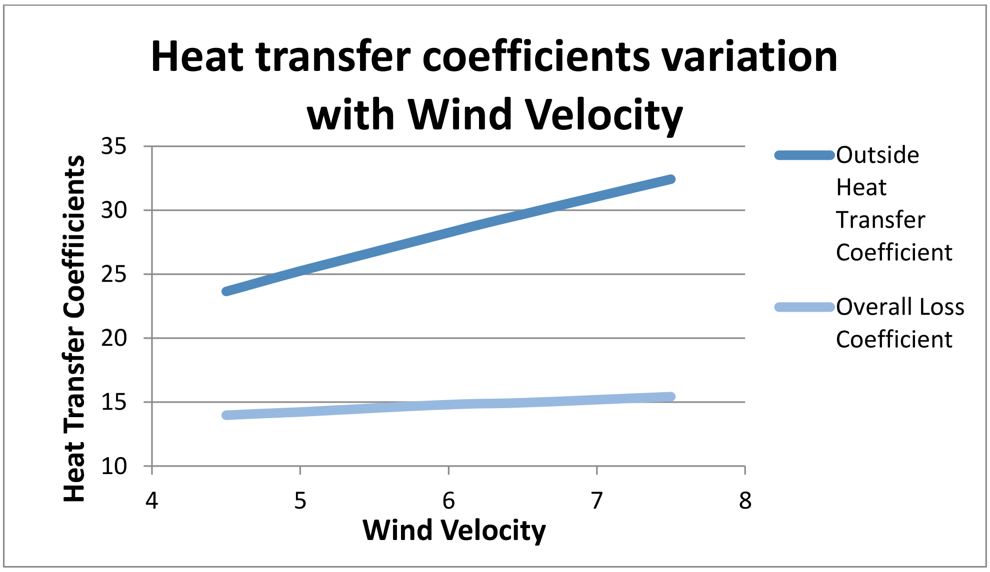

Figure: 5.3, Variation of Heat Transfer Coefficients with Wind Velocity.

The graph above clearly shows that the wind velocity has a great effect on the outer heat transfer coefficient as the convection losses increase with faster air movements resulting in the increase in the overall loss coefficient. This overall loss coefficient decreases the thermal output and thermal efficiency of the absorber tube. There is a steady rise in the heat transfer losses from outer cover.

The mass flow rate has got relation with the inner heat transfer coefficient between the absorber tube and heat transfer fluid movement. The graph below shows the variation in which there is sudden surge in the heat loss coefficient with increasing mass flow rate, but it gets steadier with increase in mass flow rate. With the inference from this graph the mass flow rate must be kept as low as possible in order to achieve more thermal output and efficiency.

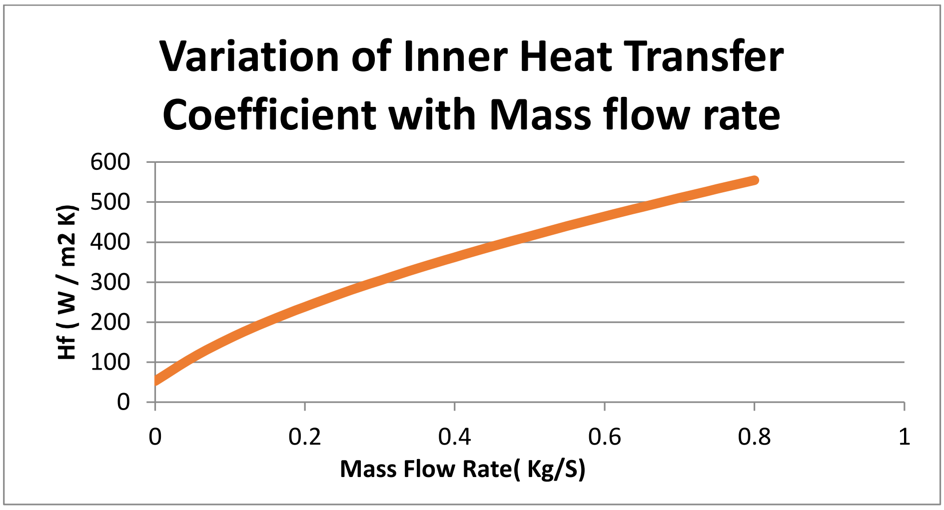

Figure: 5.4, Effect of Mass flow rate on the Inner Heat Transfer Coefficient

In order to obtain the desired temperature output in the form of hot fluid from the absorber tube temperature plays an important role. The mean tube temperature has a large effect on the two parameters – $\mathbf{H}_{p\text{-}c}$ (Heat loss coefficient between the absorber tube and the glass cover) and $\mathbf{U}_L$ (overall loss coefficient).It is found in the non evacuated tube as the air/ any other gas is present as heat transfer fluid.

The $\mathbf{H}_{p\text{-}c}$ increase steadily with Tpm (Mean Tube temperature) in starting but becomes relatively flat and then increase again but with less slope as earlier. The temperature to be obtained is 20-30° C less to the mean tube temperature. While there is decrease in the overall loss coefficient with the increasing cover temperature.

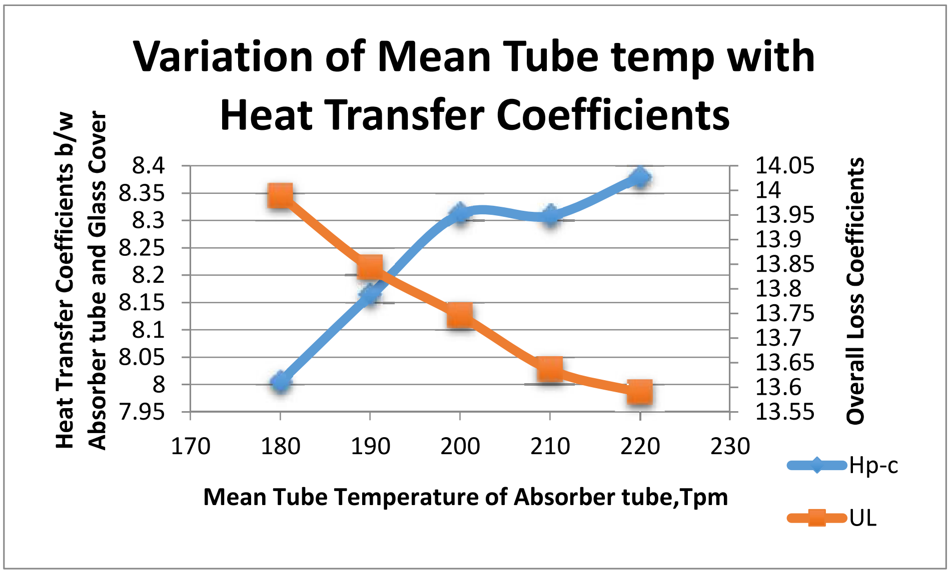

Figure: 5.5, Effect of Mean Tube Temperature on Hp-c and U_L

From the above three graphs it is validated that the overall loss coefficient is changed with the influence of various parameters that are related to the thermal output required and the environmental conditions.

5.4.3 Performance Evaluation of Non-evacuated parabolic trough Collector at Ankleshwar

The performance of Non-evacuated tube parabolic trough collector has been done only on the standard parameters for design, so in order to analyse the proper behaviour of the system at site, the analysis according to the site conditions must be done. But before that we must collect the data for solar radiation and other metrological parameters. The graph below presents the year around average solar radiation available at Ankleshwar, Gujarat (latitude & longitude is 21.6264°N and 73.0.152°E):-

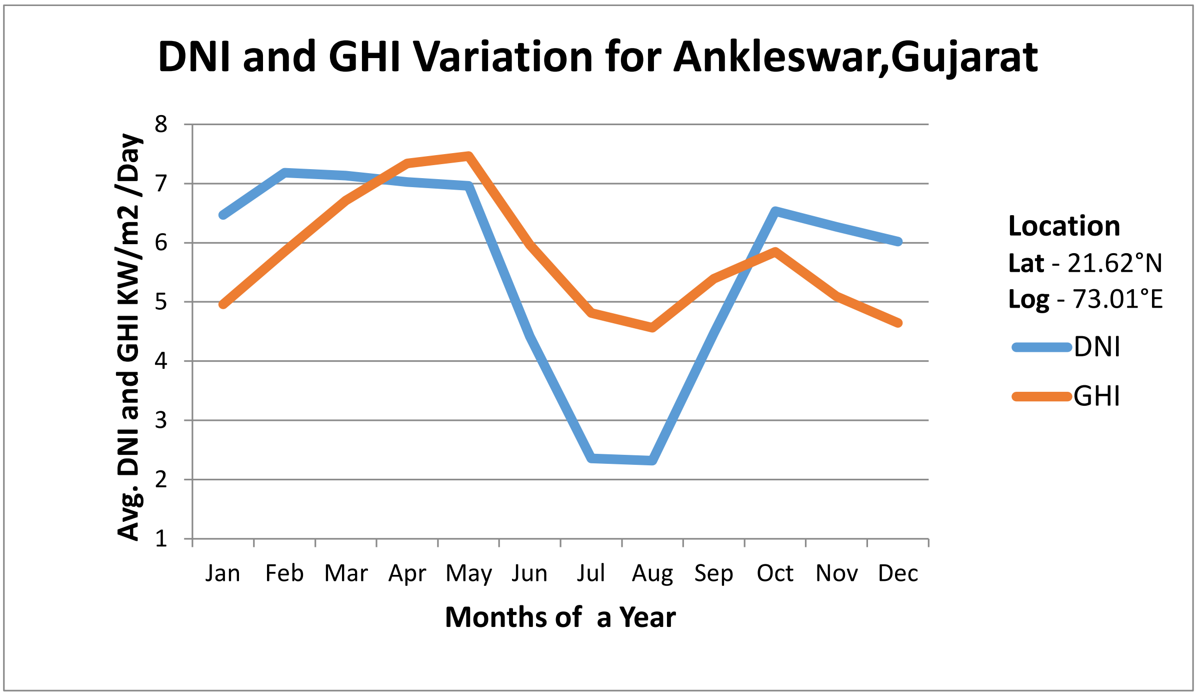

Figure: 5.6, DNI and GHI availability throughout the year at Ankleshwar, Gujarat [18]

The availability of the DNI and GHI for the year is 5.5847 KWH/m^2/day and 5.7165 KWh/m2/ Day which are quite encouraging for the use of the solar technology. DNI is main parameter influencing the use of the solar thermal technology. The months of March, April and October are having DNI availability greater than 6.5 KWH/ m2/day, while July and August are having DNI up to 2.35 KWH/m2/day. In July, August and September the availability of solar radiation is less due to the rainy season. In winters, the sky is normally clear and good amount of solar radiation are available.

For estimating the thermal output, the analysis has been done with along the year and variation of the Thermal output/day; Absorbed Solar energy and Incident Solar radiation have been studied. The average thermal output obtained is 28.98 KWh/ m2/day by the parabolic trough collector, while the highest and lowest thermal outputs are 40.13 KWh/m2/day and 12.91 KWh/ m2/day in May and August respectively. The optical efficiency touched 81.9 % (highest) and reached 62.6 %(lowest) in May and December. The detailed calculation is described in the tabular column below, which presents all the results.

Table: 5.4, Calculation for performance evaluation of PTC at Ankleshwar throughout the year

S.No	Terms	Units	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
1	Heat Removal Factor,Fr	-	1.05261	1.05261	1.05261	1.05251	1.05261	1.05261	1.05261	1.05261	1.05261	1.05261	1.05251	1.05261
2	Aperture,W	m	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
3	Outside Diameter of the Absorber Tube,Do	m	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
4	Absorbed Flux,S (Ib,rb)	W/m2	4384.69	5310.47	5761.63	5977.31	5993.05	3793.07	2027.51	1987.96	3703.66	4991.04	4357.31	3956.83
5	Length of Collector,L	m	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22
6	Overall Loss Coefficient,Ul	W/m2-K	13.635	13.635	13.635	13.635	13.635	13.635	13.635	13.635	13.635	13.635	13.635	13.635
7	Concentration Ratio	-	6.95734	6.95734	6.95734	6.95734	6.95734	6.95734	6.95734	6.95734	6.95734	6.95734	6.95734	6.95734
8	Temperature of Inlet Fluid in the Tube,Tfi	K	343.16	343.16	343.16	343.16	343.16	343.16	343.16	343.16	343.16	343.16	343.16	343.16
9	Ambient Temperature,Ta	K	298.15	298.15	298.15	298.15	298.15	298.15	298.15	298.15	298.15	298.15	298.15	298.15
10	Useful Heat Gain	WH/day	29200	35491.9	38558.1	40027.9	40130.8	25179.2	13180	12911.2	24571.5	33320.9	29013.9	26292.2
11	Per day Kwh Thermal Output	KWH/day	29.2	35.4919	38.5581	40.0279	40.1308	25.1792	13.18	12.9112	24.5715	33.3209	29.0139	26.2922
12	Unshaded Aperature Area Fraction		0.925	0.925	0.925	0.925	0.925	0.925	0.925	0.925	0.925	0.925	0.925	0.925
13	Intercept Factor,Y		0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
14	Mirror Reflectance		0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.935
15	Cos θ		0.7857	0.8571	0.9359	0.986	0.9976	0.9948	0.9967	0.9937	0.959	0.88529	0.8052	0.762
16	Ib (Solar Radiation)	W/ m2	808.299	897.412	891.674	878.138	870.125	552.262	294.638	289.763	559.375	816.575	783.799	752.112
17	ηo		0.64556	0.70422	0.76896	0.81013	0.81966	0.81736	0.81892	0.81645	0.78794	0.72738	0.66158	0.62608
18	ηthermal		0.26974	0.36573	0.42829	0.4642	0.47055	0.26731	-0.2121	-0.2319	0.24489	0.35538	0.27402	0.2222
			0.26974	0.36573	0.42829	0.4642	0.47055	0.26732	0	0	0.24489	0.35538	0.27402	0.2222
19	ηoverall		0.17413	0.25755	0.32934	0.37606	0.38569	0.21849	0	0	0.19296	0.2585	0.18128	0.13911

From the results obtained from the above analysis the Incident, Absorbed and Output thermal energy is compared in the graph below: -

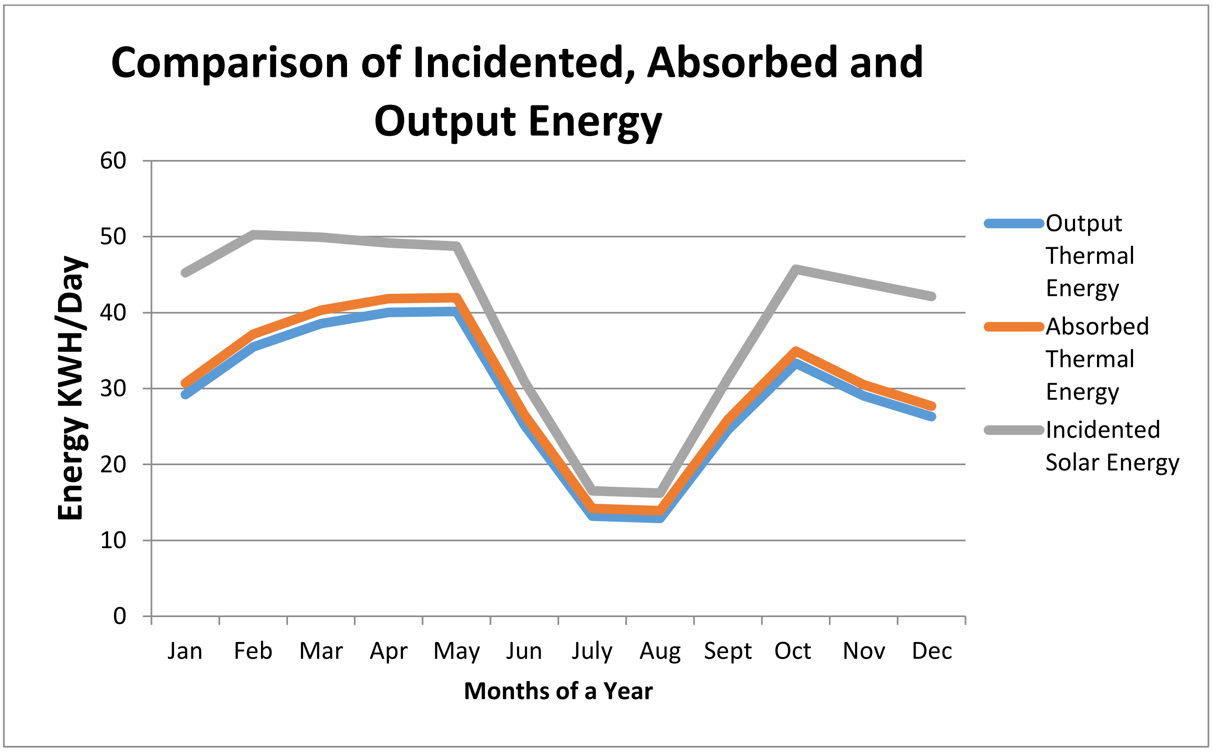

Figure: 5.7, Input and Output Energy variation over the year

The differences between the different curves on the graph are the indicating the losses associated with it in due to different reasons. The gap between the Incident Solar energy and absorbed thermal Energy is due to Tracking losses, Cosine Losses, Geometrical losses, material related other losses (Reflectivity, Absorptivity, Transmissivity) and Thermal losses (Conduction, Convection and Radiation due to high temperatures).The Inner and outer absorber tube losses are responsible for the gap between the curves.

Average Optical Efficiency is about 75%, while it varies from 62 % to 81.9 %.This variation is due the different sun path during different seasons, in summer the earth`s tilt is near to the sun ,while during winter the tilt is way from the sun. Thermal efficiency is increasing with the availability of DNI during different months, but as the DNI decreases in the month of July and August it becomes negative, so taken as zero .Overall efficiency is the product of both Optical and Thermal efficiency and has almost similar variation of thermal efficiency. The highest overall efficiency of the system is 38.5 %.Variation of Optical, Thermal and Overall efficiencies are shown below: -

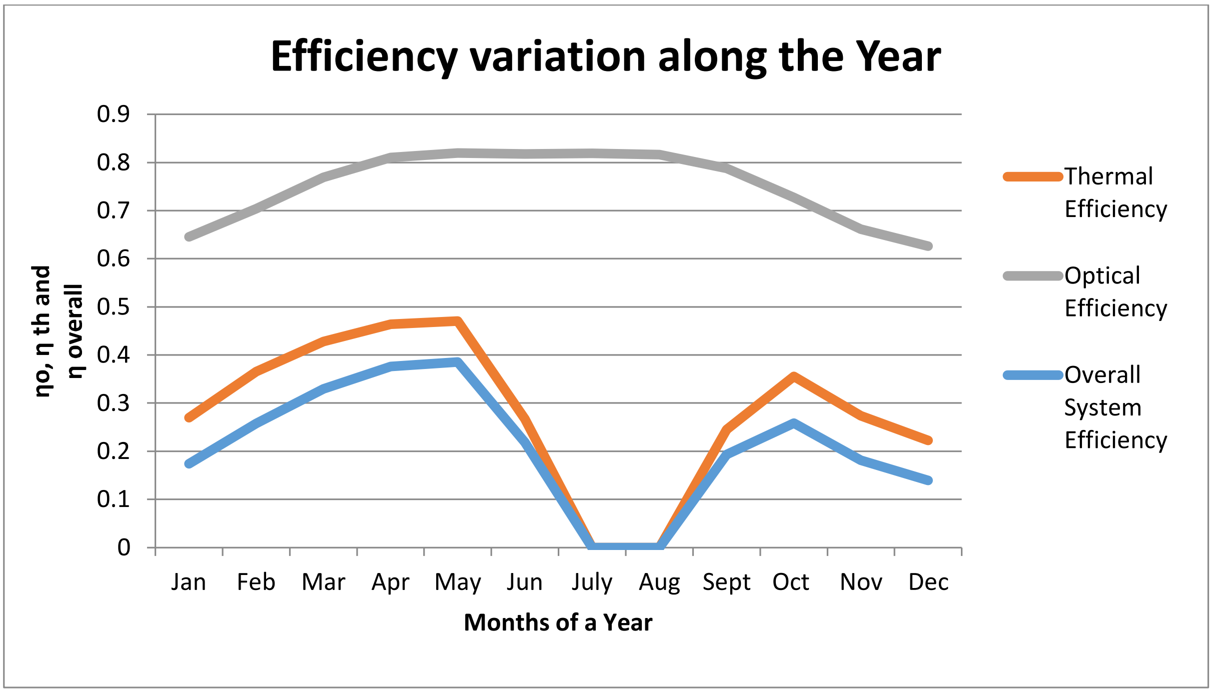

Figure: 5.8, Variation of different efficiency along the year

To obtain maximum output from the parabolic trough collector, tracking is required. Different tracking modes are available. For all the above calculation Mode III has been used, in which the absorber tube axis is N-S direction and trough is moved in the E-W direction continuously to have a minimum angle of incidence for the incident solar radiation. Cosine losses are caused when the tracked solar radiation do not concentrate it on the absorber tube. The tracking losses are also dependent on the sun path, which changes during winter, summer and equinox. In winter, as the sun is away from earth, the cosine losses are more as the sun path is lower so the radiation focussed are less. In summer, the sun path is at much altitude and hence the losses are less. Average Cosine loss is about 8.68% for the year. The graph below presents the variation of the cosine losses for the Ankleshwar, Gujarat:-

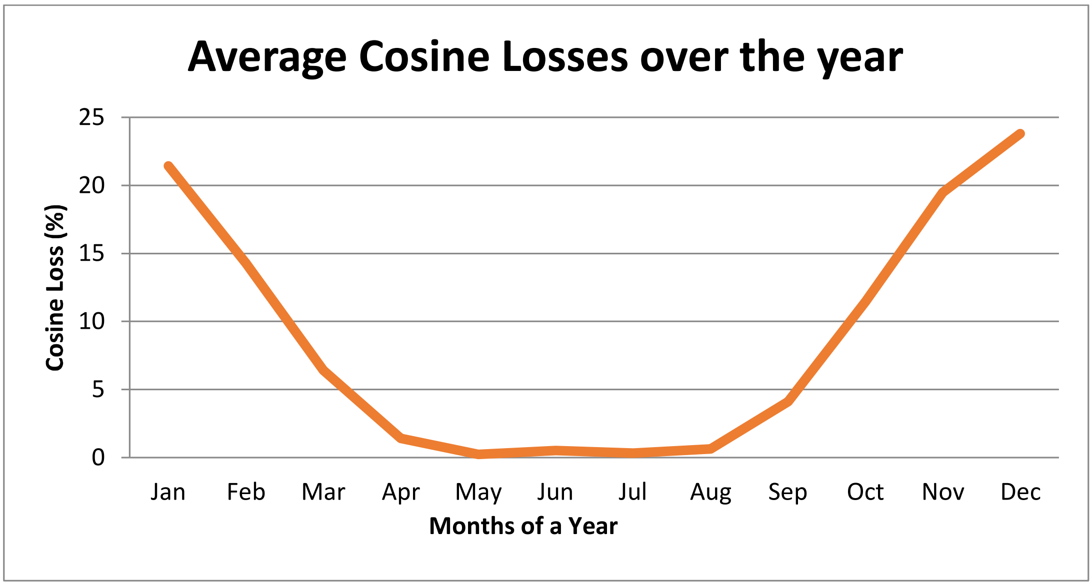

Figure: 5.9, Cosine losses over the year

Thermal Output of the parabolic trough is evaluated for the Longest, Shortest and Equinox days and comparison has been between them along with year average along the time of a day. In all the days, 21 March has the largest output of all throughout the day while 21 June has the least output due to the weather conditions. While the year average output seems to have almost constant type of curve for the day with some fluctuations, however the output decreases steadily in the evening. The comparison of these days is shown below: -

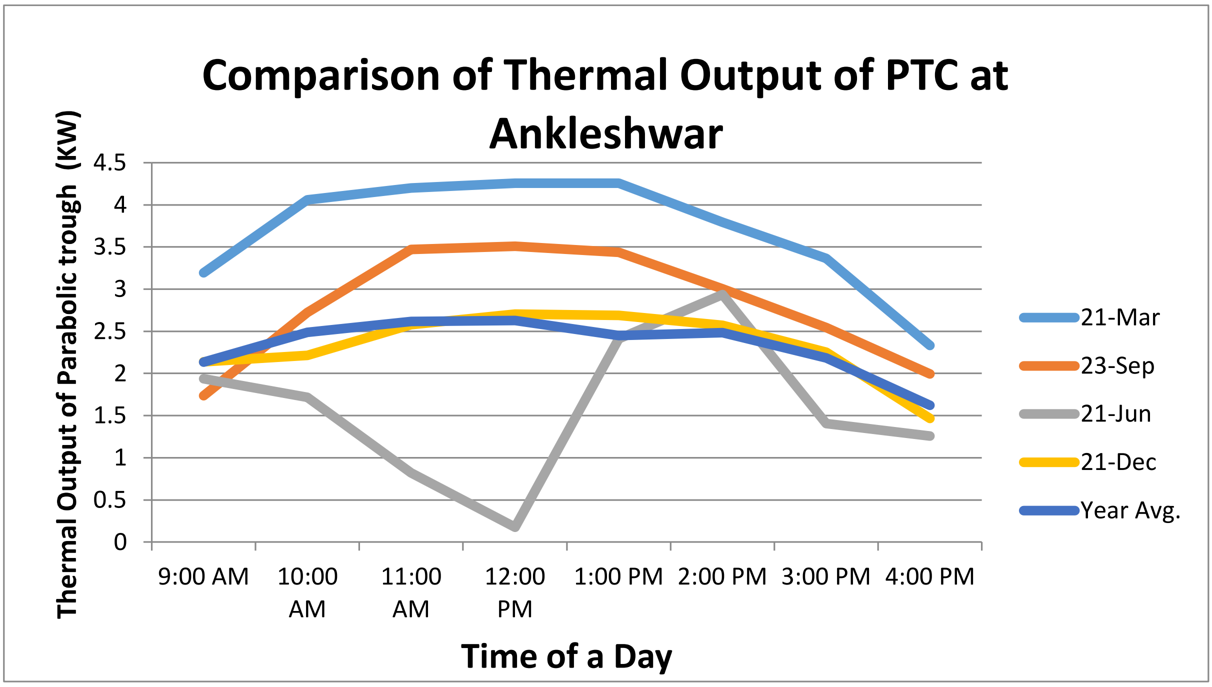

Figure: 5.10, Variation of thermal output throughout the day

Optical efficiency depends upon unshaded aperture, intercept factor, cosine factor and mirror angle. However, the cosine factor is only one which varies due to hour angle; hence an evaluation is done and is represented by the graph below: -

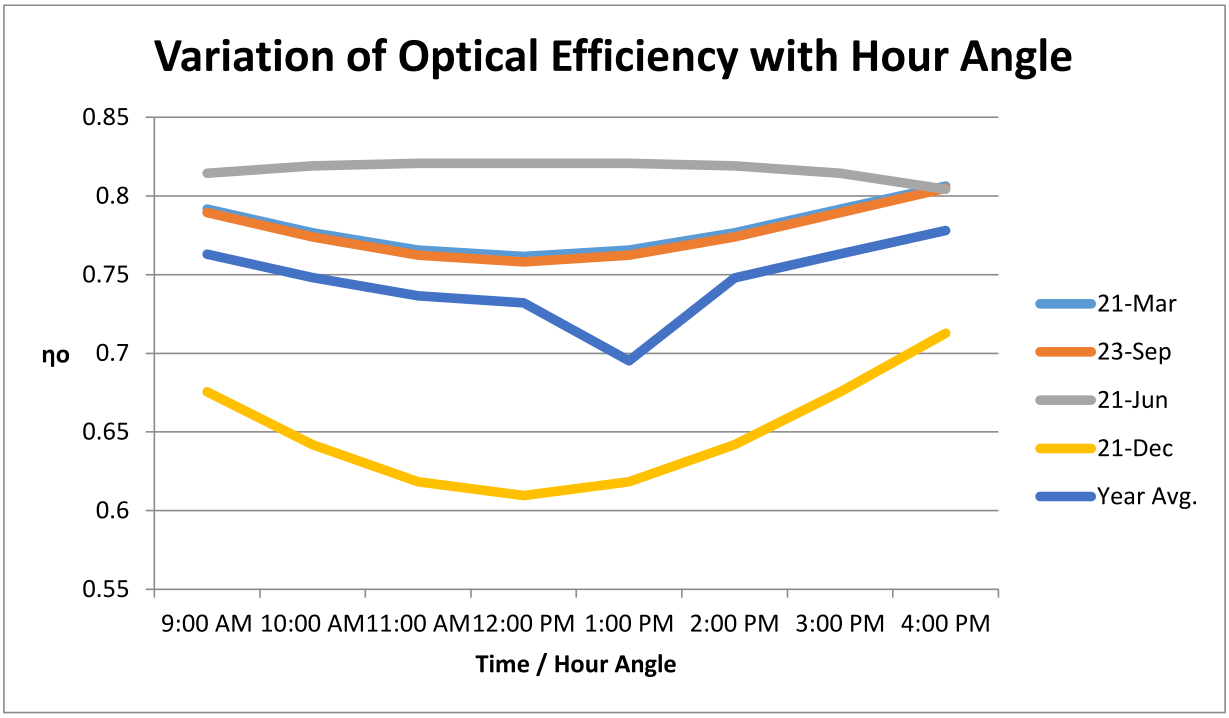

Figure: 5.11, Variation of Optical efficiency with Hour Angle (time)

The above graph shows that during the day the optical efficiency changes a lot, depending upon the variation with the time. The optical efficiency on 21st march is more than 80%, while on 21 st December reaches up to 60%. For the equinox days the curves are almost same. While the year on average is near 75%.the variation of the optical efficiency is related to the sun path which keeps on changing due to seasonal variation.

CHAPTER: 6 INTEGRATION AND ECONOMIC EVALUATION OF SIPH SYSTEM WITH CHEMICAL INDUSTRY

Parabolic trough collector designed in the previous chapter for the steam generation is to be integrated with chemical industries existing infrastructure forming a Solar Industrial process heat system which will bring down the dependence on the fossil fuels for steam generation. The system is designed in the retrofit mode such that existing system will supply the operation of the plant in case of Non sunshine hours and deficit supply of output. Thermal and hydraulic objectives are to be met by this system; the former is met by the PTC field and latter one by drawing Piping and Instrumentation (P & I) diagram. Proper integration of these systems will result in optimum payback period and smooth operation.

6.1 Introduction to Vandana Chemicals

Vandana Chemicals is one of leading and oldest names in the Indian chemical industry, which was established in 1987.It has earned a good name in the international market for supplying unique chemical intermediates and consistent supply for the customers. With compliance to the international standards and specification, Vandana Chemicals has earned a reputation. Excellent research, quality and reliability they are able to bring perfect blend to their products and have goodwill in the market. Without any compromise the quality of the products is taken care of and thus excellent services are rendered. Some of the common products supplied by Vandana Chemicals are given below: - **[65]**

2 Bromo 3'Chloropropiophenone	Para Bromo Benzyl Alcohol
Benzyl Bromide	Para Bromo Benzyl Bromide
Bis-(2-Chloro Ethylamine) Hcl	Para Cyano Benzyl Bromide
Bromo Acetic Acid	Para Nitro Benzyl Alcohol
GUAIACOL	Para Nitro Benzyl Bromide
Hydro Bromic Acid 48%	Sodium Bromide
Liquid Bromine	Tri Fluoroacetic Anhydride
Methyl Bromo Acetate	

Figure: 6.1, Products manufactured at Vandana Chemicals [65]

The existing plant machinery and infrastructure of the Vandana Chemicals have been tabulated below: -

Table: 6.1, Infrastructure at Vandana Chemicals [65]

Parameter	Specification
Boilers	600 Kg Steam Boiler
Thermopac	Thermic Fluid Heater- 2 Lac Kcal
Chilling Plant	40 TR
Cooling Tower	100 TR
Air Compressor	5 HP
Dryers	Fluid bed dryers, Tray Dryers
Filters	PP press filter, Centrifuge, Sparklers
Reactors	Stainless Steel, Brick lined, Glass Lined Reactors
Size of Reactors	0.5 KL to 6 KL
Primary Treatment plant	20 KL per day

6.2 Total Energy Requirement of the Industry

Detailed manufacturing process used for Chemicals have already been discussed in the chapter 4 and the infrastructural details available from the website of the company have been mentioned in the previous section. Both these sections when analysed together can give the energy consumption estimation by different equipments, however the interest of the study lies with the Thermal energy consumption. The tabular column below presents the thermal energy consumption of the plant assuming 10 hours of working: -

Table: 6.2, Thermal Energy Consumption per day

Type	Q (KJ/Kg)	Q (Kcal/h)	Kg/h Required	No. of Hours	Q (KWh)
Steam	2911.44	-	600	10	4852.4
Thermic Fluid	-	200000	-	10	2325.581395
Hot Air	-	150000	-	10	1744.186047
				Total	**8922.167442**

At current scenario Natural gas is the major source for thermal energy generation in both Boiler and Thermopac. The Natural gas is being supplied to the company by the pipeline system established by Gujarat Gas Company Limited and the current cost of supply is Rs. 46/ SCM (Standard Cubic Meter) inclusive all taxes. The cost of the Natural gas has been obtained by telephonic conversation between author and employee of the GGCL. The cost of the thermal energy generation in KWH $_{thermal}$ has been calculated in the tabular column below: -

Table: 6.3, Cost of Thermal Energy Generated by Boiler/Thermopac using Natural Gas

Fuel	Calorific Value (Kcal / SCM)	Calorific Value (KWh / SCM)	Cost (Rs./SCM)	Cost of Thermal Energy (Rs./ KWH)
Natural Gas	8500	9.88372093	46	**4.654117647**

So for the further evaluation of the SIPH system for the cost analysis, the cost of generation of thermal energy would be taken as Rs. 4.65/ KWh.

The procedure followed for the estimation of Annual energy consumption by the particular Chemical Industry (Vandana Chemicals) is based on two parameters – Number of working days and Number of working hours. On an average there are about 280-300 working days in a year and the industry is assumed to be running for at least 10 hours giving the energy consumption/day.

Now the annual energy requirement of the plant can be estimated using the results from the tabular column representing per day energy consumption and then multiplying with the number of working days of the plant resulting in the estimation of the Annual Energy consumption at the Vandana Chemicals. The tabular column below presents the annual energy consumption with considering 290 days of working during a year: -

Table: 6.4, Annual Energy Consumption (KWh)

Month	No. of Working Days of Plant	Amount of Thermal Energy Required/Day (KWh)	Thermal Energy Required / Month (KWh)
Jan	23	8922.167	205209.841
Feb	23	8922.167	205209.841
Mar	25	8922.167	223054.175
Apr	25	8922.167	223054.175
May	25	8922.167	223054.175
Jun	25	8922.167	223054.175
Jul	25	8922.167	223054.175
Aug	24	8922.167	214132.008
Sept	24	8922.167	214132.008
Oct	23	8922.167	205209.841
Nov	24	8922.167	214132.008
Dec	24	8922.167	214132.008
Total	**290**		**2587428.43**

The Annual thermal energy consumption for the year with 290 working days is 25, 87, 428. 43 KWH and the cost of it generating from the usage of Natural gas is Rs. 120, 31, 542.2.

6.3 Proposed system at Vandana Chemicals

6.3.1 Hydraulic Scheme for integration of SIPH system

The solar parabolic trough system needs to be integrated with existing steam, thermic fluid & hot air generating and distributing system such that it is capable of drawing the energy from both the system to meet its requirements at all times. The existing supply lines are connected with the Natural gas based Boilers and Thermopac via pipelines to deliver the required output.

Following figure shows the Piping and Instrumentation Diagram (P &I), which can be used in almost similar configuration for other plants too:-

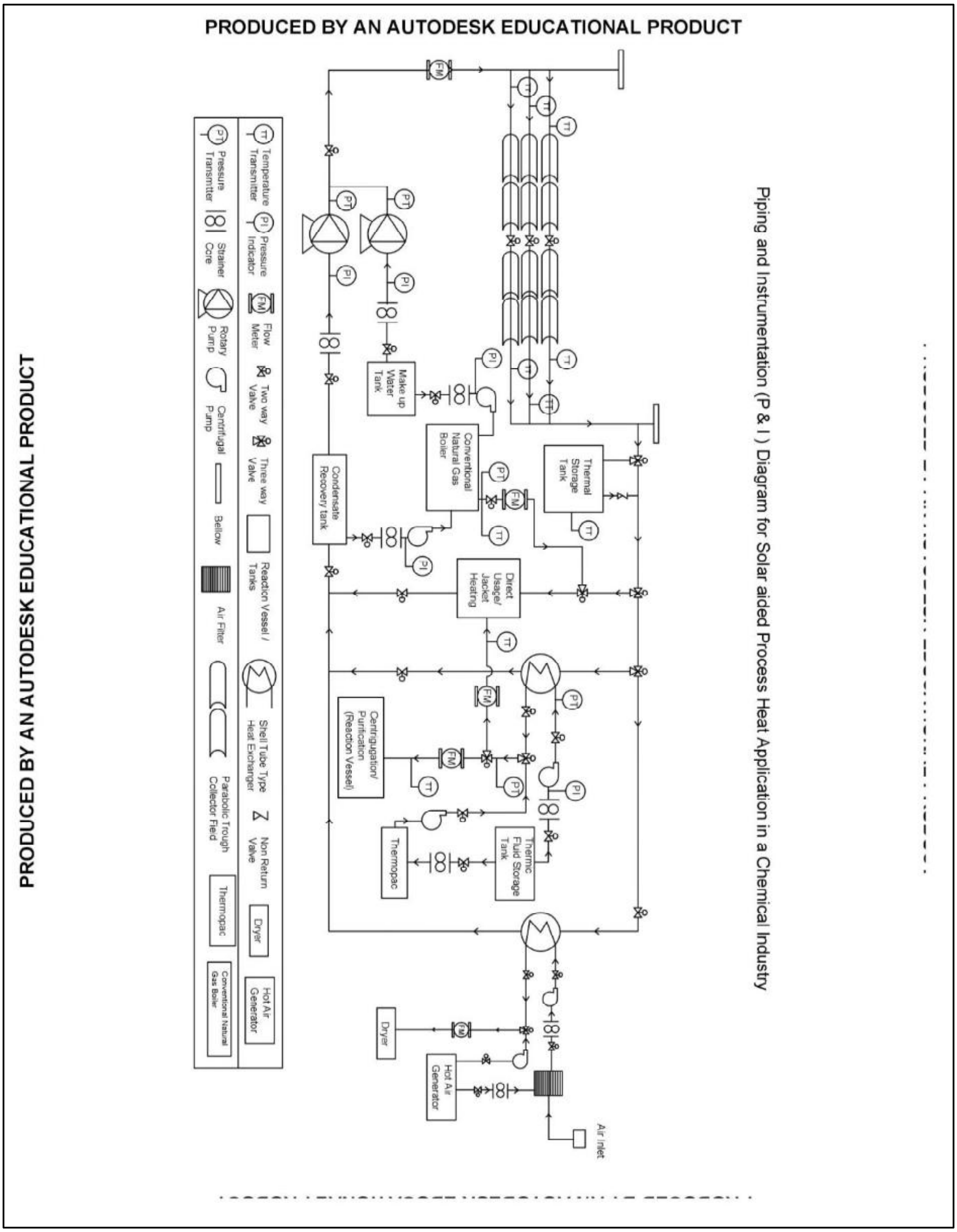

Figure: 6.2, P & I Diagram of the system installed at Chemical Industry

Parabolic trough collectors are connected to form a thermal heat generating field and generated steam is sent for the usage via well insulated pipelines connected to various points. The steam generated is sent to three places – Jacket Heating, Direct Utilization Chamber and Heat Exchangers. The first two ones use the steam in the chambers directly and the third is used indirectly by heating the thermic fluid and air generating hot thermic fluid and hot air via. Heat exchangers. The heat exchangers used are Shell and tube type where there is no contact between the heat exchanging fluids.

The conventional systems are connected in parallel to solar industrial process heat system, so that they can provide the extra amount of the heat in case less of thermal output and during non sunshine days & hours of operation. Steam after losing its energy gets converted into condensate water which is collected in the condensate recovery tank from all the three pipelines. About 70 % of the condensate is recovered and rest 30 % have to be added by makeup water tank which draws the demineralised water from the RO plant installed in the industry. The temperature of the condensate is about 90-95°C, but after mixing it is about 70°C, which is sent to the parabolic trough collector field for steam generation. Heat exchangers used in the two different circuits generate hot thermic fluid and hot air for the required purposes.

Circulation pumps – Rotary and centrifugal pumps are used for making the fluid movement in the hydraulic circuit. A large number of 2 way and 3 way valves are used for the connection between the different pipelines. Various other equipments are used – Strainer Core (filtration of fluid moving in pipeline), Air filter (removing dirt from air), Bellow (used at the end of the pipeline and maintains pressure in the pipeline) etc. The list of various instruments used are - Temperature Transmitter (for sending the signals for exact temperature), Pressure transmitter & Indictor (for estimation the pressure), Flow meter (to measure the mass flow rate of the fluid).

All the elements of the system are connected with pipe lines which are well insulated and there are Steam traps are also present in order to maintain the pressure losses and condensate removal. The pumps and most of the valves are operated with the SCADA control system used at the control office. The parameters of the system are under continuous observation via transmitting instruments and the person sitting in the control office takes the decision to vary the parameters accordingly. The valves and pups are operated and the mass flow rates are measured and the output temperature is checked using temperature transmitter.

Small Thermal storage vessel is also used for the system in order to maintain the proper thermal input to the working system and overcome fluctuations. It is of small capacity and stores about 20-30 minutes. Thermal storage is well insulated for maintain the system. A three way valve is used to supply the steam for the storage and the output of the storage is given by a parallel pipeline with a non - return valve.

6.3.2 Installation of collectors at site

The installation at site (Vandana Chemicals) has been virtually planned with axis of evacuated tube parallel to N-S axis and E-W tracking on the roof shown below: -

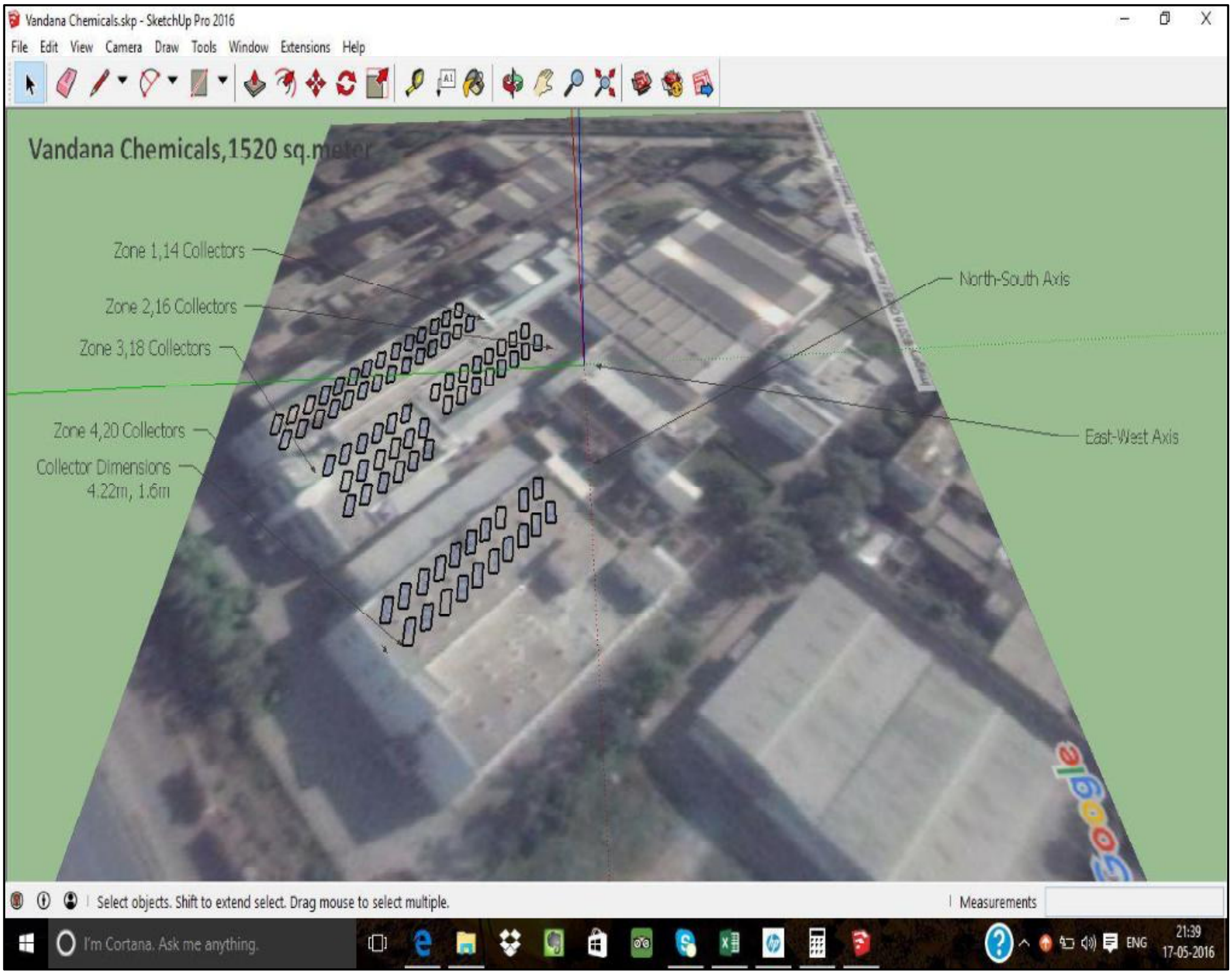

Figure: 6.3, Virtual Installation of Parabolic trough collector at Roof of Chemical Industry

The system is planned to be installed at the roof of chemical manufacturing industry which is lying vacant, so there is no need for extra land requirement for installation. However there are some challenges involved in the roof top installations – Some part of the roof is concrete and rest sheet metal, some space is used by Diesel set for electricity generation in non grid available time and exhaust outlets for hot air, cooling tower and condenser.

The planning has been done on the roof using **Google Sketch** up software and is done in accordance to the Google images available according to Latitude and Longitude. Total 82 numbers of collectors can be installed at the site in 4 different zones. The installation of PTC according to different zones on the roof is presented in the tabular column below:-

Table: 6.5, Table representing area and no. of collectors in different zones.

Vandana Chemicals				
S. No	**Length(m)**	**Breadth (m)**	**Area(m2)**	**No. of Collectors**
Zone 1	47.42	9.8	464.716	28
Zone 2	28.2	8.77	247.314	16
Zone 3	26.8	14	375.2	18
Zone 4	39.1	11	430.1	20
		Total	**1517**	**82**

6.4 Estimation of Energy generation by SIPH system

Annual energy generation is determined by calculating the thermal output generated by a single parabolic trough collector in different months and then multiplying with the no. of collectors used. The average thermal output generation is 26.09 KWh/ day. The calculation procedure followed is shown in the tabular column below: -

Table: 6.6, Annual energy generation by Parabolic Trough SIPH system

Month	No. of Sunny Days in a Month	Avg. Thermal Output (Without Circuit Losses)	Avg. Thermal Output (Including Circuit Losses)	Total No. of Collectors used	Total Thermal Output/Month	Solar Fraction
Jan	23	29.2	26.28	82	49564.08	0.241529
Feb	22	35.4919	31.94271	82	57624.64884	0.280808
Mar	24	38.5581	34.70229	82	68294.10672	0.306177
Apr	24	40.0279	36.02511	82	70897.41648	0.317848
May	24	40.1308	36.11772	82	71079.67296	0.318666
Jun	24	25.1792	22.66128	82	44597.39904	0.19994
Jul	8	13.18	11.862	82	7781.472	0.034886
Aug	10	12.9112	11.62008	82	9528.4656	0.044498
Sept	24	24.5715	22.11435	82	43521.0408	0.203244
Oct	23	33.3209	29.98881	82	56558.89566	0.275615
Nov	22	29.0139	26.11251	82	47106.96804	0.21999
Dec	22	26.2922	23.66298	82	42688.01592	0.199354
Total / Avg.	**250**		289.42686		**526554.1661**	**0.220213**

In Month of May, the highest thermal output and solar fraction is obtained amounting to 71079 KWh and 31.8 %, while the July has lowest thermal output and solar fraction amounting to7781.472 KWh and 4% respectively. The total amount of **thermal energy** output for 250 sunny days in a year is **5, 26,554.166 KWh** and an year about **solar fraction** of **22%** has been achieved which will reduce considerable amount of reduction in dependence on the fossil fuel (Natural gas) which will reduce the environmental degradation.

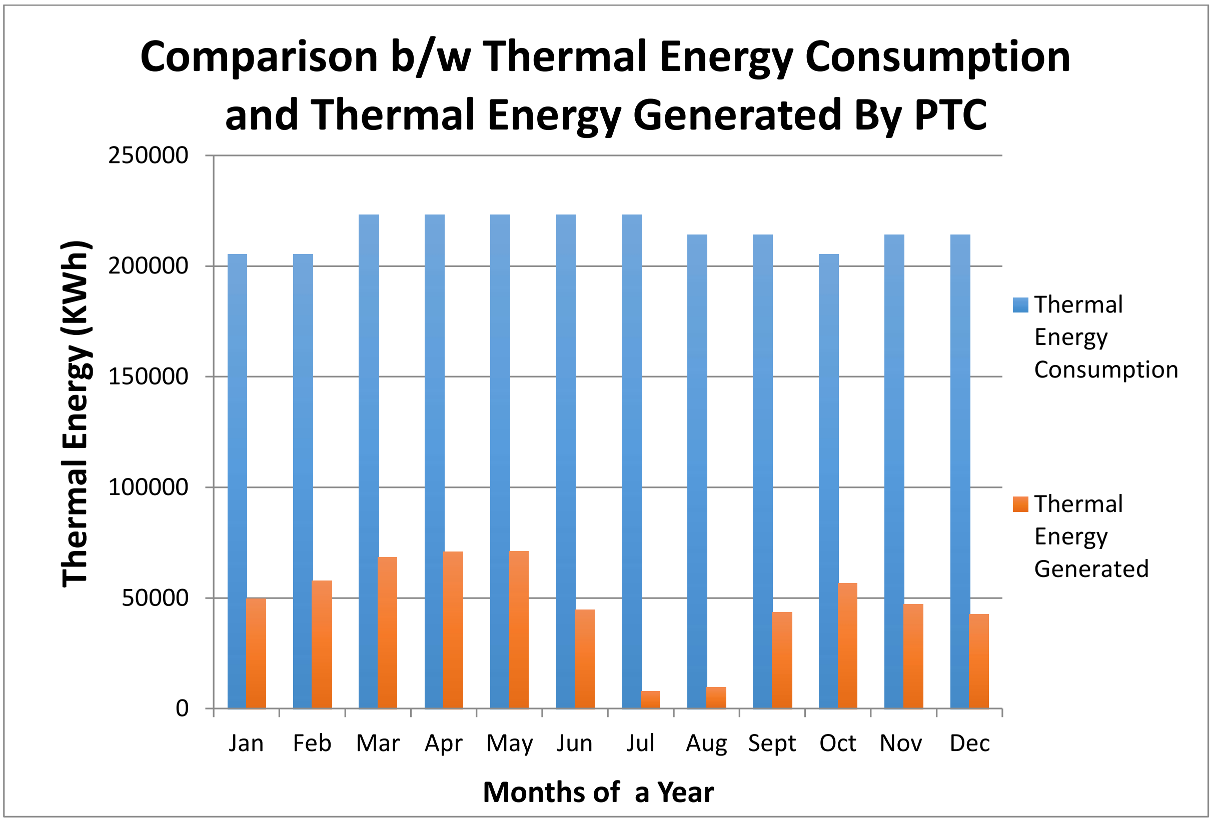

Figure: 6.4, Comparison of energy generation and consumption in a year

The graph shows the comparison of the thermal energy generated by the parabolic trough collector field and thermal energy consumption. From the above graph it is evident that during the months which are have got good sunshine hours and clear sky the thermal energy output by solar collector field is near 50,000 KWh/Month.

6.5 Payback period and Cash flow evaluation

After the designing and integration of the SIPH system, the amount of investment needed is to be calculated to determine the financial viability of the system to be installed. The project cost is determined on the basis of the MNRE bench mark cost and Capital subsidy available. On further continuation the Pay period is evaluated based on the cost of thermal energy generation by Natural gas and Income tax accelerated depreciation benefit available for the client. The following table represents the calculation procedure followed for the analysis: -

Table: 6.7, Payback period estimation

Parameters	Units	Respective Values
MNRE Bench Mark Cost for Single Axis Tracking (Non Evacuated)	Rs. / m2	**16000**
Market Cost for Single Axis Tracking (Non Evacuated)(1.1 Times Bench Mark)	Rs. / m2	17600
Total Number of Collectors used	-	82
Area of Single Collector	m2	6.76

Total Collector Area	m2	554.32
Total Market Cost of Collector	Rs.	9756032
Yearly Operation and Maintenance cost (5 % of Bench Mark Cost)	Rs. / m2	**880**
Operation and Maintenance Period	Years	3
Total Operation and Maintenance cost	Rs.	1463404.8
Total Market Cost of System (Including O & M)	Rs.	**11219436.8**
MNRE Capital Subsidy for Single Axis Tracking (Non Evacuated)	Rs. / m2	5400
Total Capital Subsidy for the System by MNRE	Rs.	**2993328**
Total Project Cost	Rs.	**8226108.8**
Under Income Tax Act 32 A , Benefit available to Customer(@ 30 % of Total Project cost and 80 % which can be used for Accelerated Depreciation) i.e. Project Cost * 0.3 * 0.8	Rs.	1974266.112
Total Investment to be done for SIPH system at Vandana Chemicals	Rs.	**6251842.688**
Total Thermal Energy Saved by the PTC system	KWh / Year	**526554.1661**
Cost of Per unit Thermal Energy saved	Rs. / KWh	4.65
Total Cost fuel Saved in a year	Rs. / Year	2448476.872
Yearly Return	Rs. / Year	2448476.872
Pay Back Period (Time for Investment to Return)	Years	**2.553359911**

Cash Flow is the term which indicates the way in which the money will flow i.e. the money which the investor has to pay for the installation which is one time cost and then yearly operation and maintenance cost to be made for running the system and will help in calculating the **IRR** (Internal Rate of return). The tabular column below mentions the calculation details:-

Table: 6.8, Cash flow calculation

Period	Cash Outflow	Cash Inflow	Net Cash Flow	Cumulative Cash Flow
0	-6251842.688	0	-6251842.688	-6251842.688
1	0	2448476.872	2448476.872	-3803365.816
2	0	2448476.872	2448476.872	-1354888.944
3	0	2448476.872	2448476.872	1093587.928
4	-487801.6	2448476.872	1960675.272	3054263.2
5	-487801.6	2448476.872	1960675.272	5014938.472

During the installation the investor invests **Rs. 62 Lakhs** (approx) and then yearly returns start coming by the reduction of the bills of Natural gas. The cash flow continues and in the mid year of the 3 rd year of working becomes the positive indicates that payback period has been achieved.**IIR** obtained for the cash flow is **25%**.

The graph shown below depicts the cash flow and pay period:-

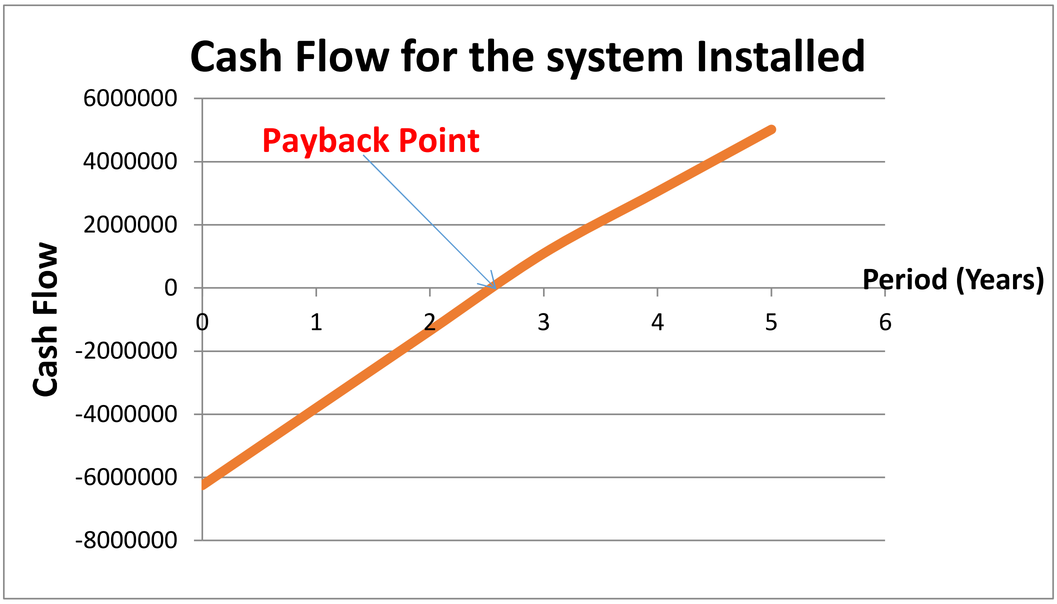

Figure: 6.5, Cash Flow Analysis

In 2.55 years the money invested returns to the investor and the profits are reaped in further years of working. For increasing the solar fraction and thermal output of the collector field, the more number of collectors are to be installed resulting in the increasing the cost of investment directly. This variation of the Investment cost and Thermal energy output with increasing no. of collector is shown below:-

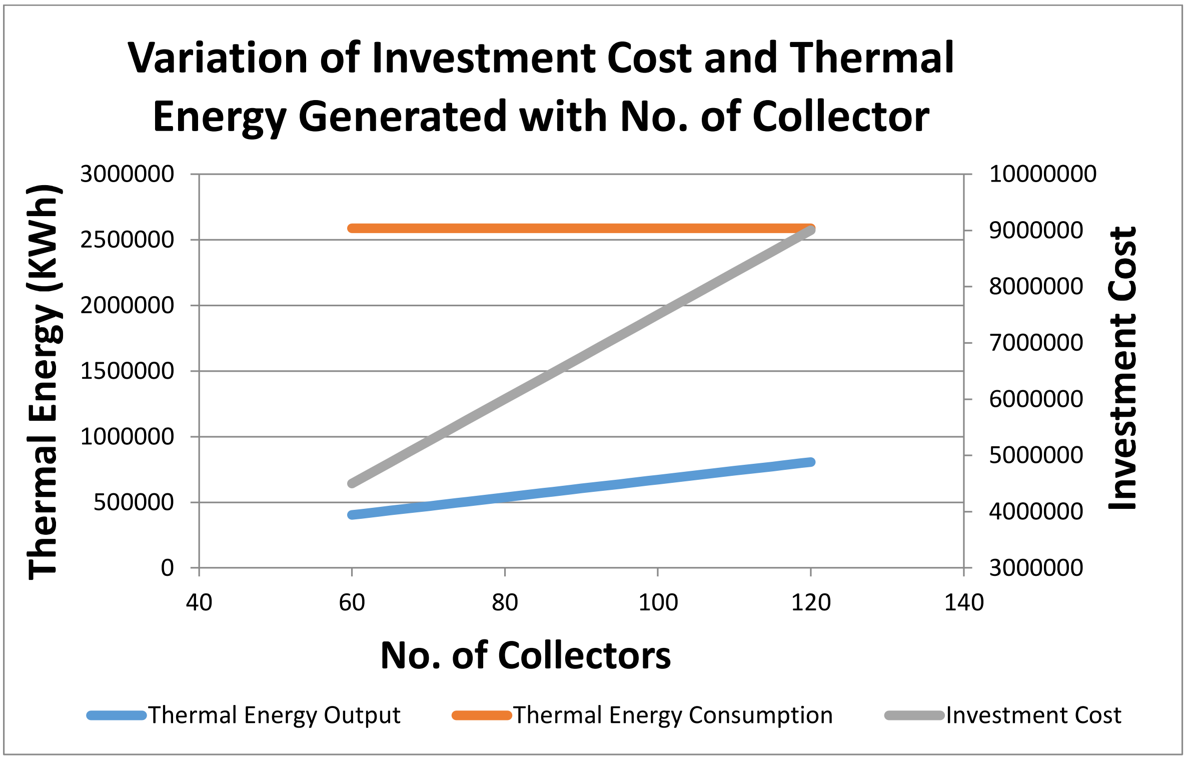

Figure: 6.6, Variation of Investment cost and thermal energy output with no. of Collectors

CHAPETER: 7 RESULTS AND CONCLUSION

7.1 Results and Discussion

After designing and analysis of parabolic trough collector for the solar industrial process heat system, we have integrated the system with current system in order to ensure smooth operation of the Industrial process. Large number of parameters has been studied for the system design and integrations such as Average thermal output, Annual energy consumption, Average solar potential, other important design parameters etc. Apart from the technical parameters, the economic viability and Cash flow results have been enlisted in the table below which play important role in its functioning and usage of the system: -

Table: 7.1, Results of present work planned for SIPH system using PTC at Vandana Chemicals, Ankleshwar

Design Parameters	Design/Output values
Length of Collector	4.22 m
Aperture	1.6 m
Focal Length	0.57 m
Rim Angle	70°
Inner Diameter of the Absorber Tube	0.066 m
Outer Diameter of the Absorber Tube	0.07 m
Inner Diameter of the Glass Cover	0.115 m
Outer Diameter of the Glass Cover	0.12 m
Emissivity of Glass Cover	0.86
Emissivity of Absorber Tube	0.65
Specular Reflectivity of the Concentrator Surface	0.935
Intercept Factor	0.95
Absorptivity -Transmissivity product	0.924
Mean temperature of the Absorber tube	210°C
Temperature of Cover	72.5 °C
Average Wind Velocity	4.5 m/s
Overall Loss Coefficient	13.635 W/ m^2 - K
Design Thermal output at DNI 1000 W/m^2	4.75 KWh
Thermal Efficiency at DNI 1000 W/m^2	44.67 %
Average Optical Efficiency	75.05 %
Overall Efficiency at DNI 1000 W/m^2	34.53 %
Average DNI available at Ankleshwar, Gujarat	5.58 KWh/m^2/day
Average thermal Output of Collector/day at Ankleshwar	28.989 KWh
Average Cosine Losses	8.68 %
No. Of Collectors used	82
Total No. Of Working days	290
Annual Thermal Energy Consumption / Demand	25,87,428.43

Total No. Of days with Sunshine	250
Annual Thermal Energy generation by PTC system	5,26,554.1661
Cost of thermal energy generated by Natural gas	Rs. 4.65/ KWh
Cost of System	Rs. 1,12,19,436.8
MNRE Subsidy	Rs. 29,93,328
Income Tax Benefit	Rs. 19,74,266.112
Investment cost	Rs. 62,51,842.688
Payback Period	2.55 Year
IRR	25 %
Solar Fraction	22 %

7.2 Conclusion

The present work gives an approval for the technical and economic viability of solar thermal technology in industry for the generation of Steam and other heat related activities. Non-Evacuated Tube Parabolic trough collectors are one of the matured and tested technologies which give promising results when used. In the present work, 22 % of the annual energy demand is being met by solar parabolic collectors and has high rate of return (25%) with a small payback period of 2.55 years. The above factors are positive signs for an investor and along with it reduced the dependence of the industry on imported fossil fuels. There is a large potential for this type of systems to be installed at chemical industry in India, thereby decreasing the emissions of the greenhouse gases in the atmosphere and lead towards sustainable development. The installation of Solar thermal system will help India in achieving its **100 GW solar mission** under **JNNSM** and meet the targets of reducing green house gas emissions pledged in **COP 21, Paris**.

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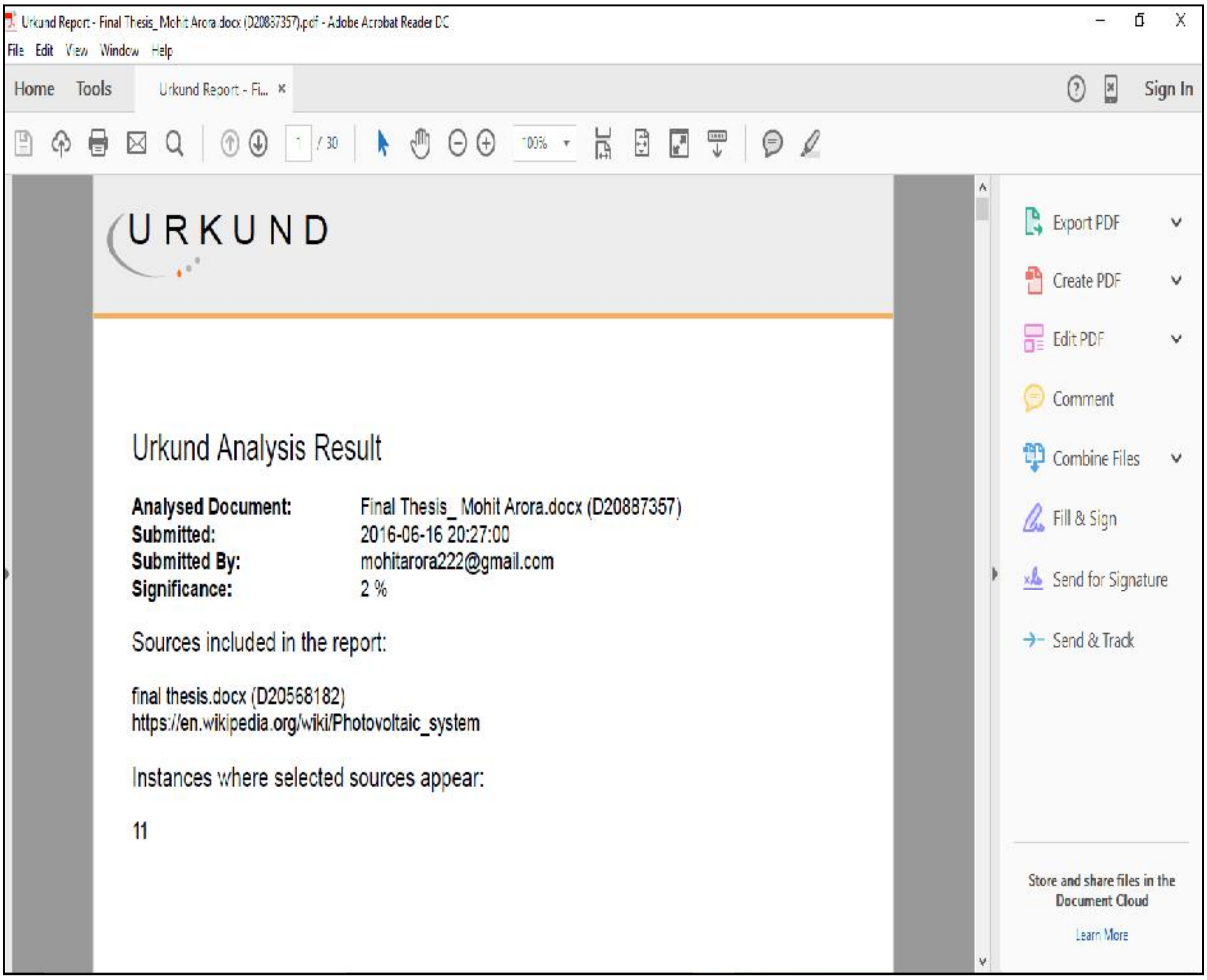
APPENDIX



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