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"Solar Thermal Technology: Potential and Industrial Applications"

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Abstract

India's electricity sector has an installed capacity of 334.4 GW as on Jan 31st 2018, with a renewable share of only 18.37%. By 2022, Indian government have targeted 175GW of energy from renewable sources with 100 GW from solar power. Solar thermal technology uses the sun's energy, rather than fossil fuels, to generate low-cost, environmental friendly thermal energy. This energy is used to heat water or other fluids, and can also power solar cooling systems. This paper discusses about the potential of solar thermal in India and industrial utilization.

1. INTRODUCTION

Solar energy is a renewable and abundant source of energy. It is also a sustainable solution for industrial processes where proper implementation will drive the industries toward zero carbon emission in future. Major industrial processes dependence on either fossil fuel or electricity to supply heat. Depletion of non-renewable sources and high greenhouse gas emission (GHG), a shift toward renewable energy is essential. The real disadvantage which hinders the scope for small and medium-sized industries to integrate renewable energy system is high installation cost and mostly to ensure a proper and continuous supply of energy.

Solar thermal systems in industrial processes and electricity production are becoming popular in different parts of the world but heavily dependence on radiation intensity. The storage system can be considered as supplementary, depending on seasonal variation, i.e. reduction of solar intensity during winters. It may improve the overall performance of the system.

2. THE SOLAR THERMAL POTENTIAL IN INDIA

Energy gained from solar irradiation after heat conversion is called solar thermal energy. Solar energy is an important renewable energy which will play a vital role in the future for supplying energy [1-4]. During the past several decades, concentrated solar power (CSP) technology became an important option for harnessing solar energy [5-8]. In January 2010, Government of India started the Jawaharlal Nehru National Solar Mission (JNNSM), and activities toward solar-based power generation took a considerable momentum [9]. The mission aims for the deployment of 20,000 MW of solar power by the year 2022 and creating a policy framework for it [10].

The estimated solar power generation for a threshold direct normal irradiance (DNI) value of 1800 kWh/m^2 is 756 GW and for a threshold DNI value of 2000 kWh/m^2 is 229GW [11] (with all the waste-lands having wind speed of 4m/s or more allocated for wind power production). Hence a large area of waste-land in India can be utilized for production of wind and solar energy.

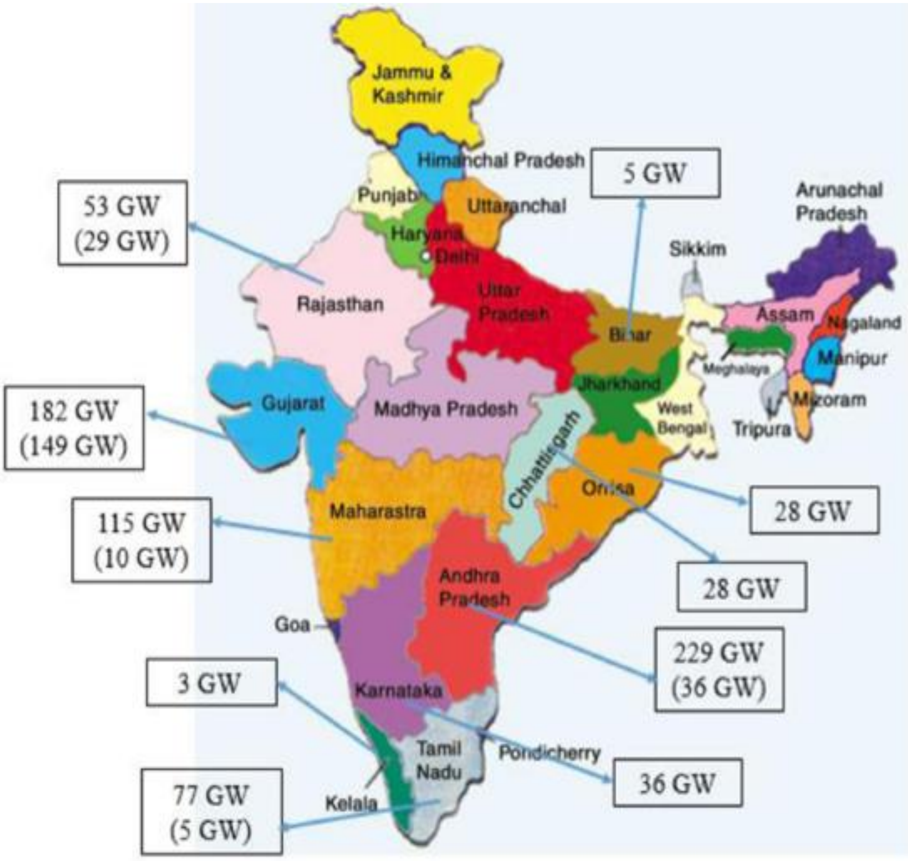

Figure 1 : CSP potential in different states. (Annual threshold of 1800 kW/m^2; Data in the bracket denotes CSP potential for DNI of 2000 kWh/m^2) [11]

3. HARNESSING SOLAR ENERGY FOR INDUSTRIAL PROCESS HEATING

The various energy sources used and amount of energy shared by individual sources, consumed by the industries vary across regions and countries, technological choice, and availability of fuels. According to a report of International Energy Agency (IEA), most of the energy demands globally are met with fossil fuels [15]. With the rapid increase in energy demand, the rate of fossil fuel consumption will increase**,** causing high GHG emission and global warming. Hence, it is a desire to reduce fossil fuel consumption while maintaining the increased energy demand. It can be achieved by (i) improving fuel efficiency in various processes and equipment [12-14], (ii) replacing fossil fuels with solar thermal energy for process heat applications.

Conversion of solar energy into thermal energy has comparatively higher efficiency than producing electricity from solar energy. For example, the efficiency of producing electricity from solar energy is between 15-20% while for heat production, the corresponding values are between 20-25% [16-18]. Also, a temperature range of 50-300^{o}C is required for major part of the industrial process [18] and can be achieved with proper technology.

Table 1: Various industrial processes and heating temperature.

Industry	**Process (es)**	**Temperature (^{o}C)**	**Medium**
Food processing, milk processing and beverages production	Cooking Pasteurization Sterilization Tempering Drying Washing Heat treatment	70-120 60-150 100-140 40-80 40-100 40-80 60-80	Steam, water Steam Steam Steam Air Steam, Air Water
Textile	Dying Drying Pressing Fixing Printing	60-90 100-130 120-140 160-180 40-130	Water Steam Steam Steam Water, steam
Pulp and Paper	Bleaching De-linking Drying Pulp preparation Boiler feed water heating	120-150 60-90 90-200 120-170 60-90	Water Steam Air, steam Pressurized water Water
Chemical and pharmaceutical	Distillation Evaporation Drying Thickening	100-200 110-170 120-170 130-140	Water Steam Air, Steam Steam
Automobile	Paint pre- treatment Baking of paints Paint drying	40-50 175-225 160-175	Water Steam Air
Steal making and other casting industries	Hardening, annealing, tempering, forging, rolling	700-1500	Air
Cement manufacturing	Lime calcing	600-1200	Air

3.1 Heat transferring media

Heat transferring media used in industries for process heating depends on the requirement of specific application or process and it may or may not have direct contact with the other working fluids. The important characteristics of heat transfer media for process heating are: (i) low vapour pressure, (ii) high heat capacity, (iii) high thermal stability and (v) low corrosiveness [19-21].

Steam is the most common heat transferring media used in industries for process heating. For e.g., in the USA, around 37% of fossil fuel is burned for the production of steam [22] and up to one-third of all energy consumption is used for steam generation in the UK [23]. The heat content of steam is mostly stored as latent heat and a large quantity of heat can be extracted efficiently at a constant temperature. Also due to high energy density than other media like hot water and thermal oil, it is best suitable for process heating.

3.2 Solar collectors

A solar collector is a device which absorbs solar radiation from the Sun, and the extracted heat is transferred to the working fluid or heat transfer media. Selection of appropriate solar collector mainly depends on four factors (i) operation temperature, (ii) efficiency of solar collector, (iii) cost and (iv) energy received annually [24-28]. Factors like availability of space and possibility of root top installation are also important.

Mainly three types of solar collector technologies are used for Solar Industrial Process Heat (SIPH) applications – flat plate, concentrated, and evacuated tube. For flat plate collectors, both water and air is used as heat transfer media. For low-temperature industrial processes, flat plate and evacuated tube collector based system are used [29]. Concentrated type collector can produce a heating temperature of up to 300^{o}C and most commonly used concentrated collectors are the parabolic trough, paraboloid dish and linear Fresnel reflector [30-32]. Table 2 gives the detail about different solar collectors.

Table 2: Type of solar collector, tracking type, temperature range and efficiency.

Solar Collector	Tracking	Temperature Range (^{o}C)	Efficiency
Flat Plat	Non tracking	30-100	ηi=0.732–3.411*(Tm-Ta/I−0.294*(Ti-Ta)^2/I [33]
Evacuated tube	Non tracking	50-100	ηi=0.62–0.395*(Tm-Ta/I-0.002*(Ti-Ta)^2/I [34]
Parabolic trough collector (PTC)	Single axis	60-300	ηi=0.71–0.3581*(Tm-Ta/I-0.0019*(Tm-Ta)^2/I [35]
Arun Dish 160	Double axis	Up to 250	ηi = 0.65–0.40*(Tm-Ta)/I [36]
Linear Fresnel reflector	Single axis	Up to 300	ηi=0.635–0.0265*(Tm-Ta/I-0.00043*(Tm-Ta)^2/I [37]

3.3 SIPH systems: Design and integration

Solar industrial process heating (SIPH) system basically consists of collectors, heat transfer media, heat exchangers, thermal storage, and auxiliary backup as an optional component. Figure 2 shows a schematic diagram of solar concentrated based process heating system for industries. Solar irradiations falling on the thermal collector is absorbed and then transferred to the working fluid, generally water. Heat rejected to working fluid is then utilized for various processes based on the industries.

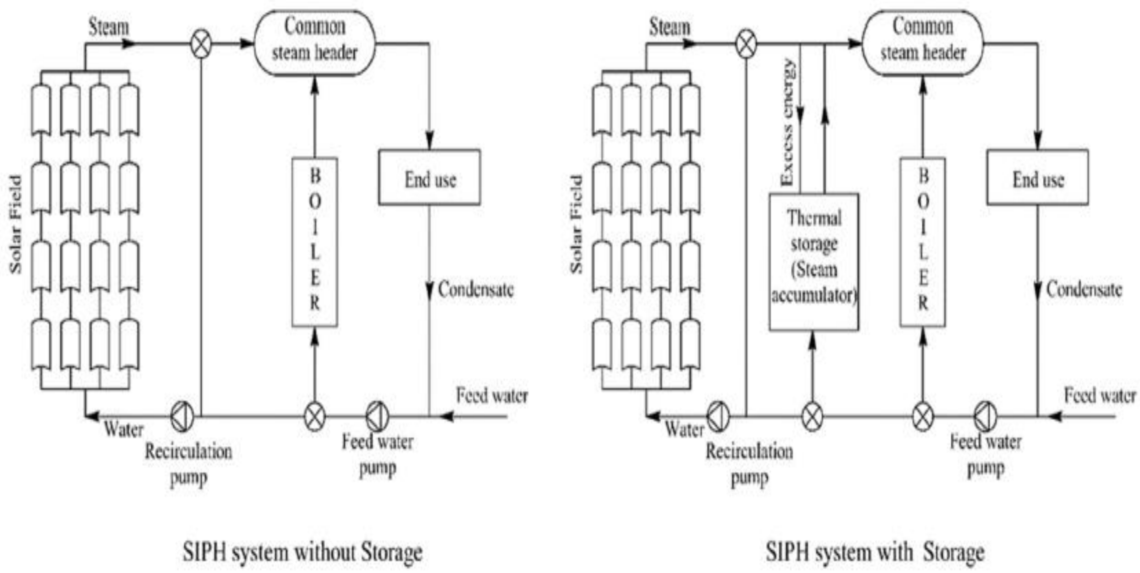

Figure 2: Schematic diagram of SIPH systems [9].

Indirect steam generation

Water/steam is not the working fluid, instead thermal oil, glycol or PCM is heated by the solar collectors and is then used to generate steam indirectly using heat exchangers. It is further configured into – flash boiler based and unfired boiler based systems. In flash boiler system, pressurized water is heated by the solar collectors and then passed through a throttling valve, due to which a part of it, is converted to steam. This steam is delivered and utilized for industrial applications. And the part of water is re-circulated back to the collectors. Feed water tank and circulation pump is also required. In the unfired boiler based system, working fluid passes through the collectors where heat is absorbed, and is then rejected to secondary fluid like air and water.

Direct steam generation

In this mode, water is the working fluid. It is boiled by the solar collectors and the generated steam is stored under high pressure with thick insulation or utilized directly. Steam is separated from the water in a steam drum. The water is then re-circulated back to the solar field. Feed water tank is also provided.

In industries, a continuous supply of process heat is demanded, hence hybrid SIPH systems are accepted. An auxiliary boiler is used as a backup during cloudy hours and night. A hybrid system is shown in fig. 3.

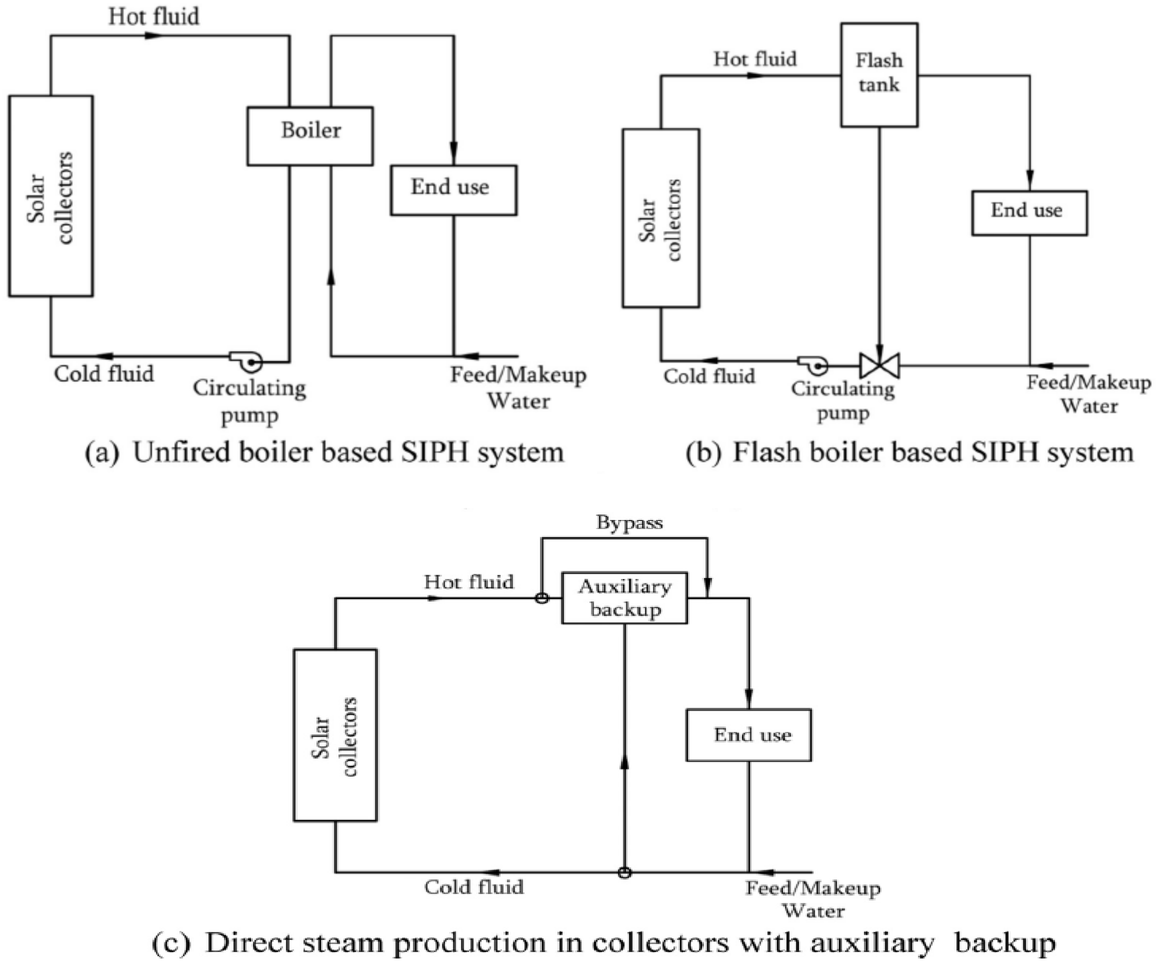

Figure 3: SIPH systems [9].

Solar collector area

Calculation of solar collector area depends on (i) DNI or GHI (Global horizontal irradiance) values (DNI in case of concentrated based system and GHI in case of stationary collectors) (ii) process heating demand (iii) efficiency of collectors.

$$SCA = \frac{PHR_h}{(\eta_c)\ (GHI_d)}$$

SCA = solar collector area; PHR_h = rate of process heat requirement; η_c = thermal efficiency of solar collector; GHI_d = Global horizontal irradiance (W/m^2)

4. PROBLEMS ASSOCIATED WITH LARGE SCALE DEPLOYMENT OF SIPH SYSTEM

Potential of solar thermal energy is very high but harnessing it is quite difficult. Various problems associated are discussed in the literature work. Several reasons are taken from them [38-39]. One of the significant barriers to the installation of the solar thermal process is the structure of the industrial sectors. Integration of solar thermal system into existing large-scale plants requires large space, heavy optimization and thorough knowledge of the system. All solar thermal process system requires a heavy initial cost. For small and medium scale industries, due to lack of financial support, the main barrier is the upfront cost and the total installation cost, even if the overall lifetime cost would be low. Also in many countries government provides subsidy or discount on fossil fuels to support industrial development. Hence small and medium scale industries prefer continuous heat from fossil fuels.

Lack of skilled labours and public awareness is also an important barrier for deployment of solar process heat system. Many small and medium scale industries do not have enough information or first-hand experience with solar thermal technology. They also prefer conventional sources which can provide a continuous supply of heat since they cannot deal with initial loss due to inconsistent heat supplied by solar technologies. Hence solar thermal technologies are being avoided by most of the industries.

There are only few research institutes with thorough and proper knowledge of solar thermal energy. To overcome this problem training and distribution of existing knowledge and concepts are needed.

CONCLUSION

For several industrial processes as shown in table 1, the temperature range required can be achieved with the proper installation of solar thermal systems. Adaption of solar thermal technologies for small and medium scale industries is beneficial for the growth of the industries as well as a sustainable development of the country. Solar collectors like the flat plate and evacuated tube can provide an operating temperature of about 30-100^{o}C. For the high temperature range of about 250-300^{o}C, parabolic trough, and linear Fresnel reflector are used in industries.

There is a huge potential of adopting SIPH systems in industries for process heating. But problems like installation of new systems into systems which are already running at full potential, installation cost, the area required for implementation, storage problem etc. are some factors which may inherit. Hence adaption of proper policies and regulations are necessary.

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