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RECENT ADVANCEMENTS IN SOLAR FURNACE TECHNOLOGY

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ABSTRACT

As the pollution and climate change is a real concern, the whole world is looking for alternatives to the fossil fuels. This has led to an increase in dependance on non-conventional sources of energy like wind, hydro and solar. There has been increasing use of non-conventional sources of energy for achieving high temperatures. One such method is the use of Solar Furnace for reaching temperatures up to $3{,}500^{0}$ C. In this review paper, a brief overview of different types of solar furnace and their main components have been described. The various parameters affecting the performance, efficiency, and achievable temperature have also been discussed. Various solar furnaces operational around the globe are discussed in this paper such as Odeillo Furnace in France, Solar Tower in Jülich, Germany, solar furnace in Mexico and USA. The principle, working, and dimensional specification have been discussed along with the infrastructural placement. Various recent achievements and innovations in the field of solar furnace have also been presented.

Keywords: Concentrated Solar Power (CSP), Concentrator, Heliostat, Odeillo Furnace, Solar Furnace

I. INTRODUCTION

The rapid climate change has raised concerns regarding the rational use of conventional energy sources and development and use of non-conventional sources of energy. There has been extensive research in the field of energy, exploring sources of clean energy having minimum environmental impacts. Solar Energy, is by far, the greatest single source of clean energy which can be converted for use in various applications. Some of the ways developed for harnessing solar energy include passive and active solar heating, heliostat fields, solar furnace, et cetera.

Solar furnace is based on the principle of concentrating solar radiation or sunlight on a small area with the use of an optical system consisting of collector and heliostat, achieving high temperatures. The other name used for, Solar furnace, is solar energy concentrators due to its capability to produce high temperatures on a small area with concentrated radiations. Solar furnaces, fitted with large parabolic mirrors, the temperature attainable is close to 3,5000 Celsius. This is generally because of the use of a large number of strategically placed parabolic reflectors or heliostat onto a concentrator, leading to a large coverage of solar radiation field. The use of this method for harnessing solar power is gaining immense popularity with applications in wide industries.

The basic advantage of using a Solar furnace is the production of no pollutants, making it a clean source of energy. The application area includes solutions for heating water, space heating air conditioning, foundry applications, hydrogen fuel production, high-temperature material testing, and extensive research work. Some of the other methods capable of producing such high temperatures are exploding wires, detonations, induction heating, and many more. But all these methods, have possible drawbacks such as shortness of time, by-products produced and many more.

II. LITERATURE REVIEW

In the research paper, the authors discuss the temperature control architecture design and development methodology with analysis results and help of two experimental tests. Further, it has discussed the various parts used for the solar furnace model as well.

In the paper, a detailed study of heliostat calibration and tracking control methods is discussed with all the errors flawing the result and successful operation of the solar furnace. The various calibration systems have been discussed as well as classified.

The research paper provides a detailed project report of the construction, assembly and testing of a 5 KW solar furnace developed by students over time. The complete description of steps involved in the completion of the project have been discussed along with detailed results and analysis.

In this paper, author has described the optical structure design for a solar furnace. Monte Carlo simulations were done to gauge the influence of the optical factors on the concentrated solar heat flux distribution. Heliostat optimum tilt was studied and the errors associated with the measurement of these optical parameters effect were discussed. Results were drawn comparing the experimentally measured irradiance with the simulated results.

In this paper, the author has discussed the working of Odeillo Furnace and its parts along with their dimensions. The dynamic heliostat mounting mechanism has been discussed. An experiment to study the heat flux distribution along with graphical outcomes is also discussed.

The author has discussed the Mexican high radiative flux solar furnace in this paper. The parts along with their dimensions have also been discussed. The two tests that were initiated with the operation of HRFSF, the acquisition of images on a Lambertian target and the melting of metals is covered and the experimental setup is briefly discussed. The results of the two tests have been discussed along with the relevant graphs.

In this paper, Mexican solar furnace along with its infrastructural properties is discussed. The hexagonal mirrors for the spherical frame have been discussed along with spherical aberration and reorientation facets. The heat flux distribution has been studied along with all the irradiance, receiver and collector graphs.

The author has discussed the SERI's high flux solar furnace. Its unique design has been discussed along with dimensional parameters. Single stage and two stage performance of the furnace has been discussed. Accentuator, computer hardware, computer software and data acquisition software parameters have been discussed. The heat flux distribution has been discussed along with relevant graph plots.

In this research paper, various case studies of solar furnace around the world is discussed, their parts and specifications. Concentrated Solar Power generated cooking system for the midday meal system in Delhi is considered and a theoretical analysis is done for the load calculation and economic feasibility.

The author discusses about the transient simulation solar tower concept with open volumetric technology. The open volumetric technology receives air as heat transfer fluid and it is used to convert electricity by using a gas turbine. This model is being developed for a location Barstow-Daggett, USA. Simulation is performed in MATLAB and its performance has been studied.

The author has described the modeling of a high temperature storage system with open volumetric receiver technology, in which air is used as heat transfer medium. Thermal energy can be stored and release as per the requirement via HTF air. The storage model was developed in MATLAB.

In this paper, the author has discussed the brief history of solar furnace and the various experiments that have been conducted and innovative ideas which are being pursued, the advantages and difficulties of concentrated solar radiation is discussed. The present opportunities and future trends are also presented.

III. BRIEF HISTORY

The application of solar furnaces is not new and many researchers have studied it over time. It was Archimedes in 212 B.C. who used this principle to destroy the Roman fleet by concentrating solar radiations using a large number of mirrors. Over the 17th and 18th centuries, the use of both lenses and mirrors were explored. Lavoisier was successful in building a solar furnace with a diameter of 5 feet and was successful in attaining the melting point of platinum. It was in 1921, Straubel constructed the first reflecting type modern furnace attaining a temperature close to 3,0000 C. Another example is of Aluminum Alloy sheet Solar furnace operational at Convair for the study of "High-Temperature Materials". However, the largest solar furnace is located at Montlouis, France. It has a 6.5 feet diameter parabolic searchlight mirrors and the number of such furnaces is six. It also has a large 35 feet diameter solar furnace with attached 3,500 small mirrors attached in a parabolic shape steel frame. Similarly, a 27 feet diameter solar furnace was built in Algiers consisting of 144 electropolished aluminum panels shaped in the form of a parabola.

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IV. TYPES OF SOLAR FURNACE

Solar furnaces can be classified mainly into Direct Solar furnace and Heliostat Solar furnace. Direct Solar furnaces have a simpler principle, using a lens to converge the direct light to the focal point. The light concentrated at the focal point acts as a furnace.

4.1 Direct Solar Furnace

Direct Solar Furnace can be further divided into various types.

4.1.1 Single Lens Direct type

This type of Solar Furnace does not have practical applications. This acts as an example for explaining the principle of the solar furnace. It includes a single lens for converging or concentrated the light at the focal point increasing its temperature.

4.1.2 Multiple Lens type

In this type, multiple lenses are used to focus light through the first series of lens. This then converges to the focal point through the second row of lens using plane mirrors as the means to direct the path towards the focal point i.e., the furnace.

4.1.3 Single Parabolic Direct type

This is also one of the simplest types where instead of a lens, a parabolic mirror is used to reflect the light towards the focal point.

4.1.4 Lens-type furnace

In Lens type Solar Furnace, an arrangement of multiple lens and mirror is used for focusing sunlight. The basic process can be defined as, the incident rays get refracted from the first lens, traveling towards the second lens. Any incident rays which might be moving outside get reflected by the mirrors located. After passing through the first lens, the rays get refracted from the second lens, converging at a single point or focal point of the whole apparatus.

These types of solar furnaces were used in the very early days of discovery. This type of solar furnace cannot change its position or keep track of the sun as the day progresses, which is a big disadvantage. Thus, they became obsolete leading to the development and introduction of heliostats. The use of heliostat in solar furnaces allows its application in heavy industrial applications where high temperatures are involved. This type of solar furnaces has a high investment cost which gets compensated by its low operating cost.

4.2 Heliostat Solar Furnace

Heliostat Solar furnaces are further divided into multiple types depending upon the orientation of the optical axis.

4.2.1 Heliostat Optical Axis Horizontal

In a Horizontal axis heliostat solar furnace, a plane mirror acting as a heliostat reflects the solar rays coming from the sun to a parabolic mirror. The reflection from the mirror makes the rays parallel and horizontal to each other. The rays reflect from the parabolic mirror and converge at the focal point which acts as the receiver. Odeillo solar furnace uses this principle for solar concentration.

4.2.2 Heliostat Optical Axis Vertical

In a vertical axis heliostat solar furnace, the heliostat reflects the sun rays directly falling on it to the parabolic mirror in such a way that the rays become vertical after reflection and converges to the focal point, acting as the receiver.

4.2.3 Heliostat Optical Axis Horizontal and Vertical

This is a hybrid version of the horizontal and vertical optical axis heliostat and can be used for customized design and applications.

V. MAIN PARTS

The main parts of a solar furnace are discussed below.

5.1 Heliostat

Heliostat is an instrument whose function is to focus sunlight continuously in a fixed direction. In a solar furnace, the heliostat tracks the sun and orients itself directing the sunlight to the concentrator. This leads to the stabilization of the sun's rays, allowing it to focus at a particular spot for optimum performance. In general, heliostats include plane and parabolic mirrors whose orientation is maintained with the help of controllers and encoders.[1] The categorization of a heliostat based on the mounting of the actuators, serial and parallel. In a serial type, the heliostat has a simple design and control but with reduced stability. Whereas, in the parallel type heliostat, provides increased stability. The mode of operation for a heliostat system is classified as closed-loop and open-loop control mode. The open-loop control mode is used by heliostats which are rigid and whose properties like geometry, rigidity, transmission ratio, etc. are maintained between successive calibrations. The closed-loop control mode is used for non-rigid heliostat and it tracks the sun's position accurately. Its fast control provides low errors in operation. The desirable properties in a heliostat used in concentrated solar power plant are high reflectivity, high optical precision, high tracking accuracy, and resistant structure.[2]

5.2 Parabolic Concentrator

The function of the parabolic concentrator is to concentrate or direct the solar energy at a particular location known as the focal point. The concentrator has several curved mirrors that help in focusing sunlight at a particular spot. The construction of a parabolic mirror as a whole is not feasible and economical.[3] Hence, many plane or parabolic mirrors are attached to the concentrator for operation. The use of several mirrors allows the incoming reflection to be focused on the collector, usually located in a tower. Although the concentrator may not be able to concentrate sunlight on a single spot, the focus area can be considered to be a circle or an ellipse. The sun rays reflected from the heliostat are focused on using the parabolic concentrator. The compound parabolic concentrator can be categorized as symmetric and asymmetric. The absorbers employed in concentrators are generally tubular and fin-type with pipe absorbers.

5.3 Attenuator/ Shutter

The attenuator is used to reduce or change the power quickly being transmitted. It regulates the amount of sunlight transmitted, thus, changing the power according to requirements. The response of the shutter should be fast and it depends on several factors such as the size of the solar furnace, location, and material. The panel used for the attenuator is generally made from aluminum. The control of the attenuator is digital, allowing it to send commands for changing the position and energy transmission.[1]

Some of the other parts of the solar furnace include the test table or reactor table. It can be defined as the location of placing the specimen in testing applications. It also consists of measurement sensors, high-temperature receivers, and reactors.

VI. PARAMETERS AFFECTING SOLAR FURNACE

The basic principle or functionality of a solar furnace is to achieve high temperature at a point, generally the focal point, by accumulating or concentrating solar radiation at that particular point. For the successful operation of a solar furnace, there are three main parts to be considered, i.e., Heliostat, Parabolic Concentrator, and Shutter.

In designing a solar furnace for a specified heat flux at the target, there are two classes of factors (theoretical and operational) which are to be considered. Both have their fair share in deciding the performance of the furnace. The first class relates to the optical geometry of the concentrator and includes six important design variables:

- Aperture
- The Ratio of aperture to focal length
- Image Diameter
- Average heat flux at the image
- Uniformity of flux distribution at the image
- Efficiency at which energy received by the concentrator is concentrated.

The six design variables considered, define the theoretical characteristics and the operational characteristics, and are the ones that help in estimating the working efficiency. [4]

The operating performance of a furnace depends on all three parts. However, the concentrator is the heart of all the process and determines the operating efficiency of the furnace. Despite continuous support for the revolution paraboloid as the ideal design for the concentrator, the considerable cost in its manufacture and its time-consuming testing are crucial parameters to be looked upon for its commercial application, besides, its extremely high demands in precision. Thus, a practical and economical alternative is using a faceted structure covered with identical curved mirror arrays. This is a more viable option and is commonly used around the globe. The overall performance in these types of concentrators depends on facet sizes and optical errors.

To judge the performance parameters, total heat flux distribution is studied and parallel conclusions are drawn. The Monte Carlo ray tracing (MCRT) method is very flexible and has been proved to have great accuracy and so is generally followed. This simulation gives four verticals of error according to which the performance of the furnace varies.

- First, the tilt error of the heliostat, which originates from heliostat facets deviating from the ideal plane.
- Second, the slope error of the concentrator, which refers to the irregular deformation of reflecting curves of the concentrator facets by the surface adjustment approach.
- Third, the layout error of the concentrator, which is caused by the same or similar shape of facets attached to the concentrator frame.
- Fourth, the tilt error of the concentrator, which arises from concentrator facets tilting.

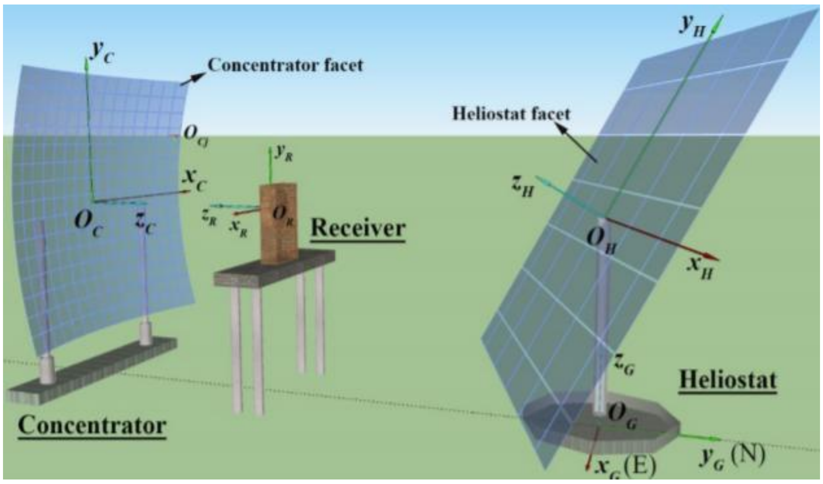

Fig.-1: Schematic structure and placements of components in a solar furnace concerning their respective coordinate systems. [4]

The main components of the optical system and receiver are placed on the same line, joining the center of the concentrator and the center of the heliostat. The tilt error of heliostat affects the non-parallelism degree of the reflected sunlight. As the error increases, both the concentrated heat flux distribution and spot does not meet in a line, i.e., they are diverging.

The FEM (Finite Element Method) is used to obtain the curved surface of the concentrator facet. The slope error of the concentrator results in the mirror unit no longer acting as an ideal surface, but rather as a complex and irregular one under constraints. The error in factors of 1~2 mm could greatly reduce the concentration ability. The layout error occurs when facets attached to the concentrator frame share a similar curvature. Its existence will not enlarge the influence of the slope error. The tilt error of concentrator facets directly affects the focusing effect. As the tilt error increases in a particular direction, heat flux along the direction scatters, while in the orthogonal direction, it maintains in the desired shape, i.e., the gaussian shape but the overall value decreases. [4]

Hence, the deviation in the mountings from the desired axis leads to errors, and as a result, the overall efficiency of the plant decreases. Apart from the mounting parameters, there are certain things regarding the components that should be kept in mind to be able to have smooth functioning.

Heliostats are computer-driven devices tracking the changing direction of sunlight as the day progresses, maintaining uniformity in the direction of the rays falling on the concentrator. It is operated in two modes, the open-loop control mode, and the closed-loop control mode. The quantity of light reflected by the heliostat depends on the area and cleanliness of the mirror. The cleanliness of the mirror decreases with time due to dust deposition and requires timely cleaning and maintenance. Depending on the time of day and dust level on the heliostat, the reflected power can vary between 85% to 90% of the available sun's power. [4]

VII. OVERVIEW OF SOLAR FURNACES AROUND THE WORLD

Many operational solar furnaces projects around the world are used for various industrial and research applications. Some of them are covered in this review paper.

7.1 Odeillo Furnace

Odeillo Furnace, the largest solar furnace in the world, is situated and operational in the south of France in Font-Romeu-Odeillo-Via, in the department of Pyrénées-Orientales, region Languedoc-Roussillon. It was built between 1962 and 1968 with operation starting in 1969 and has a power of one megawatt. The measurement facts of the solar furnace are, 54 meters (177 ft) in height and 48 meters (157 ft) width, consisting of 63 heliostats.

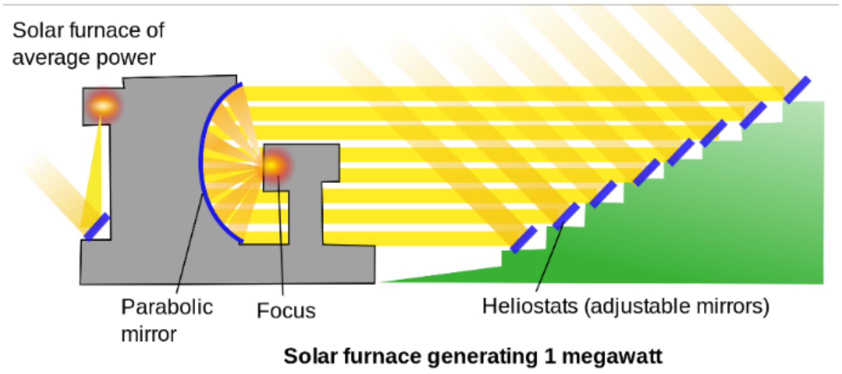

Fig.-2: Depiction of working principle

The reflecting mirrors, Heliostats, 63 in number, each having 45m² surface with 180 single mirror panes, placed in a step-wise fashion, reflecting sun rays to the concentrator. The solar furnace consists of a parabolic mirror, acting as a concentrator that converges the light on the specified target known as the "focus".[5]

The heliostats are automatically operated by photoelectric control of their reflected rays. The driving parts that are electronically coupled with the photoelectric control are hydraulic.

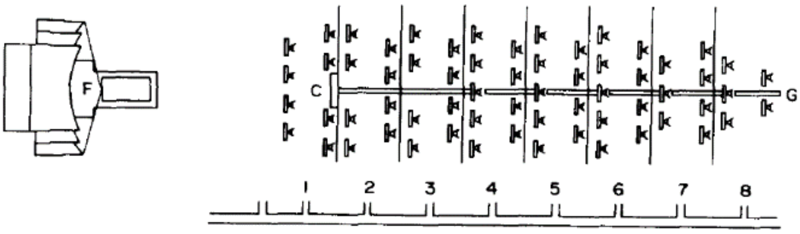

Fig.-3: Schematic diagram of the furnace [5]

The above figure is the top view of the setup with point C representing the station of oil under pressure that acts on the site, and the azimuth of the heliostats through a tunnel, denoted by point G. Each orientator is made up of 180 flat glass panes, back silvered and covered with copper and varnish. The apparent diameter is also taken into consideration while positioning the respective heliostats. This helps in achieving a coherent beam of sunlight that would be comparable to the beam that would be given by a single large orientation.

The parabolic mirror is fixed and has a focal length of 18m, 54m wide, and 40m high. It includes 9500 flat plate glasses, curved and adjusted under mechanical constraints which helps in getting an image with minimum dimension. [5] Regarding the distribution of flux density, an experiment was conducted in 1970, in which a vertical plane was located at 18m from the apex of the paraboloid. The conclusions derived, the energy distribution on the plane was rather elliptic than circular as shown in the figure, and that the distribution remained practically unchanged when the receiving plane was tilted up from the vertical position to a 25 degrees inclined position. [5]

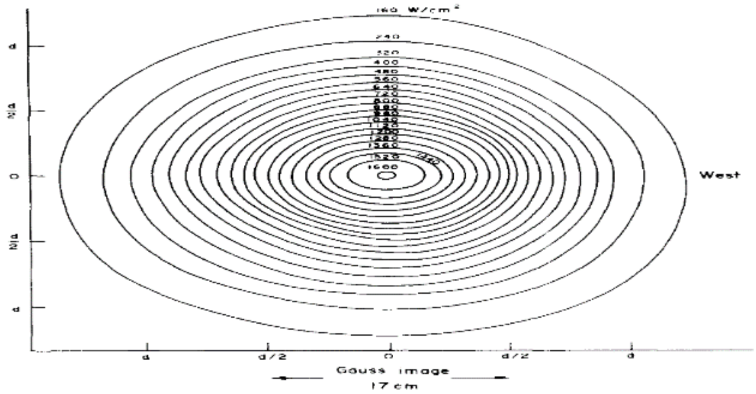

Fig.-4: Distribution of heat flux density on a vertical plane [5]

Owing to the number and the size of heliostats, and the dimensions of the mirror, this furnace concentrates energy that makes it reach a peak of 3200KW. The long-running success of this furnace lies in the fact that the energy densities achieved are comparable to the radiations of a blackbody at a very high temperature. To express this quantitatively, the equilibrium temperature at the center of the focal image would be higher than 4000 K.

7.2 High Radiative Flux Solar Furnace (HRFSF)

A high flux solar furnace facility has been operational in Mexico, located in Temixco, Morelos, Mexico. The installation was officially inaugurated on 18th March 2011. The first stage of the furnace was finished and started up in December 2011. [6]

The design of this furnace considers the intercepted power of approximately 30 KW with a peak concentration of 10,000 suns. The dimension of individual parts are as follows: heliostat of 81 m^2, a shutter made of stainless-steel blades 6.2m^2, and a concentrator of 409 spherical mirrors with hexagonal contours mounted on a spherical frame, and an equivalent focal length of 3.68m. [6]

Fig.-5: Showing Heliostat and Shutter on the left and Concentrator on the right [6]

The left side of the above figure shows the heliostat and shutter and the right side shows the concentrator.[7] As the site of the furnace has a low latitude as compared to the other existing facilities, a large heliostat is required, to illuminate the concentrator for a sufficient number of hours; three hours at least in the summer solstice and eight hours at least in the winter solstice. This facility can reach temperatures as high as 3680 K.

7.3 Solar Powered High-Tech Furnace

The solar-powered high-tech solar furnace is operational in Valparaiso University, Indiana, USA. The solar furnace consists of six main parts as shown in the figure below.

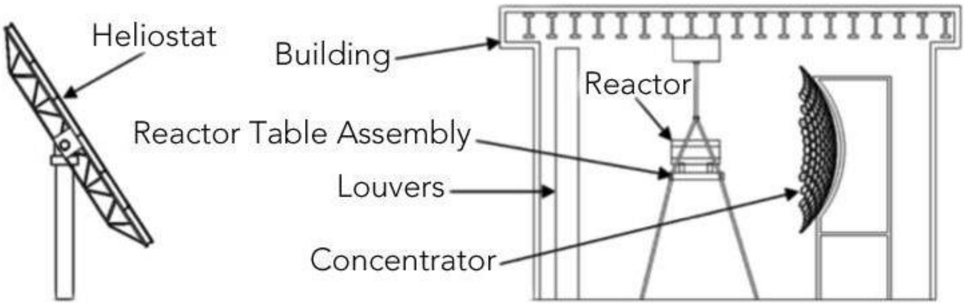

Fig.-6: Schematic diagram of the high-powered tech solar furnace

The heliostat is located in front of the furnace building and is a flat mirror measuring 20-foot by 20-foot, mounted on a pedestal outside the oval-shaped building that houses the furnace. The heliostat tracks the sun reflecting the light to the concentrator which focuses it at the focal point. The concentrator at the Markiewicz Solar Energy Research Facility consists of 306 curved mirrors. The light reaching the concentrator is regulated by a set of louvers placed in between the heliostat and the concentrator.

In this furnace, the point where all the light from the concentrator is focused, a solar thermal reactor is located. The resulting steam drives an electricity-generating turbine. This furnace is capable of generating equal to and beyond 3000 degrees Fahrenheit within the reactor.

Researches on this solar furnace, as of now, are two. First, converting water into the fuel hydrogen - Solar thermal decoupled water electrolysis project being conducted. The second one, splitting zinc oxide into zinc and oxygen, without producing any waste. Zinc can be used in a fuel cell to generate electricity or as a commodity.

7.4 High Flux Solar Furnace (HFSF)

NREL's High flux Solar Furnace (HFSF), a unique 10KW optical furnace has been in operation since December 1989 and is under the Solar Energy Research Institute (SERI). It is situated at the top of NREL's South Table Mountain campus. HFSF has supported several research experiments since it became operational.

In terms of major achievements, in July 1990, SERI researchers produced the first high-temperature superconducting material at the HFSF. Detailed measurements indicated zero resistance at 74.4 K. [8]

Fig.-7: High Flux Solar Furnace

The high performance of this furnace can be attributed to the uniqueness of its design. HFSF is capable of achieving extremely high flux concentrations in a two-stage concentration and has the capacity of generating a

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wide range of flux concentrations. It consists of a stationary focal point and is movable off-axis. This off-axis system allows considerable flexibility in size. The figure below depicts the schematics of the HFSF. [8] This furnace consists of a tracking heliostat and 25 hexagonal concave mirrors that concentrate solar radiation to deliver 10 kilowatts of thermal power to a focal area about 4 inches (~10 cm) in diameter within the laboratory control room. The solar furnace can quickly concentrate solar radiation to 10 kilowatts over a 10-cm diameter (2500 "suns"), achieving temperatures of 1800°C and up to peak solar fluxes of 20,000 suns with specialized secondary optics to produce temperatures of up to 3,000°C. Secondary concentrators can modify the focal point, tailor flux levels, and distributions to suit the needs of each research activity. [8]

The HFSF facility also consists of instrumentation to monitor solar radiation levels, automated controls to adjust the power of concentrated sunlight, data acquisition tools, and video monitoring of outside equipment. The HFSF concentrates actual sunlight, it offers an energy-efficient alternative to solar simulators, with tests performed under realistic rather than simulated conditions.

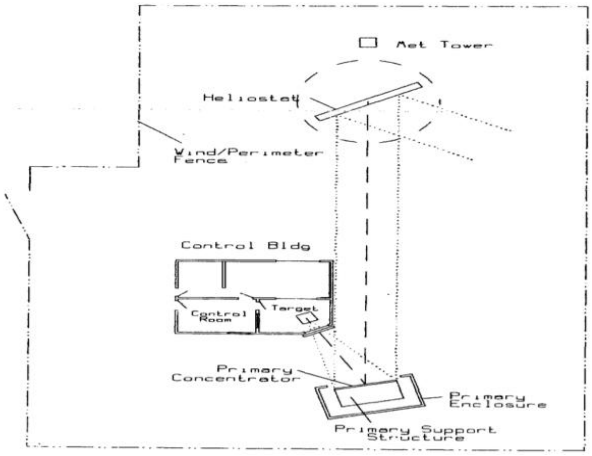

Fig.-8: Schematic Diagram of HFSF [8]

7.5 Jülich Solar Furnace

Jülich Solar furnace is located in Germany and is the first solar furnace constructed for experimental purposes having a power generation capacity of 1.5 MW. The construction of this furnace began in 2007 and it was inaugurated in the year 2009. [9]

In the solar furnace, the open volumetric receiver technology uses ambient air as heat transfer fluid (HTT). Ceramic absorber modules are used which are heated up by the concentrated irradiation. Air is sucked through the ceramic particles heating it to 680° C. This heated air is used further to generate electricity in a steam power plant using Rankine cycle. [10]

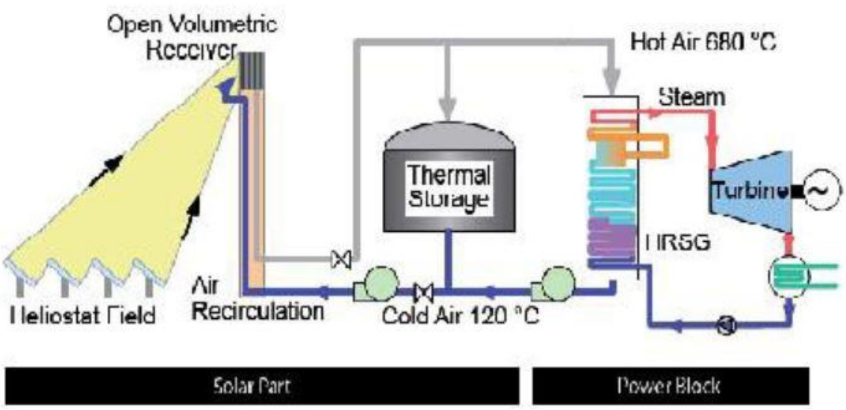

Fig.-9: Schematic Diagram of Jülich Solar Furnace [11]

The additional energy gets stored in a chamber since storing thermal energy is comparatively easy than electricity. This stored energy can be used at night or at unexpected times such as when the weather is cloudy or other factors. The heat transfer coefficient of air is low; therefore, the efficiency isn't too great for this solar furnace. [11]

The solar furnace consists of 2153 heliostats, with an individual aperture area of 8.2 m^2, making a total area of 17650 m^2. There is a 60m tower housing the concentrator, which is connected to the steam turbine to generate electricity. The cooling method used is dry cooling, whereas, the heat storage capacity is 1.5 hours. The turbine used is of 1.5 MW capacity.[9]

Fig.-10: Jülich Solar Furnace [11]

7.6 Recent Development in Concentrated Solar Energy in India

There have not been any large solar furnace projects in India as compared to the likes of Odeillo and Jülich. However, an increase in research and development in this area has led to the development of various sizes of solar furnaces and concentrated solar power projects in the country. One such project is being developed by Shri Shakti Alternative Energy Limited along with Solar Technology Advisers and Swarg Vatika Crematorium. They aim to develop a solution to decrease the consumption of LPG and biomass by using concentrated solar energy.

The operational projects using concentrated solar power principle as an energy source are Tirumala Tirupati Devasthanam kitchen at Tirupati, where 73 parabolic concentrators are used for heating water to a temperature level of 550^o to 650^o C. This leads to a production of 3600 Kg steam every day, saving about 100,000 kg of cooking gas per day. Another project is ACME solar plant, located in Bikaner, Rajasthan. It consists of 14,280 heliostats with each heliostat having an area of 1.136 m^2. The total Heliostat Solar-Field Aperture Area is 16,222m^2 and the plant has a power generation capacity of 2.5MW. [9]

VIII. INNOVATIVE RESEARCH AND ADVANTAGES OF SOLAR FURNACE

There have been various research projects undertaken in this field. Some of the projects or innovations around the world have been discussed.

8.1 Process Chamber for Thermal Dissociation of ZnO

The group based in Switzerland performed research studies and projects dealing with the thermal dissociation of ZnO. The objective was to perform redox cycle in two steps: the dissociation of ZnO using solar energy at a temperature above 2000K and oxidation of Zn with H_2O/CO_2 to produce H_2/CO. Zn which is recovered can be used to split H_2O and byproducts can be used in power generation in a fuel cell. [12]

8.2 Glass Production and Melting

The raw material of lunar origin contains high silica, content slag, and calcium oxide and is present in abundance on Moon. Due to the high cost of transportation of materials from Earth, NASA in 1979 was motivated to use solar radiation for the onsite production of glass. The research included static and semi-continuous melting experiments. Initially, in the static melting experiment, a powdered soda-lime-silica glass was used and it was shown that the crystalline raw material transformed successfully into a transparent glass. After the small-scale demonstration, the author concluded that significant research and experimental work is required before commercial feasibility can be evaluated. [12]

8.3 Solar Heat for Cement Production.

Here the author brought the focus on the CO_2 emission in the whole world. In the whole world, CO_2 production can be classified broadly into two categories: Natural and anthropogenic. Considering the anthropogenic category, which is majorly produced due to the burning of fossil fuel, cement production, and farm plowing. The burning of fossil fuel can be decreased by using non-conventional alternatives such as wind, hydro and solar energy. In the cement production, the global production of Portland cement was about 4.05 Gt in 2017 and 4.10 Gt in 2018. The manufacturing of Portland cement results in the production of CO_2 due to the decarburization of limestone.

An interesting approach to reduce the emission of CO2 can be by using a directly irradiated fluidized bed reactor to produce lime for cement production. In the research paper, the author presented a conceptual design of the reactor for the production of Portland cement where concentrated solar energy was used in a conical hole, in a cylindrical reactor. The gases produced can be collected and treated for heat recovery. [12]

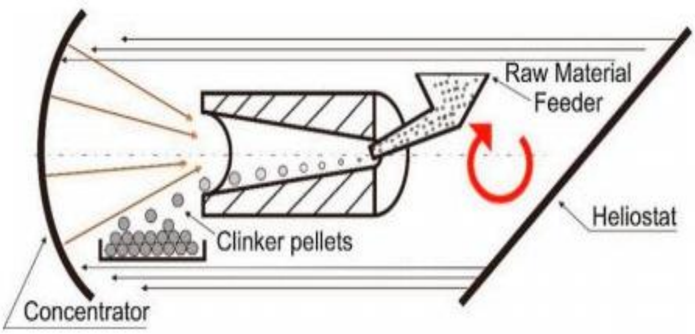

Fig. 11: Conceptual design of reactor [12]

8.4 Rapid Heating and Thermal Cooling

The rapid heating and thermal cycling are undoubtedly one of the significant advantages of the solar furnace over other traditional technologies. The rapid cycles of temperature variation at the surface of the workpiece are hard to achieve by electric resistance furnace, induction furnace, and other furnaces whereas in solar furnace this is achieved easily. Also, the solar furnace does not have any environmental impact like the other methods. [12]

8.5 Wide Spectrum of Radiation

Solar radiation consists of a very wide spectrum, from ultraviolet to infrared radiation, including visible spectrum which is not seen in many artificial sources like X-rays, microwaves, electromagnetic waves in the radar. Solar radiation and solar furnace have extensive applications in studies involving phenomena occurring on materials and structures. [12]

8.6 Difficulties in Concentrated Solar Radiation

- Solar Radiation is dependent on various factors like latitude, weather conditions, and time of the day.
- After concentration, the solar radiation becomes unidirectional thus heating the component in one direction.
- The flux of solar radiation at the focal point is non-homogeneous theoretically. [12]

IX. CONCLUSION

The new vertical of clean and environment-friendly energy sources led the world to shift from conventional sources like fossil fuels to renewable sources like solar, wind, and hydro and the past few decades have seen an unparalleled rise in the solar energy sector. India is blessed geographically that it lies near the equator and as a result, receives one of the highest solar irradiations on earth.

Solar Furnace has been an alternative for higher temperature production in many fields but due to the capital investments and logistics involved, it is yet to be used at its full potential in India, and though the work in this direction is being carried out, we need a Public-Private Partnership (PPP) model that can back up the shortcomings associated with a large-scale solar furnace such as Odeillo Furnace in France and this falls in line with the Paris Agreement that we be more cautious towards the climate change.

The Solar furnace has the potential to replace the furnaces used in metallurgy, cupola furnace, for example, that uses coal as a source of heat and other such applications where high temperatures are involved and this replacement accentuates the fact that the target of 100 GW solar energy by 2022 could be met.

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