International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 2 Issue 6, June-2013, pp: (42-50), Available online at: www.erpublications.com

Status of Parabolic Dish Solar Concentrators

Vanita Thakkar

Associate Professor, Mechanical Engineering Department, Babaria Institute of Technology,
BITS Edu Campus, Vadodara, Mumbai, India

Abstract: Concentrated Solar Power (CSP) Technology promises solutions to several problems in the present Energy Crisis and Global warming. Parabolic Dish Solar Concentrators have shown high conversion efficiencies and operating temperatures (around 750°C at annual efficiency of 23%-29% peak). Research is on, with some prototypes tested world-wide. Dish Engine Technology has high investment costs, almost twice as those for parabolic troughs. Dish Engine system industries and initiatives are mostly confined to the US and Europe. These facts, along with high potential for using Parabolic Dish Concentrators in various industries, especially in India, encourages research and need of development.

Solar concentrator for process heat requirements of community, industrial and commercial establishments is an emerging and exciting opportunity in India, which is gaining attention from scientists, engineers and developers. This paper traces development of Parabolic Dish Solar Concentrator Technology and explores scope of work in the field, with special focus on India.

Keywords: Concentrated Solar Power (CSP) Technology, Dish Engine Technology, Parabolic Dish Solar Concentrators, Solar Concentrators

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Introduction

Energy is a basic necessity of Life. Sun is the main source of Energy for Earth. Solar Energy converted and inter-converted to and from various forms, supports Life on Earth. The development of human ability to harness and utilize energy from various sources has had a major influence on evolution of Human Life and Civilization. Industrial Revolution resulted into great changes in energy conversion and utilization patterns [1], which brought about great changes in human life style, socio-economic and political conditions and environment, as well. USA has the largest per capita energy consumption in the world [2]. India ranks sixth in the world in terms of energy demand accounting for 3.5% of world commercial energy demand in 2001 [3]. The per capita energy consumption in India is less than that of most countries (290 kg per capita), even less than that of neighboring Pakistan (293 kg per capita) as per the records in April, 2001 at the Ministry of Environment and Forests [4], owing to high population. By 2030, the population of India will become more than that of China and by 2050, India will consume 1/3rd of the total global energy demand [5].

Energy Crisis and Global warming are glaring effects of the outcomes of those changes which commend urgent concern for developing and implementing cleaner and greener methods of sustaining Life. Solar Energy Technology has a major role to play in this context. Solar Energy can be utilized through Solar Photovoltaic and Solar Thermal Systems. Solar Thermal Systems can be Flat Plate type (for low temperature ranges) or Concentrator type (for medium and high temperature ranges), which show considerable potential as best options to overcome the crisis / problems. The use of Solar Concentrator Technology in various industries, including the Process Industry, which holds considerable potential in medium temperature applications, is in the process of gaining due attention from scientists, engineers and developers. The unexplored potential gives ample scope for Research and Development.

Energy Crisis and its solution: Renewable Energy – Solar Energy

The energy crisis facing the world today has left an open debate as to where the answers lie for the problem. It is no secret that fossil fuels will not last forever with the worlds growing hunger for energy. With the cost of fossil fuels raising on a daily basis it is becoming more apparent that renewable types of energy must be looked at as possible solutions to the problem. It only makes sense that we should look to the largest source of energy for Earth in the universe for some answers – Solar Energy, which is the basic energy from which all other forms of energy including fossil fuels, wind energy, biomass energy, etc. are obtained. Many experts believe that solar energy can play a huge part in meeting the world's energy needs [6].

Over the last few decades, there have been significant changes in the way people use the world's energy resources. There has been an increasing effort from governments, industry and academic institutions to find alternative sources of energy and to improve energy efficiency. This, plus an ever growing pressure from different sectors of society to reduce carbon dioxide emissions, has motivated the development of emerging technologies to reduce the dependence on fossil fuels and the optimization of existing systems in order to minimize energy consumption.

Solar energy is one of the alternative energy sources that has vast potential. It is estimated that the earth receives approximately 1000W/m^2 amount of solar irradiation in a day [7]. Abbot [8] shows that this amount of irradiation could generate around 85,000TW and estimates that the current global energy consumption is about 15TW. Taking into account the power obtained from all renewable resources as illustrated in Figure 1, he concluded that the solar energy alone has the capability to meet the current energy demand. This is confirmed theoretical calculation of Liu et al. [9] who estimates that by harnessing the solar energy from eight different solar power plant sites throughout the world, the energy generated from these plants has the capability to supply more than enough electricity to satisfy the present global energy utilization. These sites are located in the deserts in Southwest Asia, China, Australia, Southern South America, United States and Mexico.

Energy Source	Max. Power (TW)
Total surface solar	85 000
Desert solar	7650
Ocean thermal	100
Wind	72
Geothermal	44
River hydroelectric	7
Biomass	7
Open ocean wave	7
Tidal wave	4
Coastal wave	3

Figure 1: Power available from Renewable Sources [8]

Solar Energy Technology

There are two ways to harness energy from the sun. First is by using the concentrating solar thermal system. This is done by focusing the heat from the sun to produce steam. The steam will drove a generator to produce electricity. This type of configuration is normally employed in solar power plants. The other way of generating electricity is through a photovoltaic (PV) cell. This technology will convert the sunlight directly into electricity [10]. This technique is now being widely installed in the residential house and at remote places. It is also contributing to the significant increase in the development of Building Integrated Photovoltaic (BIPV) system.

However, despite numerous efforts done by the government and private sectors, solar energy only contributes to less than 1% of world's energy demand [11].

Some of the main drawbacks for the solar technology are due to the high investment cost and long payback period [12]. For an example, for an installation of a simple solar PV system, around 55% of the total cost comes from the PV module [13]. In terms of efficiency, only 15% to 30% of the sunlight is converted to electricity, depending on the type of semiconductor used in the PV. The highest efficiency recorded so far is by the Fraunhofer Institute for Solar Energy Systems, at 41.1% [14].

If we could reduce the cost of the PV module, or minimize its usage in the solar cell, while maintaining the same amount of output, it is feasible and affordable to use the solar technology.

Solar concentrator is the most favourable solution to this problem [15].

Solar Concentrators: Literature Review

Concentrating Solar Power (CSP) energy systems convert sunlight into electricity using parabolic mirrors capable of concentrating the solar radiation by a factor of over 13,000 for Stirling dish systems [16]. The concentrated solar energy is either focused on a photovoltaic module, or a receiver that absorbs the solar energy and transfers it to a working fluid such as a high temperature oil, molten salt, or hydrogen. The working fluid is then directly or indirectly used as the thermal source in a power cycle. Many of these technologies can operate with thermodynamic cycles similar to conventional power plants fueled by coal or natural gas; however, they have been modified to run off of solar energy as the primary fuel [17]. Solar concentrator is a device that allows the collection of sunlight from a large area and focusing it on a smaller receiver or exit. A conceptual representation of a solar concentrator used in harnessing the power from the sun to generate electricity is shown in Figure 4 [18].

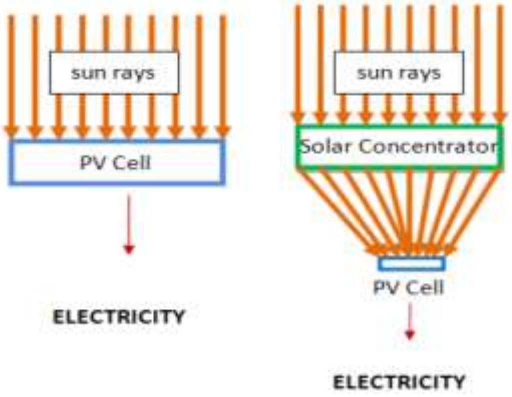

Figure 2: Generating electricity from the sun, with and without a solar concentrator [18]

The material used to fabricate the concentrator varies depending on the usage. For solar thermal, most of the concentrators are made from mirrors while for the BIPV system, the concentrator is either made of glass or transparent plastic. These materials are far cheaper than the PV material. The cost per unit area of a solar concentrator is therefore much cheaper than the cost per unit area of a PV material. By introducing this concentrator, not only the same amount of energy could be collected from the sun, the total cost of the solar cell could also be reduced. Arizona Public Service has concluded that the most cost-effective PV for commercial application in the future will be dominated by high concentration collector incorporated by high-efficiency cell [19].

Some of the benefits and drawbacks of using the solar concentrators are summarized below.

Benefits:

1. Reduce the dependence on silicon cell [20], [21], [22]
2. Increase the intensity of solar irradiance; hence increase the cell efficiency [20], [22]
3. Reduce the total cost of the whole system [20], [21], [22]

Drawbacks:

1. Degrade the PV cell lifespan [23]
2. Require mechanical tracking system [24], [25], [26]
3. Need to cool down the PV to ensure the performance of the PV is optimum [27], [28].

- For the past four decades, there have been a lot of developments involving the designs of the solar concentrators. Depending on their optical principles, Solar Concentrators can be categorized as shown in Figure 3.
- Figure 4 summarizes the advantages and disadvantages of each type of Solar Concentrators.

There are numerous projects implemented which make use of solar concentrators. These projects have been done by research centres, universities and companies to investigate and analyze the reliability and the performance of the concentrator. Figure 5 shows some of the projects which have been conducted throughout the world, showing the principal investigator's name and the location of the project. It presents the estimated output obtained as well as the overall efficiency of the system [18].

Type	Description
Reflector	Upon hitting the concentrator, the sun rays will be reflected to the PV cell Example: *Parabolic Trough, Parabolic Dish, CPC Trough, Hyperboloid Concentrator.*
Refractor	Upon hitting the concentrator, the sun rays will be refracted to the PV cell. Example: *Fresnel Lens Concentrator*
Hybrid	Upon hitting the concentrator, the sun rays can experience both reflection and refraction before hitting to the PV cell. Example: *DTIRC, Flat High Concentration Devices*
Luminescent	The photons will experience total internal reflection and guided to the PV cell. Example: *QDC*

Figure 3: Types of Solar Concentrators [18]

Type of Concentrator	Advantage	Disadvantage
Parabolic Concentrator	• High concentration.	• Requires larger field of view. • Need a good tracking system.
Hyperboloid Concentrator	• Compact	• Need to introduce lens at the entrance aperture to work effectively.
Fresnel Concentrator	• Thinner than conventional lens. • Requires less material than conventional lens. • Able to separate the direct and diffuse light - suitable to control the illumination and temperature of a building interior.	• Imperfection on the edges of the facets, causing the rays improperly focused at the receiver.
Compound Parabolic Concentrator	• Higher gain when its field of view is narrow.	• Need a good tracking system.
Dielectric Totally Internally Reflecting Concentrator	• Higher gain than CPC. • Smaller sizes than CPC.	• Cannot efficiently transfer all of the solar energy that it collects into a lower index media.
Flat High Concentration Devices (RR, XX, XR, RX, and RXI)	• Compact. • Very high concentration	• Difficulty to create electrical connection and heat sinking due to the position of the cell. • The cell dimension must be designed to a minimum to reduce shadowing effect.
Quantum Dot Concentrator	• No tracking needed. • Fully utilise both direct and diffuse solar radiation	• Restricted in terms of development due to the requirements on the luminescent dyes.

Figure 4: Summary of Advantages and Disadvantages of Solar Concentrators [18]

Name	Location	Concentrator type	Focus (Point/ Linear)	Output (kW)	Sun concentration $(X)^2$	Tracking (yes/no)	Efficiency of the system
Alpha Solarco,	Pahrump, Nevada, USA	fresnel lens	point	15	n/a	yes	n/a
AMONIX and Arizona Public Service	Arizona, USA	fresnel lens	point	300	250	yes	24.0%
Australian National University	Spring Valley, Australia	parabolic trough	linear	n/a	30	yes	15.0%
PETAL	Sede Boqer, Israel	parabolic dishes	point	154000	400	yes	16.5%
BP Solar and the Polytechnical University of Madrid	Tenerife, Canary Island, USA	parabolic trough	linear	480	38	yes	13.0%
Entech Inc	Ft. Davis, Texas, USA	fresnel lenses	linear	100	20	yes	15.0%
Fraunhofer-Institute for Solar Energy Systems	Freiburgh, Germany	parabolic trough and CPC[3]	linear and point	n/a	214	yes	77.5%
Polytechnical University of Madrid	Madrid, Spain	flat concentration devices (RXI)	point	n/a	1000	no	n/a
Photovoltaics International, LLC	Sacramento California, USA	fresnel lens	linear	30	10	yes	12.7%
Solar Research Corporation, Pty. Ltd.	Australia	parabolic dish	point	0.2	239	yes	22.0%
SolFocus	Ben Gurien University, Israel	paraboloid and hyperboloid[4]	point and point	0.25	500	yes	81%
SunPower Corporation	USA	fresnel lens	point	n/a	250 - 400	n/a	27.0%

Figure 5: Worldwide projects related to solar concentrators. Adapted from [15]

• Parabolic Dish Solar Collectors: The two dimensional design of a parabolic concentrator is equals to a parabola. It is widely used as a reflecting solar concentrator. A distinct property that it has is that it can focus all the parallel rays from the sun to a single focus point, F as shown in Figure 5. It is not necessary to use the whole part of the parabola curve to construct the concentrator. Most of the parabolic concentrator employs only a truncated portion of the parabola.

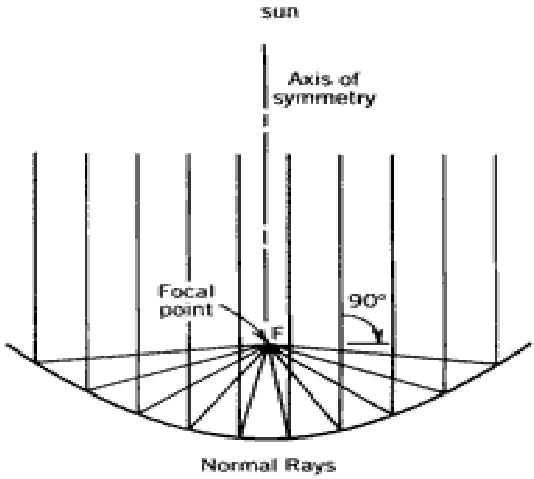

Figure 6: The sun rays are focused at the focal point of the parabola [29]

- Currently, there are two available designs of parabolic concentrator. One is by rotating the two dimensional design along the x-axis to produce a parabolic dish, and the other way is by having a parabolic trough. Both of the designs act as reflectors and are used mostly in concentrating solar power system in big solar power plant [29].

Although this concentrator could provide a high concentration, it requires larger field of view to maximize the sun energy collection. To obtain maximum efficiency, it needs a good tracking system, which is quite expensive. That is why this type of concentrator is not preferred in a small residential house [18].

Parabolic Dish Solar Concentrators have shown high conversion efficiencies and high operating temperatures, of the order of 750^{o}C, at annual efficiency of 23% and 29% peak [30], [31].

They are still in research stage, with only a few prototypes tested world-wide. Given the fact that autonomous operations and off-grid applications are the first priorities of this technology, more long-reference endurance test references need to be accumulated. Dish Engine Technology investment costs, which are twice as high as those of parabolic troughs [32], would have to be drastically reduced by mass production of specific components such as engines and concentrators. Dish Engine system industries and initiatives are basically confined to the US and Europe [17].

The dual-axis solar tracking is accomplished through azimuth-elevation tracking or polar tracking. Azimuth-elevation tracking rotates the concentrator in a plane parallel to the earth (azimuth) and in another plane perpendicular to the earth (elevation) [33]. For polar tracking, the concentrator rotates in a plane parallel to the rotation of the earth at a constant rate of 15 degrees per hour, and the declination axis rotates perpendicular to the polar axis by slowly varying between plus and minus 23.5^o over the year. Larger Stirling dishes have used azimuth-elevation tracking and smaller Stirling dish systems have used polar tracking.

Sector-wise Energy Consumption Patterns in the industry

A major portion of conventional energy sources – the fossil fuels, is expended in generation of electricity, which has found wide-spread acceptance world-wide because of the ease in its transmission and distribution and its interconvertibility to and from various forms of energy.

Industrialized nations use energy for : Residential / Commercial uses, Industrial uses, Transportation. Less developed countries use most energy for residential purposes : Cooking and Heating. Developing countries use much of their energy to develop industry. Industrialized nations have 20% of the world's population, but use 60% of the world's electricity. Per capita use in North America is 25 times greater than that in less-developed countries. It is worth noting that in North America, 75% of energy used for residential and commercial purposes is used for air conditioning and heating as well as water heaters. In India 57% of total energy is used for residential and commercial purposes [34].

Manufacturing industry accounts for about one third of total energy use worldwide. Roughly three quarters of industrial energy use is related to the production of energy-intensive commodities such as ferrous and non-ferrous metals, chemicals and petrochemicals, non-metallic mineral materials, and pulp and paper. In these sectors, energy costs constitute a large proportion of total production costs. So, the scope to improve energy efficiency tends to be less in these most energy intensive sectors than in those sectors where energy costs form a smaller proportion of total costs, such as the buildings and transportation sectors [35].

Industrial production is projected to increase by a factor of four between now and 2050. Although renewable energy has received a good deal of attention for power generation and for residential applications, its use in industry has attracted much less attention. Renewable energy plays only a relatively small role in industry today. Biomass currently makes by far the most significant renewable energy contribution to industry, providing around 8% of its final energy use in 2007. The present analysis of the long-term potential for renewable energy in industrial applications suggests that up to 21% of all final energy use and feedstock in manufacturing industry in 2050 can be of renewable origin. This would include contributions from Biomass feedstock and process energy, process heat from solar thermal installations and heat pumps. Figure 7 shows the regional and sectoral breakdown of biomass potential for process heat industry in 2050, excluding interregional trade [35].

It is important to note that industrial energy consumption differs significantly from that of other sectors, particularly residential and commercial. The industrial sector is relatively less dependent on purchased electricity than the commercial and residential sectors since it produces a significant fraction of its own power through direct fuel inputs and some industries, through cogeneration. A form of cogeneration is combined heat and power (CHP), which produces thermal and electric energy from a single fuel source [36].

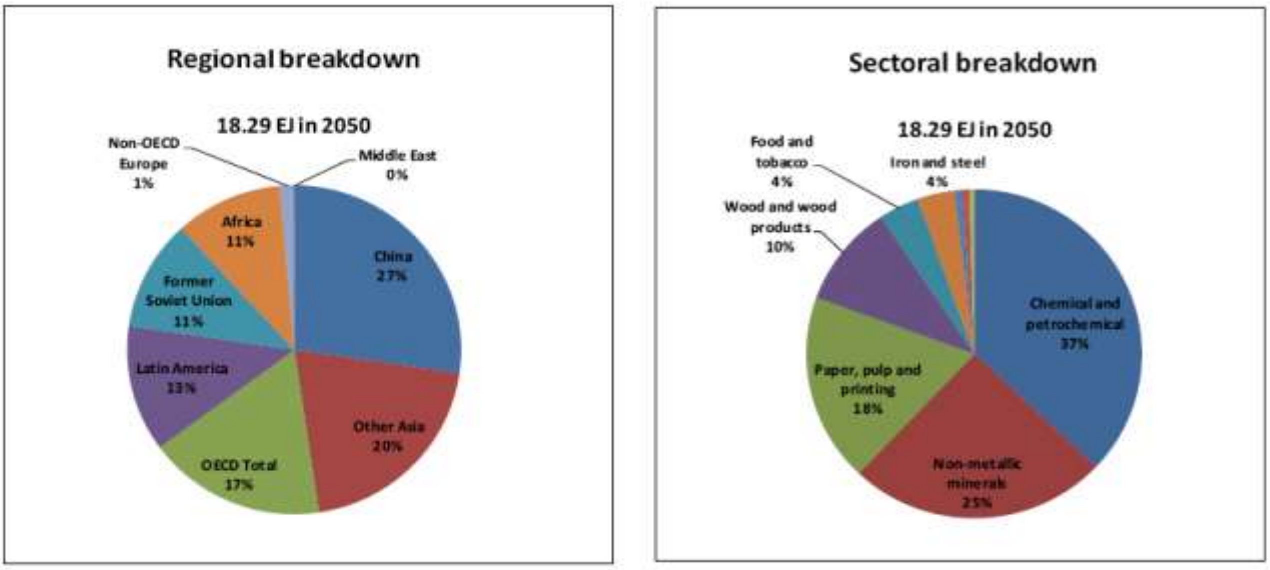

Figure 7: Regional and Sectoral breakdown of Biomass potential for process heat in industry in 2050, excluding interregional trade, UNIDO Analysis [35].

Sector-wise Energy Consumption Patterns in Indian Industries

Energy intensive industrial sectors can contribute to rapid scaling up of off-grid solar applications if they actively exhibit eagerness and willingness to substitute their energy requirement from conventional sources to solar energy. However, it is important to identify industrial sectors that possess significant potential for adopting solar applications to meet their process energy requirements in a commercially viable manner so that these industries act as successful demonstration projects with a high replication potential. Figure 8 shows Industrial Sectors Promising for Commercialization of Solar Energy in India, identified on the basis of the following parameters :

- Grade of heat required (high/low)
- Growth prospects of the sector
- Ongoing interventions in the sector

The identified sectors were ranked on the basis of a weighted parameter analysis considering the following parameters:

- Energy consumption
- Heating/Cooling load as percentage of total energy consumption
- Power Generation/DG sets/Captive Load
- Number and dispersion of units within a sector in India
- Past solar experience in identified sector

Each of these parameters was provided a weightage and each sector was given scores from 1 through 15 (15 being highest) against each parameter, to rank all the 15 sectors and arrive at the top 10. Sector specific data for each parameter was collected using extensive interactions and secondary research. The ranking for all 15 sectors is as shown in Figure 8 [37].

India consumes 100 Million Tons oil per year. Industrial Process Heat (IPH) applications up to 250°C use about 15 to 20% of this. If only 25 to 30% of this can be saved by putting up Solar Concentrators, it will save import of 4.5 MT oil per year. This is about 6% of our oil imports [38].

Sector	Total marks	Rank
Textile (Finishing)	900	1
Pulp and Paper	790	2
Pharmaceuticals	770	3
Leather	730	4
Food processing	730	4
Dairy	690	6
Textile (spinning and weaving)	630	7
Electroplating/Galvanizing	620	8
Automobile	600	9
Agro malls	500	10
Rubber	490	11
Breweries	480	12
Jute	370	13
Tobacco processing	300	14
Petroleum offshore rigs	290	15

Figure 8: Identification of Industrial Sectors Promising for Commercialization of Solar Energy in India [38]

Status of Parabolic Dish Solar Concentrators in India

In India, Dish Technology to harness solar energy for generating electricity is yet to get established. However, pioneering work on use of Scheffler Dish for SOLAR COOKING was done by Shree Deepak Gadhia of Gadhia Solar, Valsad, Gujarat to overcome the shortcomings of box type solar cooker (could only boil and roast the food) and mini concentrating dish type solar cookers (cumbersome outdoor usage). It was introduced for community cooking about two decades back and was successfully used for other applications like desalination, food processing, etc. Gadhia Solar supplied and installed several Solar steam cooking systems of different sizes ranging to cook from 500 to 40,000 people and for different user groups starting with temples and ashrams and Army, Hospitals, Industrial Canteens, Hostels etc. [39]

Parabolic collectors using thermic fluid as working medium were developed and are successfully working for cooking at Muni Seva Ashram, Goraj, Gujarat to overcome the limitations of steam as working medium – better thermal storage, transfer and control [40].

Some efforts initiated for use of Solar Concentrators in IPH in India, as can be seen from the following (apart from those by Gadhia Solar) :

Prototype design of solar parabolic dish collector with truncated cone shaped helical coiled receiver made up of copper, coated with nickel chrome at focal point. Instantaneous efficiency of 63.9% has been achieved in this system, which can be used for heating boiler feed water, laundry applications and other steam generation applications [41].

Development of ARUN brand of SCS for pasteurization of milk at Mahanand Dairy in Latur, Maharashtra [42].

A parabolic dish collector is developed from low cost technology and tested outdoors. The absorber, made of aluminum alloys and coated with black paint, is placed on the focal receiver. The calculated overall heat transfer co-efficient varies from 130 to 180 W/m^2K for actual climate conditions at Tiruchirappalli, India. The thermal efficiency of collector is found to be 60% and the cost is minimized to half the cost of a collector that is available in the market with same specifications [43]. The Megawatt System (MWS Solar Dish Concentrator) - A High Efficiency 2-Axis Tracking Concentrator: Megawatt is a Co. in Delhi, which has developed indigenous parabolic dish type collector of $90m^2$ area. Prototype has been built and is being tested at Solar Energy Center of Ministry of New and Renewable Energy (MNRE). Now, it is proposed that this technology undergoes field testing under R & D support of MNRE for industrial heating applications.

Universal Medicap Ltd. (UML) is an industry having 6×10^6 kCal biomass heated thermic fluid heating boiler. It uses thermic fluid heat at 195^oC in its process, which returns back to the boiler at 185^oC. 16 MWS dishes of $90m^2$ will be installed to produce heat during day time using solar concentrators and the existing boiler will be used as back-up.

The dish concentrator has an effective area of $90m^2$, has two-axes tracking and is a solid paraboloid concentrator that always faces the Sun with cavity absorber at point focus having thermal output capacity ranging upto 63 kWth and an operating temperature upto 500 with various working fluids including hot water, pressurized water, low pressure steam, thermic fluid. This is integrated with user-end thermal circuit for saving existing fuel. Components with ISI mark or reputed suppliers will be used wherever applicable and available.

System life: The Concentrating Solar Collector system, M90 is designed for 30 years life under standard operating conditions and regular maintenance as per the manufacturer’s instructions.

System De-rating: System performance derating is expected up to 1% per annum for initial 2 to 3 years and then, about 0.5% to 1% per annum depending on the site specific conditions. The author had visited UML to study the system there and to see the progress of the work. The MWS Solar Dish systems are under installation.

Conclusion

Solar Energy Technology has an important role to play in the present Energy and Environment crises. Solar Concentrator Technology has good potential for various applications. Parabolic Solar Dish Concentrators can be very useful in Industrial Process Heat applications, which use about 20% of total oil consumption in India. If only 25 to 30% of this can be saved by putting up Solar Concentrators, it will save import of 4.5 MT oil per year, which is about 6% of our oil imports. Scope of Research and Development is ample in this area, owing to the fact that very little work has been done on it. Most of it has been done in the US and Europe. With the help of indigenous developments in such fields, India can step forward towards self-reliance in Energy Sector.

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