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Concentrating Solar Energy for Steam Generation and its Application in Mega Kitchens

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Abstract

India is a vast country with many mega kitchens where cooking for a large number of people is done. This requires a lot of fuel to burn to cook food daily. Most large kitchens use LPG as fuel. The same can be achieved using a Scheffler dish based heating system, wherein the conversion of water to steam would occur by using solar heat. This system would require a large initial investment, but it would be compensated with a short payback period, leading to increased profits due to decreased operating costs. Also, this system would be non-polluting, leading to less stress on the environment. The major drawback in the operation of this system is the availability of Sun only in day hours.

In contrast, the food is being cooked in the early morning before the Sun and in the evening after the Sun has set and also the rainy days. This could be tackled in two ways, First by integrating the Scheffler dish based heating system with the existing LPG supply, so that LPG can be used at times when there is not apt solar energy, and Second, by stimulating the storage of solar power. This paper presents three case studies where the Concentrated Solar Power system has been implemented for mass cooking used in BrahmaKumaris region of Mount Abu, Temple of Shirdi and Shrine of Tirupati. Estimation of daily savings of fuel and costs is also done. Finally, the annual saving is estimated on implementation of a hypothetical Scheffler-based heating system. The break-even point is calculated, which shows that the recovery period would be small, i.e. around 3-4 years, leading to faster recovery of costs and reduced costs. This paper shows that the implementation and faster recovery of costs would lead to a reduction in operating costs and maintenance costs.

Keywords — *Solar thermal, Scheffler dish, Cooking, India, Concentrated Solar Power.*

I. INTRODUCTION

The world is moving more and more towards renewable energy sources (RES) to address climate change and to establish sustainable development. In the developing countries like India the focus to add Solar Energy in the National grid. He is harnessing infinite energy reserves such as will help in saving a lot of fuel and other non-renewable resources. For instance, Sun sends more energy to earth in 45 minutes than human consume in a year (1). Amongst the different techniques for using solar energy, one is concentrated solar power (CSP) where heat is absorbed through direct normal irradiance (DNI) and is used to boil water to run turbines.

There is a huge scope of CSP in India with many applications in metro stations, dry cleaning, energy generation, etc. Amongst all these, this research paper concentrates on its use in mega kitchens, which use as much as 1671 kg of LPG in a year (refer 5).

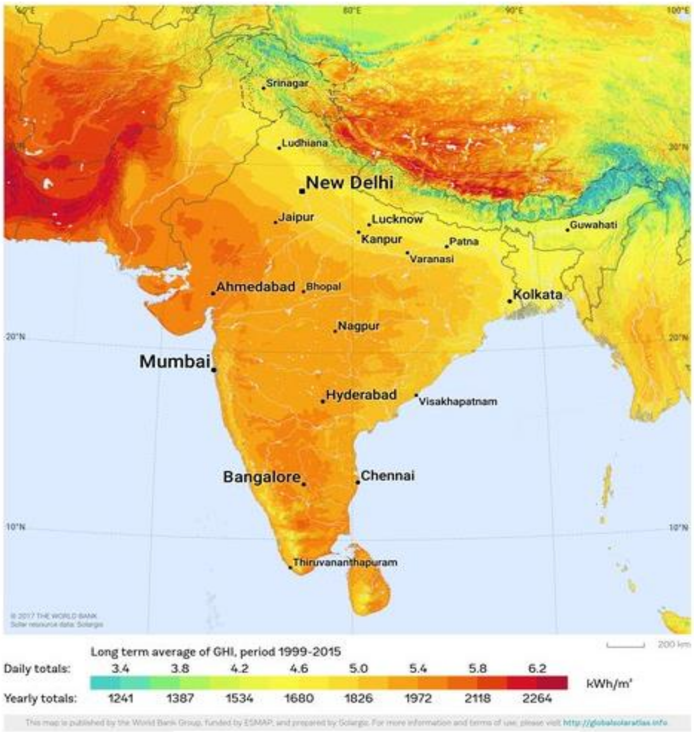
A. Parameters to measure Solar Radiation

The solar radiations reaching the Earth's Surface can be measured in a number of ways. In this paper, the researcher will take Global Horizontal Irradiance (GHI)/Global Solar Radiations and Diffuse Horizontal Irradiance (DHI)/ Diffuse Solar Radiation as the parameters to measure Solar Radiations in the states of Delhi-NCR and Karnataka.

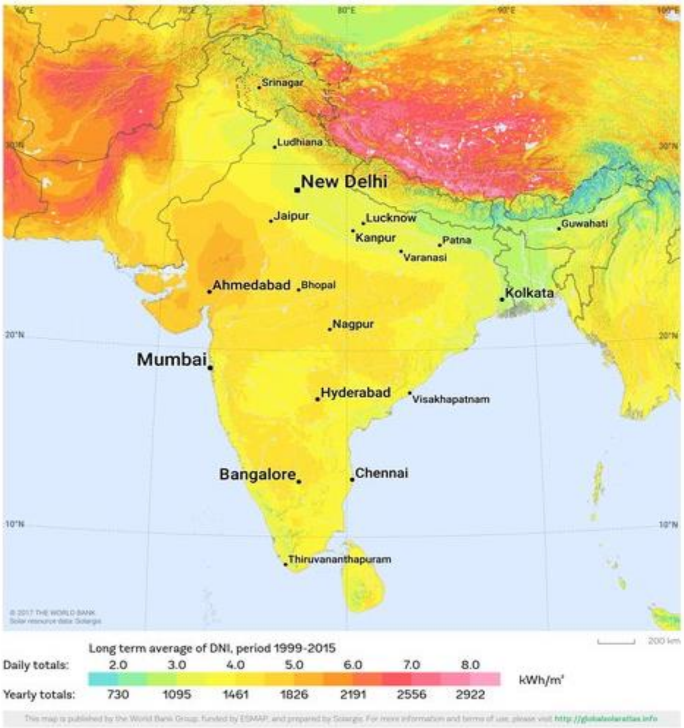
B. Solar Radiations in India:

India being a tropical country, receives great sunshine with an average number of 300-330 clear sunny days. It receives solar energy equivalent to 5000 trillion kwh per year. In India, the daily GHI value is around 5 Kwh/m^2 in northeastern and hilly areas to 7kwh/m^2 in the western region with the sunshine hours ranging from 2300- 3200 a year.

Map 1 shows that in most parts of the country, the GHI varies from 5-7 khw/m^2 and Map 2 shows that DNI variation in India.



Map 1: GHI Map of India [1]



Map 2: DNI Map of India [1]

C. Scope of using CSP in India:

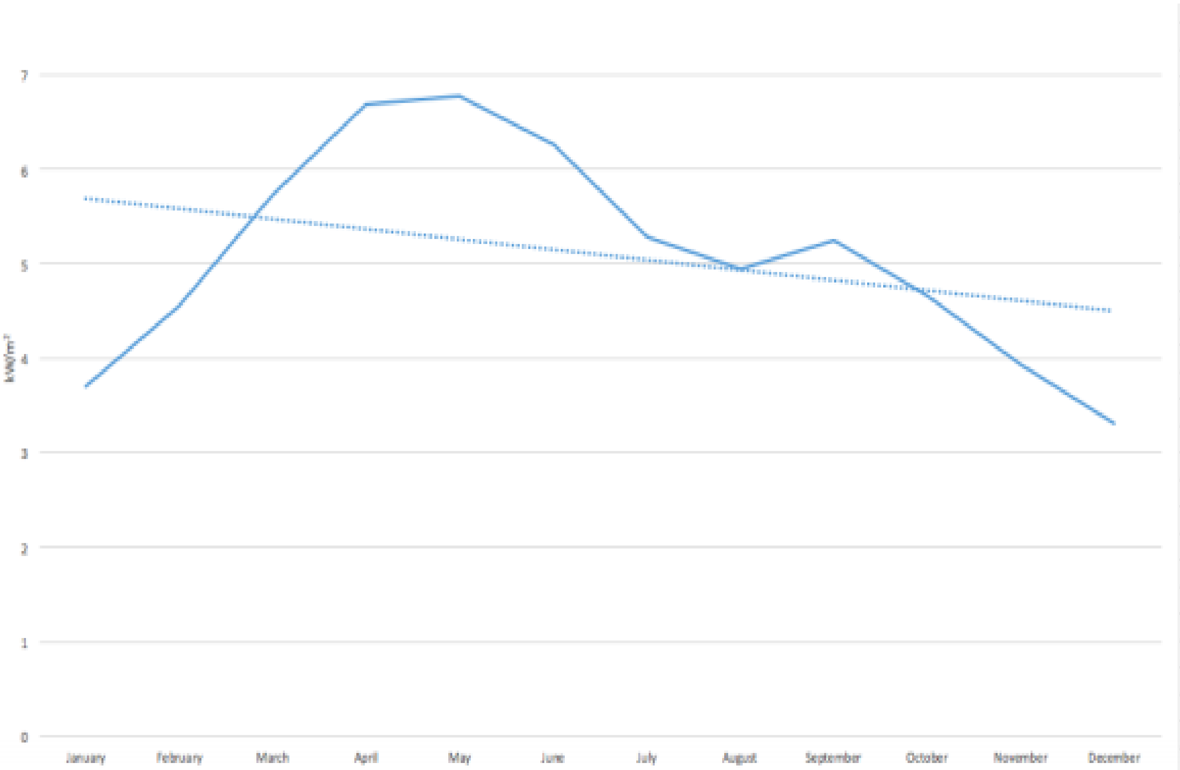
India is a vast country with several mega kitchens where food for lakhs of people is cooked in a day [5]. A few of these kitchens considered in this paper are:

1. Taj Sats, New Delhi- It is one of the largest Indian Airline catering serving 11000 people a day.
2. IRCTC Kitchen in Noida- This kitchen serves food in Indian Railways serving over 25000 people a day.
3. Akshay Patra in Hubli, Karnataka- It is an NGO which works for serving mid-day meals to schools. This branch of the NGO prepares food for 1,50,000 students in a single day.
4. Dharamthala Manjunath temple in Karnataka- It is a shrine whose kitchen serves over 60,000 people a Day on an average day. The number goes up to 1,00,000 on the festive days.
5. Jagganath Temple in puri, Orissa- Kitchen of this temple serves 50,000 people a day.
6. The Golden Temple, Amritsar- It serves 1, 00,000 people every day.

Such mega kitchens use LPG to cook their food and thus require an average of 70-80 cylinders of LPG a day. By using CSP in these places can save up to 50% of the fuel consumption.

D. Solar radiance in Delhi-NCR and Karnataka:

As per the lists mentioned above of mega kitchens in India, most of them lies in Delhi-NCR and Karnataka states of India. Thus, it becomes essential to analyze the solar radiations falling in these states throughout the year.



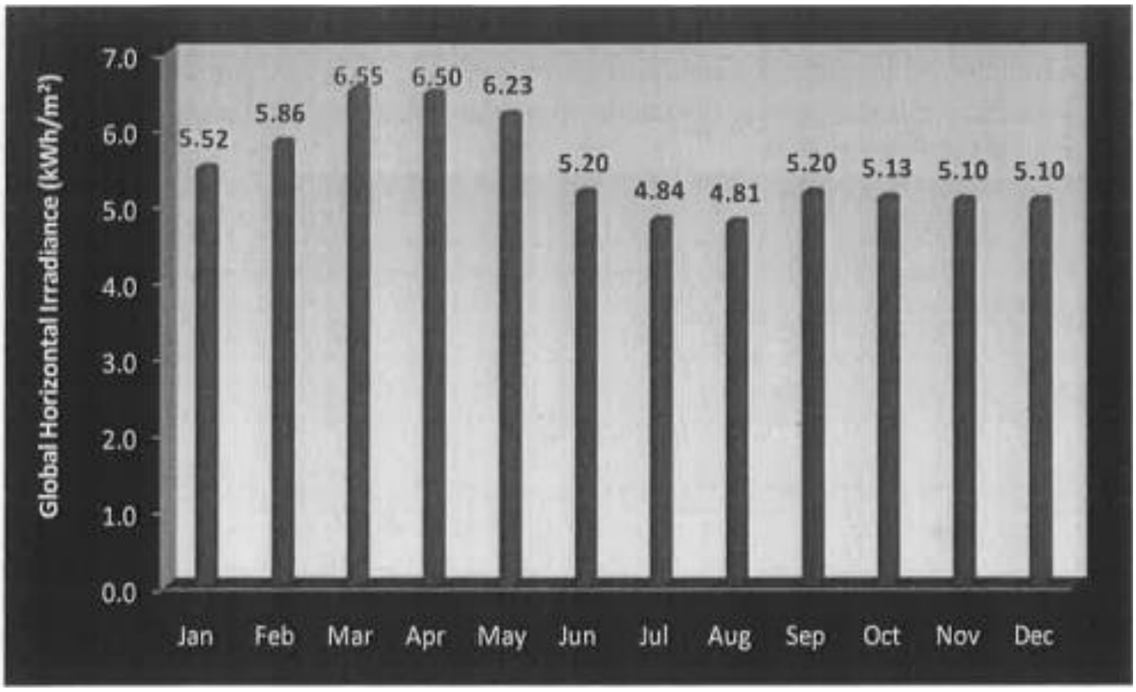
Graph 1: Monthly Variation of Global Solar Radiant Exposure In Delhi

A. ***Solar Radiations in Delhi-NCR:***

The above graph plots the monthly variation of Global Horizontal Irradiance in Delhi. It shows that the maximum solar radiation falls on Delhi in May. The trend line shows that, with the onset of winter in the latter part of the year, the amount of solar radiation falling on Delhi falls. The average global radiation is about 5 kW/ m2, which suggests that Delhi is very well-suited for the use of solar power.

B. Solar radiations in Karnataka:

Graph 2 depicts the monthly variation of GHI in Karnataka. It shows that the maximum solar radiation falls on Karnataka in March. With the onset of winter in the latter part of the year, the amount of solar radiation falling on Karnataka falls. The average global radiation is about 5.5 kW/ m2, which suggests that Karnataka is very well-suited for the use of solar power.



Graph 2: Monthly variation of GHI over Karnataka

I. LITERATURE REVIEW

A considerable number of studies have been done in analyzing the use of CSP technologies in various fields in different countries. Some of which have been discussed as:

T.V Ramchandra states that Karnataka has solar energy as a great sustainable option and has 300-330 sunny days.

Jesko[18] classifies different types of solar collectors for water heating

Anita Nene[12] has estimated the performance of Scheffler dishes using different thermal optimization techniques.

Mercer[13] describes the design of solar cooker using Scheffler dish. The system was experimentally analyzed. Its behaviour was predicted when subjected to solar conditions in Rajasthan, India. The calculation

Was done for monthly intervals and the results were then used to generate third-order polynomials to that describe the energy into the storage unit during the collection period, from 7 AM to 4 PM in Iowa and 8 AM to 5 PM in Rajasthan. These polynomials allow for subsequent calculations involving the behaviour of the system throughout the collection period.

Akhade et al. analyzed the performance of 2.7 m2 Scheffler reflector by keeping 10-litre water at a fixed focus. The experiment was conducted from 10 AM to 2 PM for different days, and readings of ambient temperature, radiation, water temperature, the wind speed were taken at an interval of 10 minutes. It was concluded that to use Scheffler reflectors for household cooking, the intensity of solar radiation falling on it must be maximum.

Dafle et al. describe the design, fabrication and performance evaluation for 2 bar pressure and 110 OC temperature cooking application using a 16 m2 Scheffler reflector. The efficiencies are calculated by considering various design parameters and losses. The average efficiency for a week is found to be 57.41%.
A. Kassem et al. [14] discusses the use of concentrated solar power in Saudi Arabia and the various simulation possible. He presents a techno-economic analysis by using SWOT (Strengths, Weakness, Opportunities and Threats) Analysis. SWOT analysis reveals that parabolic trough collectors are the most mature and are used majorly in CSP installations.
Massimiliano Renzi et al. [15] discusses the use of small scale CSP system for residential applications.
J. Forrester[16] talks about the thermal storage of the power generated by the CSP system. He discusses that the addition of thermal storage will increase the efficiency of the CSP system.
J.P. Kesari[17] discusses the use of CSP technology and Scheffler dishes in Dry-cleaning industry in India.

II. PROCESS OF STEAM GENERATION IN SCHEFFLER SYSTEM

Scheffler dishes are parabolic. When sun rays fall on the dish, it concentrates the rays to a fixed focus, called the receiver. The dish has daily and seasonal tracking of sun rays. This is done by East-West and North-south movement of the dish. There is also a change in inclination angle, thus resulting in a sharp focal point. Water from the header pipe passes to the receiver (thermosyphon principle). At the receiver, the hot water or steam generated water and collected in the header pipe flows to cook food.

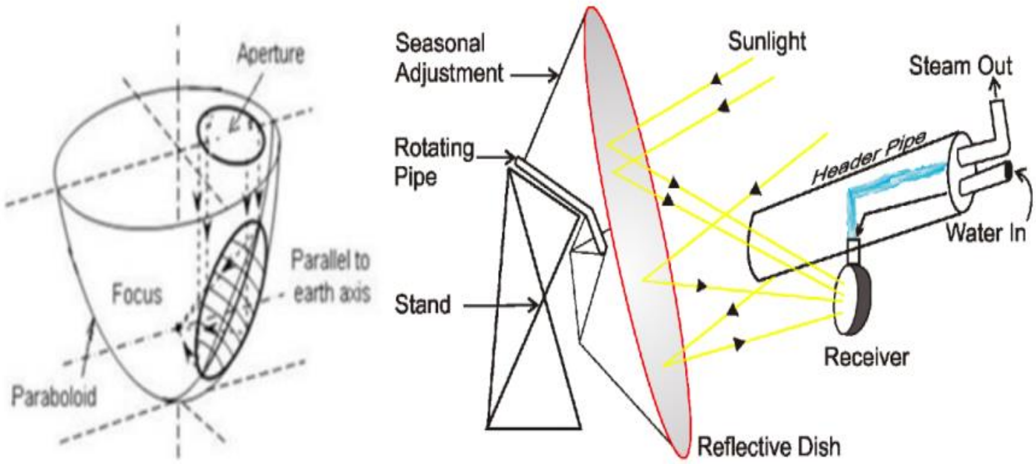
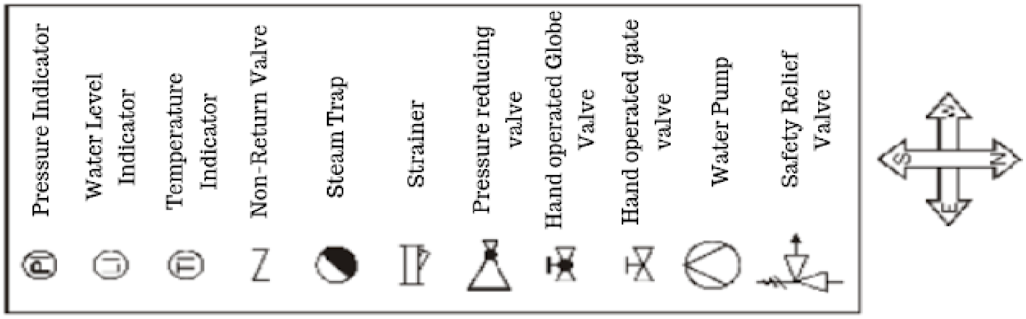


Fig: Scheffler System [19]

IV. P-I DIAGRAM

A P&I (Piping and Instrumentation) diagram shown below in Figure is used by engineers to represent a full system view and the flow of water through the system.
This diagram is useful to diagnose and rectify problems.[20]



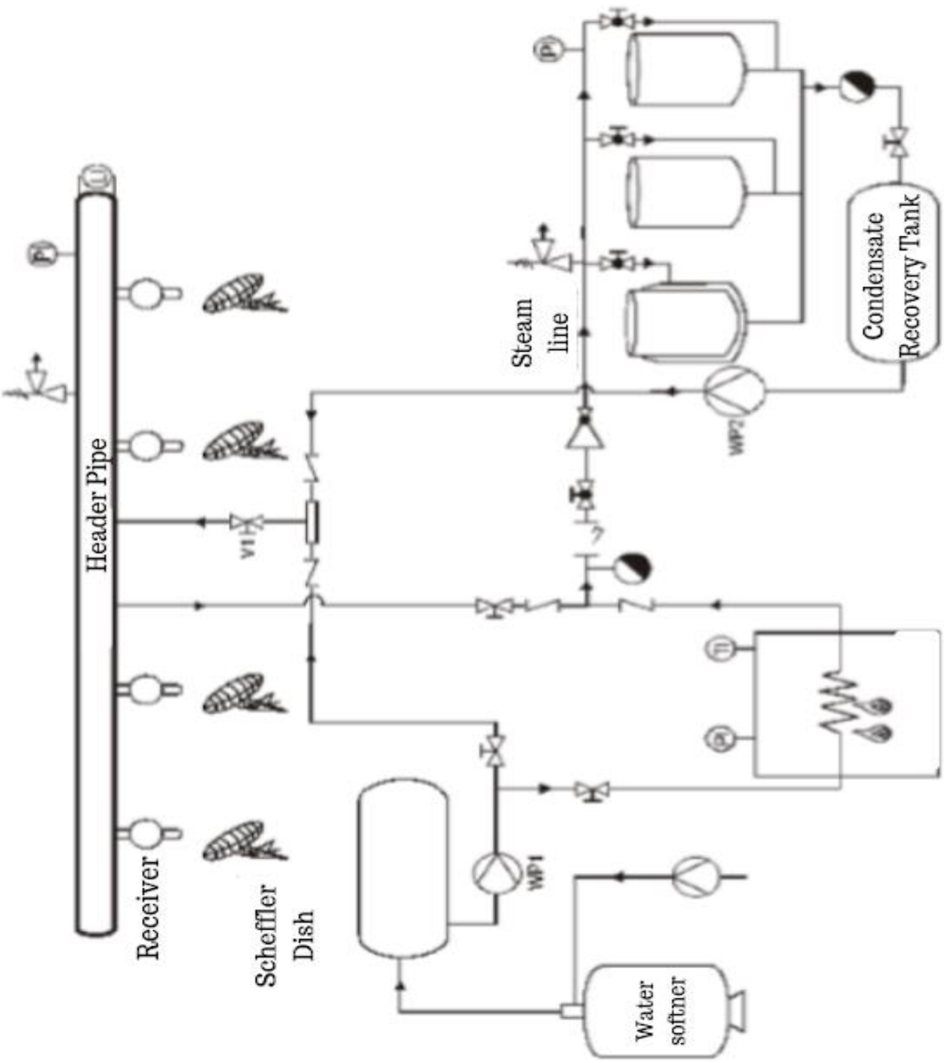


Fig: Diagram of scheffler dish generating steam for cooking purpose

V. CASE STUDY

A. India One Project, Mount Abu:

The Brahmakumaris in Mt Abu has installed a 1MW Concentrated Solar Power system with 25 acres of area which provides energy on demand. It is the biggest power plant in India to work on concentrated solar thermal power technology.

The plant is jointly funded by the Indian and German governments which use 770 newly developed parabolic reflective dishes, each one with an area of 60 sq. metres. They facilitate thermal storage for continuous operation. The plant can generate enough heat and power for 25,000 people and is a milestone for decentralized and clean power generation in India.

Fig : India One Project, Mount Abu [7]

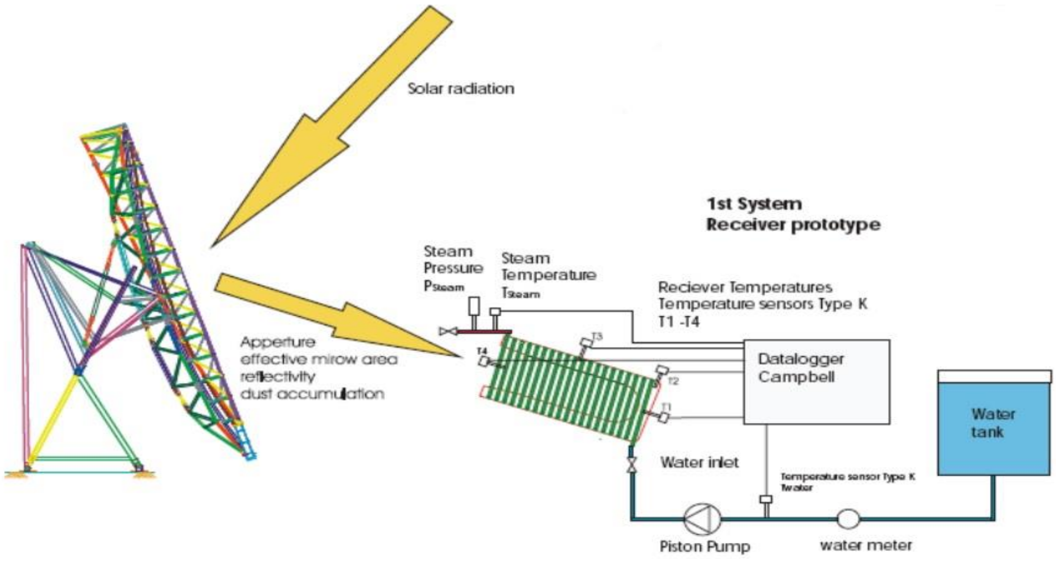


Fig: Working of CSP Model in Mount Abu

Above diagram represents the working of CSP system at Mount Abu. The solar thermal power plant is based on three key technologies: parabolic reflectors, thermal storage and Rankine cycle. The 60-sq meter dishes focus the solar rays towards the in-house cavity receiver, which is made of iron casting and, thus, provides excellent thermal storage. The heat exchanger coil is connected to the thermal storage and allows for an improved heat transfer. Good insulation and automated shutter avoid substantial energy losses at night or in cloudy conditions. The thermal storage operates between 250C to 450C and can be discharged on demand. By means of the total thermal mass, the capacity will be sufficient to run the turbine.

B. Shirdi Sai Prasadalaya

The Sri Sai Prasadalya has one of Asia's biggest dining hall with a seating capacity of 5500 people at a time and thus, serving 1 lakh devotees on an average single day. The number is even more on Festive days.

This Prasadalya was built in 2009. The Sri Sai Prasadalya spends Rs.190 million annually in feeding pilgrims who visit Shirdi. This holy place has installed a concentrated solar thermal plant for cooking and has received a Solar Cooker excellence award from the ministry of Non-conventional energy sources.

The system takes an overall area of 1168m2 which comprises of 73 concentrates with 16 m2 area.

The system was authorized by Gadhia Solar Energy Systems Pvt. Ltd. during 2009. Prior to the instalment of CST for cooking, the kitchen used LPG for end-use consumption. Sai Baba Prasadalya uses a parabolic type

the water temperature to 550°C to 650°C. This system is integrated with the existing boiler to ensure continuous cooking even at night and during rain and cloudy weather. It is still working on the storage of the Solar Power collected.

The main aim of the instalment was to reduce the usage of LPG to 50%. It, therefore, helps in saving $7000 a month. The system generates 3600 kg steam daily and thus, helps in saving 100,000 kg of cooking gas annually. It's cost Rs. 1.3 crore. Out of which, Ministry of Non- renewable energy provided Rs. 58 lakhs as subsidy.

The system installed reached break-even in 7 years and 8 months.

Fig; Cooking in Shirdi Sai Prasadalya[8]

C. Tirumala Tirupati Devasthanam kitchen at Tirupati

Tirumala Tirupati Devsansthan is one of the most revered pilgrimage places of India situated at Venkatachalam in Andhra Pradesh. Seventy thousand pilgrims visit the shrine on an average day. Given the high amount of people visiting and staying at the shrine, the requirements for food and power is high. The temple has thus installed solar-powered cooking system.

The installation of solar concentrators was accomplished in September 2002 and was launched the next month. The system requires only 10 kg per sq

Solar concentrating solar steam cooking system. It makes use of 73 parabolic concentrators and raises

Cm of space to cook meals for more than 14,000 persons. It produces 4000kgs of steam per day at 453 Kelvin. At that time the cost of setting up the system was just Rs. 1 Crore. The water is converted into steam by the help of 106 solar dishes. The fuel saved more specifically, diesel accounts to 1.2 litres each year. Each day 50,000-kilo grams of rice with Sambhar and Rasam is cooked in a very unconventional way that is with the help of steam that reaches the kitchen through pipes. Chefs also find it more convenient as it is far more efficient at takes way less time as compared to the traditional method.

Fig: Scheffler dishes at Tirupati [10]

VI. ECONOMIC ANALYSIS

Firstly, we will use a single Scheffler reflector to calculate the heat output. This heat output helps in calculating the fuel saved in litres per day and then, the cost savings involved. This calculation is then multiplied for a system of 50 Scheffler dishes (estimating that an average of 50 Scheffler dishes is used in any mega kitchen in India).
Considering one scheffler dish,
Let number of sunny days in a year = 300
And the cooking hours = 8/day
Aperture area = 16 cos(43.23 + δ2) , δ is the seasonal angle deviation
Taking δ as 3 degrees,
Hence, aperture area = 16 cos(43.23 + 1.5)
Taking DNI radiation = 5 kWh/m2 /day
Heat output of one scheffler reflector = 11.732 x 5= 58.5 kWh/day
= 50448.16 kCal/day
= 211176 kJ/day
= 211.176 MJ/day

Also, the calorific value of LPG = 46.1 MJ/ Kg
Per day fuel saving in Kg = 211.176/46.1 kg = 4.58 kg
Price of 1 kg of LPG (as on 10/04/19) = Rs. 49.77
Therefore, per day saving = 4.58 * 49.77
= Rs. 227.94

Annually money saved = Rs. 227.94 × 300 = Rs. 68,383.98

Now, for a mega kitchen, an average of 50 Scheffler reflectors would be required to generate an adequate amount of energy. The annual fuel savings and the payback period can be calculated.
Considering a system consisting of **50 Scheffler reflectors**,
Cost of one Scheffler dish = Rs. 2.5 lakhs
Therefore, cost of 50 Scheffler dishes = Rs. 125 lakhs
Adding the cost of equipment and other auxiliary systems = Rs. 10 lakhs
Thus, **total set-up cost = Rs. 135 lakhs**
Heat output of the system = 10,558.8 MJ/day
Per day fuel savings in kg = 10558.8/46.1 = 229.04 kg
Per day cost savings = 229.04 * 49.77 = Rs. 11399.38
Annual Savings = Rs. 11399.38 x 300 = Rs. 34,19,814
Payback Period = (Set −up Cost) /3419814
= 3.94 years **= 4 years**

This calculation shows that with the utilization of Scheffler reflector system consisting of 50 Scheffler dishes, the set-up cost would be recovered in under 4 years.

VII. CONCLUSIONS

In this study, the use of concentrated solar energy for cooking in mega kitchens have been analyzed. Cooking done by solar power requires less time and saves fuel to a large extent. The researcher has used the values GHI and DNI to fing out the areas in India for the installation of the CSP system with the availability of mega kitchens. Delhi and Karnataka are among the two states with GHI values between 5-7 khw/m^2 and availability of mega kitchens as well, thus making them ideal areas for this study. It includes the working of CSP system for steam generation using Scheffler dishes and then discusses the use of these technologies in three places in India. Economic analysis suggests the payback period to be around 3-4 years after which the installation will have become profitable. Integrating the system with further technologies like thermal storage system, solar tower, etc. will make the system more efficient and reduce the payback period furthermore.

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