Solar Thermal Energy Utilization for Medium Temperature Industrial Process Heat Applications - A Review

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Abstract: The paper presents a review of solar thermal utilization to various commercial and industrial process applications. The current trend around the world has shown that the growth of solar thermal energy for Industrial use is slow compared to domestic applications due to higher temperature requirement and available solar system’s low efficiency. An extensive research on solar thermal applications in various process industries along with systems have been discussed in research papers. The aim of this review work is to identify the trend on solar thermal energy applications to various process industries with various solar thermal systems available in the market. It also focuses on the challenges on appropriate solar collector selection based on type of process industries and temperature range on which it operates. Therefore the current paper aims to fill the gap between available solar thermal energy systems and their process integration based on type of process industry aiming to enhance the practical application of these systems without sacrificing on the performance and economic feasibility of the systems.

1. Introduction
In the recent years energy has become very crucial in the manufacturing industries in turn rapidly increasing green house gas emissions. This has become inevitable as manufacturing sector has a greater impact on the country’s economic growth. Developing countries like India is trying to industrialize through new opportunities in the area of renewable energy formulating its own energy policies. These energy policies in the developing countries offer environmental friendly zero carbon technologies for the industrial sectors. Process industries consume energy in both electrical and thermal forms. Solar thermal energy in process industries can be used in various applications like dyeing, bleaching, pasteurization, chilling, drying etc. Most of the process industries require energy for heating but it again depends on the type of process, products being processed and the type of industries. There is a huge range of temperature requirement from one process industry to the other but coincidentally 50% of thermal energy demand is in the range of 30°C-400°C. These industrial processes account for a significant share of energy consumption indicating a potential for the application of solar thermal technologies at low and medium to high temperature ranges. Conventional flat plate collector (FPC) and evacuated tube collectors (ETC) both can provide low-temperature level up to 120°C which covers 30% of the industrial segment. Solar concentrators like parabolic dish,
parabolic trough and Fresnel collectors which can generate steam with the temperature up to 400°C covered around 22% of the industrial segments.

This paper deals with the solar process heat industries, with the available solar collectors for low-medium temperature industrial applications. An effort is made to study solar industrial process heating (SIPH) database which gives information on currently installed promising plants for different industrial sectors and the discussion is confined to Indian scenario. The review also includes most widely used industrial solar thermal process applications based on current potential, process integration and collectors being used depending on the temperature requirement.

2. Literature Survey

It is very important to identify the potential industrial sectors for the integration of solar heat by taking the reference of existing SIPH plants in a developing country like India. Globally a very few research papers have made an attempt to study the potential of solar industrial process heating and Kalogirou.et.al [1] from Cyprus is one among them. In this paper process sectors like food and beverage was selected to simulate the yield of solar integrated process heat for different temperature levels and heat demand. The description of the paper is limited only to Cyprus and do not provide any adequate numerical values from the estimation study using a simulation software TRNSYS. An attempt was made by Lauterbach et.al [2] to estimate annual specific energy gain to determine the potential in the field of SIPH. In this study a comparison made between simulations and compared with the available model. The solar heating and cooling (SHC), with the aim of promoting solar thermal utilization, established in 1977 made many collaborative activities by involving experts from (International Energy Agency) IEA members [3]. As a result of this collaboration IEA SHC task33 and solar paces task IV made a study on identifying solar heat for industrial process and discusses the potential industrial sectors for SIPH integration. According to IEA report solar array installation will supply around 45% of energy demand in the world by 2050. S.Mekhilef et.al [4] made an attempt to study the solar energy systems utilization in industrial applications and looked in to the industrial applications which are more compatible to be integrated with solar energy systems.Taibi.et.al [5] discussed renewable energy potential in industrial sector by using biomass and low temperature solar systems. Various studies have made based on process heating potential aiming on individual industrial segments from different countries. It has found that 25pJ of SIPH potential for paper industries and 6.40pJ for diary industries [6, 7]. The integration of SIPH in the existing conventional heating system is a challenging task where heat demand is required without any interruption for the process. Kulkarni et.al [8] suggested hybridization and thermal storage as a feasible option to avoid process intermittency but is ultimately leading to an additional cost. Caldeorni et.al [9]made a detailed economic analysis on feasibility of solar process heating system integration in Tunisia.Montes.et.al [10] analyzed the impact of process integration using parabolic trough collector to various industries and showed that 40-50% saving of conventional fuel but prolonged period to recover the capital investment. Efforts have also been made on the solar collector design and optimization by keeping primary emphasis on performance enhancement through optical and thermal losses. Few examples on these approaches are cohen.et.al [11] designed a new spherical shaped stationary reflector and tracking type absorber. Kedare SB.et.al [12] designed a Fresnel paraboloid concentrating solar collector with two axis tracking and tested in India.Frein et.al [13] studies describe the design procedure to analyse the basics of integration of a solar thermal plant in to an industrial heating system. Many of the researchers Coccoa.et.al [14] and Larcher.et.al [15] have attempted experiments to investigate the solar collectors (Parabolic Trough Collector) used to solar process heating.

Though the review includes a very large estimated potential for SIPH, actual installation at industrial levels are very small in comparison with its potential. The worldwide SIPH plant database of IEA indicates the installed capacity to be around 100MW by 160 operating systems at the end of 2015. Also, review revealed that 70% of the installed plants were based on low and medium temperature
scale with Flat plate collector and Evacuated tube collector technologies. Most of the SIPH is done for food and beverage industries which included water pre heating washing, cooking etc. operations.

In this review work an attempt is made to study different process industry with SIPH integration in India. The process stages are being elaborated on type of industry, type of solar collector, temperature range, and geographical location. In the later part of the paper an attempt is made to list out the currently operating SIPH in India at various industries. Attention is focused to identify the potential industrial sector for SIPH and problems of integration are also discussed.

3. Assessment of solar thermal energy and process potential.
It is known that a strong solar resource is one of the key factors for providing solar heating solution to a process industry. So it is important to assess the available installation space based on open land or roof top along with available solar resource on Direct Normal Irradiance (DNI) annual data. The radiation received on earth’s horizontal surface known as global horizontal irradiance (GHI) which consists of both normal or direct beam and diffuse irradiation is essential for low and medium thermal applications using either line focusing with single axis tracking or point focusing with two axes tracking. The available DNI of India is indicated in the following Table.

It is very well published [16] that the daily average global solar radiation is around 5-7 kWh/m² across the country for sunshine hours ranging between 2300-3200 hrs per year. It is estimated around 25-30% as diffuse radiation out of annual GHI data of 1600kwh/m² - 2200kwh/m² at most of the Indian locations [16]. The unavailability of useful DNI data is a major barrier towards implementation of low-medium SIPH projects across India. In spite of this, there are three ways to assess DNI data over any location a) Measurement data using pyrheliometer b) Measurement of reflected radiation and c) Statistical approach using ground and satellite data sets. Currently, following are the three sources from which one can get DNI data, namely NASA, SEC-NREL and Meteonorm 7.0 database for global and Indian conditions. The following table 1 represents district wise DNI for all 29 states and 6 union territories from India and the annual average of solar irradiance (DNI) from Meteonorm database.

Second most important parameter which plays a major role in successful implementation of SIPH is Process Integration. Solar energy integration to any process industry expects an energy saving potential through technical optimization of the process. It is a very complex operation of integrating solar heat in to industrial heating process as compared to any other conventional process of integration. It is essential to consider the energy efficiency and heat recovery during the process of integration which further could lead to economical and technical improvements for an organization.

In general there are 3 ways to provide integration for a process industry.

a) Pre heating, b) Direct Steam Generation and c) Process heating

More about the integration guideline can be referred from IEA solar heating and cooling task 49. The process integration is also known as Pinch Analysis which is a field of engineering helps to optimize operational energy efficiency. The variables in the supply of energy depends on daily solar radiation, ambient temperature available, thermal storage options and optimized solar collectors which help to reduce economic inefficiencies.

| State           | Districts/Stations | Annual DNI (kWh/m²) through Meteonorm Data |
|-----------------|--------------------|------------------------------------------|
| Andhra Pradesh  | 23                 | Min: 1184, Avg: 1529, Max: 1867          |
| Name of the collector | Type of Motion | Type-of Absorber | Heat transfer medium | Indicative temperature range in °C | Possible Application |
|-----------------------|----------------|------------------|----------------------|-----------------------------------|---------------------|
| Flat plate            | Stationary     | Flat-Non Concentrating | Water or Air         | 30-80                             | Pool heating, crop drying, Low temperature Industrial process heating |
| Evacuated Tube        | Stationary     | Flat-Non Concentrating | Water or Air         | 50-200                            | Space heating, cooling, Medium temperature Industrial process heating |

4. Illustration of the most widely used solar collector type and criteria for selection:

The most important component of a solar system is the solar collector. It is a sort of heat exchanger which transforms the energy from radiation to internal energy of the transport medium. As shown in the table solar thermal collectors can be classified based on motion of the system, the collector type, the absorber type, concentrating or non-concentrating type of the system and the range of temperature delivered.
Selection of an appropriate solar collector for meeting the process heating demand of an industry depends on:

- The selection of solar collector type meeting the operating temperature of the industrial heat demand and the efficiency of the solar collector.
- The solar process circuit should support the chosen heat transfer fluid (HTF).
- The solar collector should be certified by national standard such as Bureau of Indian standards.
- Check the energy output from the collector’s certification/accreditation done by the third party firms.
- The solar collector should withstand the operating pressure.
- The solar collector should adequately handle maximum temperature condition generally referred to as “stagnation” and prevent overheating.
- Finally the cost of the collector should be 50-70% of the total project cost.

The flat plate type and evacuated tube collector is generally used for low temperature industrial process applications like pre heating of boiler feed water. The solar collectors which can be used upto a temperature of 300°C are included with parabolic trough collectors and Fresnel type which is categorized as medium temperature collectors. The cost of collector is again depends on the life of the collector type. The general life for a FPC is around 20 years and for ETC it is around 15years. Again ETC type are made of glass and are fragile in nature in comparison to FPC which contains metallic components.

It is important to estimate the required solar collector area which is a major step in designing SIPH project. The collector area estimation depends on required process, heating demand, performance characteristics of the selected collectors and irradiation data for the location of SIPH project. It is very important to consider DNI data for installation of concentrating type of collectors and GHI data for non-concentrating type of collectors. The following table gives the list of suppliers of solar collector in India:

| Collector Producer                  | Type of collector         |
|------------------------------------|---------------------------|
| ATE Enterprises                    | Parabolic Dish Collector  |
| Akson’s Solar                      | FPC                       |
| Inter Solar Systems                | FPC                       |
| Megawatt Solutions                 | Parabolic Dish Collector  |
| Oorja Energy                       | Parabolic Trough Collector|
5. Potential of a solar industrial process heating based on temperature range.
Industrial process heat requirements depend on the temperature ranges on which the process has to be operated. However, it can broadly be categorized into low temperature and medium temperature depending on the type of process industry. Low temperature is applicable where pre heating of water and space heating requirements are needed. Medium temperature is by using steam as a medium of working fluid. Generally for both low and medium temperature process heat requirement both focusing and non-focusing collectors are preferred. It is essential to assess properly the actual process temperature requirements to calculate the efficiency of a solar thermal integration for a manufacturing process. Both evacuated tube and flat plate collectors are commonly used in low and medium temperature requirements. ETC is suitable for use in cold climate as they have no freezing issues but they are made up of glass which is fragile in nature as compared to FPC.

Following picture shows the type of collectors in use and temperature range.

![Different types of collectors](image)

**Fig1** Different types of collectors

Solar process heat can be replaced efficiently when temperature below 100°C are required. The theoretical potential for use of solar thermal energy as a heat source with respect to industry is around 73%. Processes below 100°C are most suitable for integrating with solar thermal system. The temperature ranges involved for different processes from various industrial segments (section 6) have been discussed below.

6. Solar heating currently used for process industries from various sectors across India
   a) Dairy:

   India is one of the largest milk producing country and continues to be the largest producer of milk in the world. Milk production during 2014-15 and 2015-16 was 146.3 million tones and 155.5 million tons respectively showing an annual growth of 6.27%. The success of the dairy industry has resulted from the integrated co-operative system of milk collection, transportation which results in 60% of the installed processing capacity.

   According to source by ASI database 2007-08 the energy consumption in a dairy is around 45% through electricity, 28% petroleum products and 26% through other fuels.

   The major steps involved in a dairy industry are as below
   a) Processing the raw milk and delivery.
   b) Production of milk derived products including powder, ghee, butter etc.

   The detailed process flow for the processing of liquid milk and its derived products as shown below
The dairy industry consumes a major thermal energy for milk processing like pasteurization, sterilization, spray drying etc. and also consumes electrical energy for refrigeration during milk pre-chilling, cold storage and packed milk etc. The following table shows the opportunity for solar thermal application in a diary industry which demands water at a temperature less than 120°C.

**Table 4:** List of process in diary

| Process                        | Energy/Fuel being used                              | Application media | Temperature required °C | Recommended Solar Technology |
|--------------------------------|-----------------------------------------------------|-------------------|--------------------------|-----------------------------|
| Washing and cleaning           | Electricity and boiler fuels like furnace oil, rice husk | Hot water         | 40-60                    | FPC                         |
| Pasteurization                 | Boiler fuels like furnace oil, rice husk            | Process heat      | 70                       | FPC                         |
| Sterilization/Evaporation      | Boiler fuels like furnace oil, rice husk            | Process heat      | 100-120                  | ETC or Solar Concentrators  |
| Spray drying                   | Boiler fuels like furnace oil, rice husk            | Process heat      | 120                      | Solar Concentrators         |

**Table 5:** List of operational dairies which are integrated solar thermal for various processes

| Organization                      | Industrial Operation                                      | Solar Collector                                      | Operating Temperature | Collector Supplier                        |
|-----------------------------------|----------------------------------------------------------|------------------------------------------------------|------------------------|-------------------------------------------|
| Himachal Pradesh Dairy State Co-operative | Hot water used for steam boiler as feed water. | No Pressurized FPC solar collector with a gross area of 120m2. | Hot water 60-80°C     | Kotak Urja Pvt Ltd Bengaluru.             |
| Dausa Milk Chilling Plant Rajasthan | Hot water of 75°C to 85 is used for washing of milk tanks and cans. | Non Pressurized flat plate collectors with a gross area of 110m2 | Hot water 75C-85°C     | M/s Photon energy Systems limited Hyderabad. |
| Milma Dairy Kozhikode             | Hot water is used for steam boiler as a feed water.      | Non Pressurized flat plate collectors with a gross area of 276m2 | Hot water 60-80°C     | M/s Tata Power Solar systems Ltd, Bengaluru. |
| Aavin dairy, Tirunelveli,          | Hot water is used for steam boiler as a feed water, can washing cleaning of processing tank | Non Pressurized flat plate collectors with a gross area of 360m2 | Hot water 60-80°C     | M/s Photon energy Systems limited Hyderabad. |
| Amul Fed Dairy                    | Steam heating for Milk Pasteurization, evaporation and Sterilization. | Parabolic trough collector field with a gross area of 560m2. | Steam at 140 °C       | M/s Thermax Pvt Ltd                      |
| Mahanand Dairy, Latur             | Steam heating for Milk Pasteurization,                  | Dual-axis tracker and has a Fresnel parabolic concentrator, one solar collector with 160m2 aperture area | Pressurized hot water at 180 °C with 18bar pressure | M/s Clique Technologies                   |
b). Pharmaceutical:

The Indian pharmaceutical industry has ranked 3rd in the world in terms of production and is at 14th place in terms of domestic consumption value with a growth rate of 14% per year. The industry produces a range of products which is in the form of tablets, capsules, ointments and powder. This sector needs intensive energy for the manufacturing process consists of both electrical and thermal energy depending on various processes and products.

The following processes in a pharmaceutical industry can replace with solar thermal energy:

| Table6. List of industrial process in Pharmaceutical Industry |
|----------------------------------|
| **Industrial Process** | **Application Media** | **Temp required °C** | **Recommended solar technology** |
| Distillation | Hot water | 55-80 | FPC/ETC |
| Evaporation | Steam | >120 | Solar concentrators |
| Drying | Steam/Hot air | >120 | Solar hot air system |

| Table7. List of operational Pharmaceutical Industries which are integrated solar thermal |
|----------------------------------|
| **Organization** | **Industrial Operation** | **Solar Collector** | **Operating Temperature** | **Collector Supplier** |
| Sunil Health care | Second largest capsule shell manufacturing industry. | No Pressurized FPC solar collector with a roof area of 11,760m2. | Hot water 75 °C | M/s Inter solar a Pvt Ltd Chandigarh. |
| Synthokem Labs - Sanath Nagar | Solar water heating system for pre-heating steam boiler feeding water for industrial processes. | Evacuated thermal collectors | Hot water 75°C-85°C | M/s Photon energy Systems limited Hyderabad. |

c) Automobile:

The Indian automobile industry is one of the largest market in the world sharing second largest manufacturer of motorcycle and seventh largest in the world for passenger car and light commercial vehicle. It is manufacturing about 23 million vehicles in fiscal year 2015-15 as compared 21.5million vehicle produced in the year 2014-15 with an annual growth of 8.6%. Most of the processes in an automobile industry require both thermal and electrical energy. The thermal energy alone accounts for 70% of the total heat energy consumption including both hot water and steam energy which is again depends on 40% fuel dependency delivered from petroleum products.
Most of the operations included medium temperature applications with a range of 80 °C-140 °C or steam up to 2 bar pressure for various types of applications as shown below with opportunities for replacing with solar thermal energy.

**Table 8.** List of Industrial process in an automobile Industry

| Process Steps                          | Energy or Fuel Being Used | Application Media | Temperature need °C | Recommended solar technology |
|----------------------------------------|---------------------------|-------------------|---------------------|------------------------------|
| Degreasing of automobile parts         | Natural gas               | Pressure hot water| 90                  | ETC                          |
| Drying of cleaned parts                | Natural gas               | Hot air           | 90                  | ETC/PTC                      |
| Dip Zinc Phosphating process           | Electricity               | Hot water         | 80                  | Flat plate collector         |
| Paint shop preconditioning             | Electricity               | Hot water         | 40                  | Flat plate collector         |
| Paint shop- curing of automobile paint | Natural gas               | Hot air           | 200                 | Linear Fresnel collectors    |
| Paint Shop evaporation drying          | Natural gas               | Hot air supply    | 100                 | PTC                          |

The following table shows installed solar process heating at various locations of India for an automobile segment.

**Table 9.** List of solar process heat integration done at various locations for an automobile Industry

| Organization                                                                 | Industrial Operation                                                                 | Solar Collector                      | Operating Temperature           | Collector Supplier                  |
|------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|--------------------------------------|---------------------------------|-------------------------------------|
| Mahindra and Mahindra Vehicle Manufacturing limited, Chakan, Pune            | Hot water to wash engine components                                                   | Dual axis tracked Fresnel paraboloid | Pressurized hot water at 120°C  | M/s Clique Technologies             |
| Wheels INDIA limited, TVS group, Chennai                                     | Wheels after casting are cleaned and washed in a tanks                                | ETC plant with 1365m2 collector area | Hot water at 55°C knock of degreases at 70°C | Aspiration energy pvt ltd          |
| Sonakyo Steering automobile parts manufacturing, Chennai                      | The vehicle steering components before being painted undergo hot water wash          | ETC based with 455m2 gross area      | Hot water for washing at 60°C-70°C| M/s Solar Hitech Geyser- Bengaluru |
| Harita Seating – TVS group, Chennai                                           | Leading manufacturer of automotive seating systems. Heat demand for degreasing and phosphating process | ETC based with 1200m2 gross area      | Hot water at 55°C-60°C           | Aspiration Energy pvt ltd-Chennai   |
| SKF Technologies pvt ltd, Mysuru                                              | Heat the water for circulation through the treatment tanks in the phosphating plant. | Parabolic trough based with a installation area of | Pressurized hot water at 130°C  | M/s Thermax India pvt ltd           |
d) Textile:

Textile is the largest and the oldest sector in the country providing second largest employment after agriculture. Textile sector is contributing 4% GDP to the country, 18% of employment in industrial segment, 16% of the country’s total export earnings. The segment has different ranges of products like cotton yarn, khadi, woollen, polyester fabrics, handlooms, silk and jute products. The different processes involved based on the type of textile products with range of different fuels. It is estimated that 17% petroleum products, 16% coal and 43% electricity are being used as different source of fuel from various textile product segments. The textile finishing industries involve lot of operations to convert the inputs in to a final product and the chart below represents the major operations involved.

Most of the operations require hot water at a temperature ranging from 40°C to 110°C. The hot water of this range can easily be generated using FPC and ETC technologies and the table below represents the opportunities of replacing with solar thermal systems.

| Process       | Energy being Used | Temperature required °C | Recommended Solar Technology |
|---------------|-------------------|--------------------------|-----------------------------|
| De Sizing     | Thermal           | 60-90                    | ETC                         |
| Scouring      | Thermal           | 90-110                   | ETC/Concentrators           |
| Bleaching     | Electrical and Thermal | 90-93              | ETC                         |
| Mercerizing   | Electrical and Thermal | 60-70              | FPC                         |
| Dyeing        | Thermal           | 70-90                    | FPC                         |
| Finishing     | Thermal           | 40-100                   | ETC                         |

Table10. List of Various Industrial process in a textile industry

Table11. List of Solar heating process integrated at various textile Industries.

| Industry                  | Industrial Operation                                           | Solar Collector                                      | Operating Temperature                  | Collector Supplier                      |
|---------------------------|-----------------------------------------------------------------|-----------------------------------------------------|----------------------------------------|-----------------------------------------|
| Chelsea mills gurgaon    | The plant is a garment manufacturing company producing apparels wear majorily denims. | Non pressurized FPC solar water heating system with a 943m2 total aperture area. | Non Pressurized hot water at 60°C-65°C | M/s Inter solar systems pvt ltd Chandigarh. |
| Sharman shawls Ludhiana  | Manufacturer of textile                                        | Flat plate collector with 360m2 gross area          | Hot water at 60°C-80°C for bleaching,dyeing and washing garments | Aspiration energy pvt ltd               |
| Purple creations-        | Children clothing company                                       | 30 dishes of Scheffler concentrating collectors with an absorber area of 480m2 | Steam at 150°C at 6bar                 | M/s Thermax India pvt ltd               |
| Baramati                  |                                                                  |                                                     |                                        |                                        |

7. Economics and barriers

Though there are many advantages with solar thermal for process heating, there are certain barriers for their applications and they are

- Significant capital cost of installation for a small and medium scale industries
- Lack of awareness on virtual simulation software used to get clear overview about the efficiency of solar industrial process system to check.
- Requirement of Life cycle or PLM costing analysis to bridge between manufacturing and consumers.
- Effective Economic evaluation of SIPH systems
- Difficulty in integrating solar process heating system in the existing and optimization of process heating streams.
- The number of large scale energy intensive industries is rather less in number.
- Small Scale units require tailor made solutions for each specific industry.
- High upfront cost of SIPH systems for small and medium industries.
- Unavailability of qualified and component designers, installers as well as software support.
- Lack of compact thermal energy storage (TES) options.
- Unavailability of adequate policy, regulatory support and promotional incentives.
- Awareness relatively due to low marketing and lack of knowledge.
- Policy recommendation.
- Lack of accurate DNI data.

8. Conclusion
From the study of the literature it is evident that Indian industries are in line with the global industries in the usage of Solar technology for their thermal energy requirements. The four sectors studied namely, Diary, Textile, Automobile and Pharmaceutical indicated the extensive use of solar technology with appropriate collector systems. Though the industries are aware of the solar technologies, they are not trying to improve the efficiency of the system and also not concentrating on its cost. More technical competency is required to design, analyse and install the solar thermal systems through available softwares and efficient technical knowhow. Government policies also a play major role in incorporating this technology into all the appropriate industries. If policies are made to incorporate Solar energy resources in the design and development stage itself and also by announcing incentives to the industries, solar resources can be made more efficient and popular.

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