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Concentrated Solar Heat Integrated with Geothermal Energy for Thermal Energy Requirements in India

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***Abstract*: Geothermal and Solar Energy Sources are the only two natural sources of heat energy which provide heat as it is, without any burning or conversion requirement. These technologies are being used for power generation and heating applications. Power generation will be the center focus of this paper while simultaneously focusing on other industrial heating applications as well. During their operational life, Geothermal Power Plants often lose their pressure, temperature, and mass flow rate and they are unable to run on their full capacities as desired or expected. This loss in energy over time can be recovered by integrating the power plant with some other energy resource. Concentrated Solar Power (CSP) can be one such green energy resource which can directly supply heat energy derived from sun. Such operational hybrid plants and their working were studied. Apart from power generation, CSP is a great resource to be tapped for other mechanical and industrial heating processes. While both of them are being used separately or collectively (on a small scale), using them collectively can help us achieve greater efficiency and energy volume. Data of surveys and research in Indian scenario were compared with already functional plants to draw conclusion on the potential that lies ahead in the field of geothermal energy in India.**

***Keywords*: Concentrated Solar Power, Geothermal Energy, Green energy, Hybrid, Process heating**

1. Introduction

This paper discusses the scope and advantages of using the two direct heat energy resources of nature for heating applications in industry. Energy requirements are ever increasing and these need to be met in ways which are sustainable and leave behind least carbon footprint possible. Since a major amount of energy is lost in conversion from one form to another, it becomes all the more necessary to maximize the usage of energy in its original form. Converting solar heat into electrical energy and again reconverting it into heat energy through some electrical heater for industrial heating leads to huge amount of energy being lost to efficiency losses of conversions. Power generation, being one major and central process involving heating process, is discussed majorly in this paper.

Coming to power generation sector, geothermal energy apart from being green and renewable source of energy has quite a few added advantages. Geothermal Power Plants are capable of running all round the clock 365 days a year without being dependent on weather conditions. These plants also have less water consumption and greenhouse gases emissions through their lifespan when compared to other conventional energy resources. These plants can reuse the waste water of cities by injecting them into the geothermal wells to maintain the steam output pressure. The solid waste generated by these plants often contains minerals which can be sold to recover some part of the cost.

CSP in comparison with other energy resources is a better suited resource to integrate with a geothermal power plant as there is no energy conversion needed. The energy is absorbed as heat energy and transferred to geothermal plant as heat energy itself. Thermal Energy Storage has higher energy dispatchability and also cheaper to store energy in comparison to the batteries which need regular replacement too. The efficiency losses are way lesser when using CSP due to the above cited reasons. This way the life of the plant can be extended and also the cost of drilling extra wells can be saved. India has abundant solar energy resource, even if 10% of available usable land is used for installation that may result into solar energy potential of 8 million MW [1].

Talking about India, Geothermal Energy is untapped but has some great potential when integrated with CSP to bridge the thermal energy gap present. Investigations and surveys have been conducted and in-process at various sites across India. Their findings when compared with the operational plants and processes abroad can be concluded in the opportunities and challenges that lie ahead of us.

2. Review of literature

CSP is a proven technology. Around the world total power produced through CSP has reached beyond 4GW. Solar to electric efficiency for CSP plants range from 15% to 25%. However, the thermal energy when used directly without any conversion involves no cyclic losses and just the heat transfer losses. Thermal Storage losses are almost negligible. That is why CSP should be used in its raw form as much as possible without involving any conversion. Conversion efficiency however, increases with higher operating temperature; therefore, working fluids capable of running at higher temperatures have to be employed.

A Reliance Power subsidiary, Rajasthan Sun Technique Energy has commissioned a 100MW CSP plant facility in Rajasthan, India. As of 2017, Spain leads in overall installed CSP generating capacity with 2300 MW.

Review of [2] shows that: The main ground of superiority of CSP technology over other renewable resources is the ability to provide dispatchable power by storing the energy through thermal energy storage (TES). Land requirement for parabolic trough without storage and for Linear Fresnel without storage is 2 hectare and 4 hectare per MW. It also has the capability to compete with steam powered plants due to technologies which can handle 540°C and above also. CSP is expected to meet 11.5% of global energy needs by 2050. National Solar Mission which commenced in Jan'10 with the aim of establishing India as global leader in Solar Power Generation. CSP and PV projects had equal share in the first phase mission but it was subsequently slashed due to expensive bids compared to average electricity price then. Rajasthan is the richest state in terms of its solar resource and if tapped even partially, the state can play a pivotal role in meeting the electricity demand of India by 2052. The Thar Desert region with a border by Jodhpur district has the highest Direct Normal Irradiance (DNI) of 5.89KWh/m^2/day. Rajasthan has the potential to generate 456 TWh/year electricity by 2052 by CSP plants with accelerated advancement and modernization of higher temperature technologies.

Review [3] shows that: Performance or biddings in the first phase of Jawaharlal Nehru Mission lead to reduction of share of CSP projects in its second phase to 30% from 50% initially. Theoretically, India has a good potential for generating 700-2100GW of energy. A report by National Renewable Energy Laboratory (NREL) suggested that Capacity Utilization Factor (CUF) which gives the measure of sensibility of a particular technology in a specific geographical location, of CSP plant can go up to 40%-50% with 6-7.5 hours of storage. Higher efficiencies of hybrid plants were supported if we use the CSP heat to preheat the boiler hence reducing the dependency on the primary resource. However, there are a few challenges too, like: No reliable data as the previously available data didn't turn out to be accurate, Projects are yet underway and no big successful project. Financially, high cost of operation and maintenance and unavailability of local manufacturers also added to the high costs.

Review of [4] shows that: currently there is no geothermal power plant in operation anywhere in the country. Seven regions on the basis of surveys and magneto telluric surveys have been recognized. Main R&D priorities are life cycle analysis, sustainable production from geothermal resources and conversion efficiency cycles. Main cost, almost 33% to 50% of the total cost can be attributed to drilling the wells which are around 2 kms deep. Hard hot rocks are used to heat the production fluids in a cyclic manner. Steam or hot water is not transportable beyond 2 miles. Barriers in setup of geothermal plants are: location surveying and drilling, competition with established wind, solar and hydro sources. Exploration stage is expensive and risky due to terrain difficulties. While there is also an added risk of harmful gases but there is also added profit earnings through selling the solid waste that comes along and contains minerals.

Review of [5] shows that: Annual temperature decrement for geothermal plants range from 0.5%-0.8% and these underperforming plants can be brought back to life by additional thermal heat by addition of solar heat. There can be five ways to do this out of which direct heat addition to the geothermal fluid is the most efficient one. Levelized Cost of Energy (LCOE) is also found to be lower for the hybrid system in comparison to standalone CSP plant.

Review of [6] shows that: Solar Industrial Process Heat (SIPH) consumption and potential was studied in California due to its high DNI resource. In most industrial purposes, the direct-heat temperatures needed mostly is less than 260°C. The focus was laid on the five industries that are the largest users of natural gas for these applications: food, paper, petroleum, chemicals, and primary metals manufacturing. The annual requirement of about 48 TWhth, when met with solar energy was found to be cost effective at the state of technology and costs then.

3. Materials and methods

For using Integrated Concentrated Solar Power and Geothermal Energy for power generation, there are basically two ways to integrate them depending on whether the geothermal or CSP is the primary energy source.

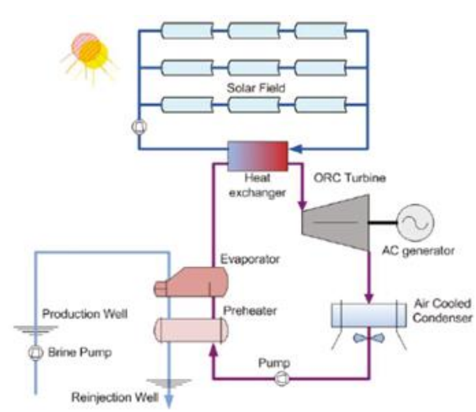

Fig. 1. Hybrid geothermal/ solar thermal system with solar heating of the ORC working fluid [8]

If the major energy source is CSP and Geothermal has to provide the supporting role, following methods can be used [7]:

- Preheating Binary cycle brine
- Preheating flash cycle brine to increase vapour fraction in the flash tank

- Superheating the Organic Rankine Cycle (ORC) working fluid
- Reheating brine and recycling the fluid to power cycle

It was concluded by the authors of the paper "Geothermal / Solar Hybrid Designs: Use of Geothermal Energy for CSP Feedwater Heating [8]" that by annual geothermal energy input of 11.4%, the power output of the integrated plant was 8.5% higher compared to a standalone CSP plant with same solar input.

If the major/primary energy source is Geothermal and CSP provides the minor share of energy to maintain or add to the potential of the Geothermal Power Plant, there are five methods to do this [5]:

- Addition of solar thermal energy to the brine that has to be re-injected into the geothermal reservoir.
- Adding solar thermal energy to re-injection brine until it is 50% vapor.
- Adding solar thermal energy to condenser water.
- Adding solar thermal energy directly to the geothermal production fluids.
- Adding solar thermal energy to the brine that leaves the first flash tank.

On the basis of studies conducted on geothermal plants in California and Nevada, the authors of the paper "Hybridizing a geothermal power plant with concentrating solar power and thermal storage to increase power generation and dispatchability [5]" observed that:

- The first law efficiency and net power generated over the whole range of varying thermal power added to the process is highest for the direct heat addition to geothermal production fluids. Solar Collectors when to directly raise the temperature of the geothermal fluids increase its enthalpy and steam generation.
- The hybrid power plants solar thermal energy to electricity efficiency is 24% and the power output of the earlier 22MW to 24MW (9% increment).
- It was also found to be the most cost-effective way to increase the output and efficiency of the geothermal power plant.

For using Concentrated Solar Power for industrial heating purposes, the type of solar collector or CSP system is chosen depending upon the operating temperature of the heating process (Table 1) and then narrowing down on the types of collectors which can meet the temperature demand. Following this the total energy requirement is estimated and through the data available on the factors such as solar irradiance, no. of sunny days in the year, the size of solar field is estimated [9].

The solar resource can be used in parallel with conventional heating resources by using Thermal Energy Storage, which uses molten salt technology to store thermal energy with minimal loss of efficiency. Assessments in 2006 foretold an annual productivity of 99%, a reference to the energy retained by collecting heat before turning it into electricity, versus transforming heat into electricity directly [10]. This way the solar thermal energy can be provided at the times when there is no sun i.e. during night or cloudy days.

Table 1
Key features of five CSP technology categories

Technology	Annual Solar to electricity efficiency	Practical operating temp. (°C)	Commercial maturity
Parabolic trough	12-15%	150 to 400	High
Central Receiver Tower	20-30%	300 to 1200	Medium
Linear Fresnel	8-10%	150 to 400	Medium
Fresnel lens	12-15%	150 to 400	Medium
Parabolic Dish	20-30%	300 to 1500	Low

For using Geothermal Energy for industrial heating purposes, any industrial heating requirement can be met if the heating temperatures required aren't too high (more than 130°C). Most of the sources in India are lying in this range and hence it makes them fit to be used directly. Some of the industries which use this heat are pulp and paper, cement, food, aquaculture, lumber, and more [11]. Hot water from the geothermal fields can be directly utilized to meet the heating and cooling needs of buildings, towns using heat pump. The heat pump can be reversed in summers to provide cooling effect. Also, if we study the temperature pattern in the region, we can directly use hot water to provide heat in the industrial heating processes. Current methods are used for direct usage where a well is drilled into a geothermal reserve to yield a steady stream of warm water. Steam or the hot water is drawn up from the well through pumps and pipes which transfers the warmth directly for its designed usage.

For using Integrated CSP and geothermal energy for Industrial Applications, Thermal Energy Storage needs to be utilized to combine the heat energy of the two sources and use it throughout the day. Also, the brine from geothermal source can be used as the working fluid which absorbs heat from the heated brine of CSP circuit and then is re-injected into the ground. For this even waste water of cities can be used after minimal processing.

4. Opportunities and challenges in India

As we can see in the map (Fig. 2), around 2.5 million sq. kms area of Indian mainland receives Annual Global Horizontal Irradiance (GHI) 5.0-6.0 kWh/m2/day. GHI gives the total amount of shortwave radiation received from above by a horizontal surface on the ground. It includes both the Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DHI). India's renewable energy sector has been ranked third in the Renewable Energy Country Attractiveness Index (RECAI) which is majorly due to the solar resources that India possesses. India's current installed capacity is less than 1% of the potential that surveys claim. Indian states of Gujarat and Rajasthan receive the highest avg. solar energy per unit area per day.

Roughly the whole southern and western parts of India receive high average solar energy.

As we can see in the geothermal map of India (Fig. 3), Chhattisgarh-MP belt and J&K region are the hotspots of Geothermal Energy in India. It has been estimated from geological, geochemical, shallow geophysical and shallow drilling data that India has about 10,000 MW of geothermal energy potential that can be utilised for various purposes [4]. Indian geothermal resources are divided into 7 provinces according to their geographical locations out of which the Puga Valley of Ladakh is the most promising one. Geothermal Atlas of India, which is developed by the Geological Survey of India (GSI) provides knowledge/data of around 340 geothermal potential sites. Geothermally heated water can be used for various purposes which need heat. Its uses involve providing heat to buildings (separately or whole locality) during winters, cultivating plants in nurseries, heating water at fish farms, drying crops, and other industrial processes, such as pasteurizing milk. According to an article on livemint.com dated 9th June, 2016, India aims to harness 10 GW of geothermal energy by the next decade by an effective global collaboration with nations such as USA, Philippines, Mexico and New Zealand.

When we compare the maps of Solar and Geothermal Energy simultaneously, common sites with abundant resources of both the energies lie in the northern part of Rajasthan, Gujarat, western coast of Maharashtra and the MP- Chhattisgarh belt. These sites can be utilized for setting up integrated CSP and geothermal power generation plants. NTPC is already on its way to setup a geothermal plant in Chhattisgarh's Tatapani reservoir.

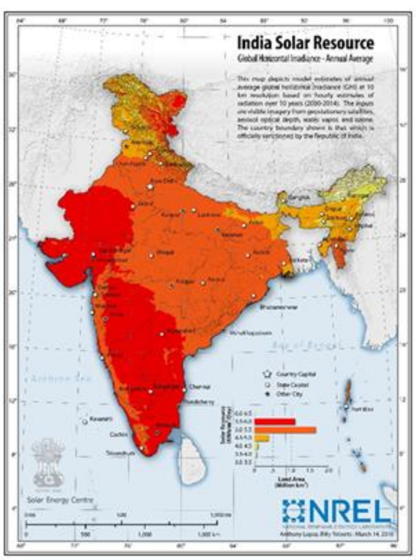

Fig. 2. Annual Global Horizontal Irradiance (GHI) of India (Source: NREL)

The industries in consideration are textile, paper & pulp, Dairy, Leather and Automobile. The results of "Solar Energy for Process Heating: A Case Study of Select Indian Industries by Suresh N S and Badri S Rao [9]" for these industries are combined with their geographical locations to suggest possible geographical sites where solar and geothermal resources can be directly utilized to derive thermal energy.

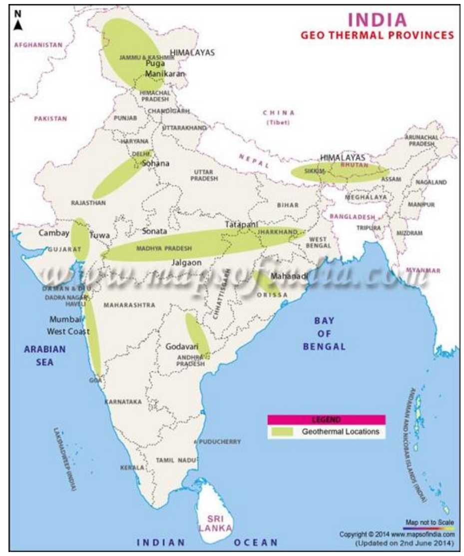

Fig. 3. Geothermal Locations (Source: mapsofindia.com)

Table 2
Status of geothermal fields in India [4]

Geothermal Field	Estimated (min.) Temp (Approx.)	Status
Puga, Ladakh	240°C at 2000m	From geochemical and deep geophysical studies
Tattapani Sarguja (Chhattisgarh)	120°C-150°C at 500m 200°C at 2000m	Magneto telluric survey done by NGRI
Tapoban Chamoli (Uttarakhand)	100°C at 430m	Magneto telluric survey done by NGRI
Cambay Garben (Gujarat)	160°C at 1900m	Steam discharge was estimated 3000 cu meter/ day with high temperature gradient.
Badrinath Chamoli (Uttarakhand)	150°C estimated	Magneto-telluric study was done by NGRI Deep drilling required to ascertain geothermal field
Surajkund Hazaribagh (Jharkhand)	110°C	Magneto-telluric study was done by NGRI. Heat rate 128.6 mW/m^2
Manikaran Kullu (H P)	100°C	Magneto-telluric study was done by NGRI Heat flow rate 130 mW/m^2
Kasol Kullu (H P)	110°C	Magneto-telluric study was done by NGRI

All of these industries mostly require temperatures below 150°C and the sites with availability of temperatures above this should be tapped for power generation. The suggestions with the map links being considered are presented in a tabulated form (Table 3).

Table 3
Key features of five CSP technology categories

Type of Industry	Temperature Requirement (°C)	Geographical Location (Major Cluster)	Map link	Suggested Thermal Energy Resources
Textile	60-110	Western and Southern Part	https://business.mapsofindia.com/india-industry/textile.html	Abundant Solar Radiation through Evacuated Tube Collector Woolen Industry in Kashmir can utilise Geothermal resources
Paper & Pulp	60-150	Maharashtra-Telangana Border and Orissa	https://business.mapsofindia.com/paper-and-pulp-industry/	Abundant Solar Radiation through Evacuated Tube Collector Godavari Geothermal Province can be utilised in Telangana
Dairy	< 120	Western half of country	http://i1.wp.com/mpstudy.com/wp-content/uploads/2016/06/9815369933_1c807c1289_o.png?w=560	Solar Radiation through Linear Fresnel or Evacuated Tube Collector
Leather	< 100	Tamil Nadu & around Delhi	https://www.mapsofindia.com/maps/india/leather-industry.htm	Solar Radiation through Evacuated Tube Collector
Automobile	200 approx. for drying	Spread throughout	https://business.mapsofindia.com/automobile/automobiles-industries-in-india.jpg	Solar Radiation through Parabolic Dish

5. Conclusion and future recommendations

Concluding the paper, it can be said that:

- Geothermal should be the focus of India for the next decade to achieve its target of 10GW geothermal energy by 2030. Also, it is an utilizable green resource going waste in 21st century.
- Due to its nature, Geothermal Power Plant needs a partner to assist in achieving its potential for a longer and healthy duration for which CSP is best suited. Common hotspots of both these resources like Rajasthan, Gujarat, Sonata and Tatapani should be targeted for integrated Power Plants.
- Failure and delay of CSP in Phase 1 of National Solar Mission due to technical, financial or policy problems should be worked upon rather than completely neglecting the potential of CSP.
- CSP and Geothermal Energy for Thermal Industrial Purposes should be promoted by the government in the areas where it is not feasible to set up power generation facilities.
- If standalone power plants of Geothermal or CSP are not feasible in some area of abundant resources, it should be tried to be integrated with gas, coal or biomass power plants.
- More R&D and support is needed to develop the parts for CSP within the nation. This would make the technology cheaper and affordable.
- Lethargic policies and behavior towards projects and investors have led to failure and delay of previous projects which has resulted in hesitation and air of doubt among the stakeholders/prospective investors.

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