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MEDIUM TEMPERATURE APPLICATION OF PARABOLIC TROUGH COLLECTOR FOR INDUSTRIAL PROCESS HEATING - REVIEW

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ABSTRACT

Application of solar energy in commercial and industrial companies in present days is insignificant compared to other non-renewable energy. Solar applications in industrial processes have only occurred on a relatively small scale and been mostly experimental in nature. However, if one compares the energy consumption of the industrial, transportation, household and service sectors then one can see that the industrial sector has the highest energy consumption in countries. Just one third of this energy demand is related to electricity, but two thirds are related to heat. The major share of the heat, which is needed in commercial and industrial companies for production, processes and heating production halls, is below 250°C. The low temperature level (< 80°C) is consistent with the temperature level that can easily be reached with non-concentrated collector. Here use of smaller parabolic troughs, with concentration ratios between 10 and 20, can operate at temperatures between 100°C and 250°C. In this paper, various application of parabolic trough collector is reviewed for industrial process heating along with available case studies.

Keywords: Application of PTC, Industrial Process Heat, Parabolic Trough Collector

I. INTRODUCTION

In recent years many countries started running behind renewable energy due to reduction of non-renewable energy, for various applications such as air heating, desalination, refrigeration, small scale and large scale industries and electric power generation. Although many developments done to extract maximum energy from various renewable sources. Renewable energy sources like solar, wind, biomass, hydropower and tidal energy are CO_2 free alternatives [1, 2]. By applying renewable energy scenario the global consumption of renewable sources by 2050 reach up to 318 exajoules [3]. Solar energy is the most useful source of energy which has been readily available in earth for thermal power generation, and for industrial heating applications. Some developing countries have high level of solar radiation like India, Egypt, Morocco and Mexico are moving to concentrating solar power for electricity. An environmental analysis has been conducted in 58 places in India for viability analysis of parabolic solar trough power plants [4]. In India, on an average 3000 to 3200 h/year solar radiation receives, which delivers approximately 2000 kWh/m^2 per year of solar radiation on the horizontal surface [5].

According to a National Renewable Energy Laboratory survey, Gujarat received an average of above 6.7 kWh/m^2 of solar radiation per day [6]. According to the Central Energy Authority of India on November 2016 the total installed capacity for electricity generation was 308,834MW and the various sources are shown in Figure 1. India requires a peak demand of 153,824MW whereas peak met is 152,295MW. Also, specifically, the state of Gujarat has a peak demand of 14,134MW electricity [7].

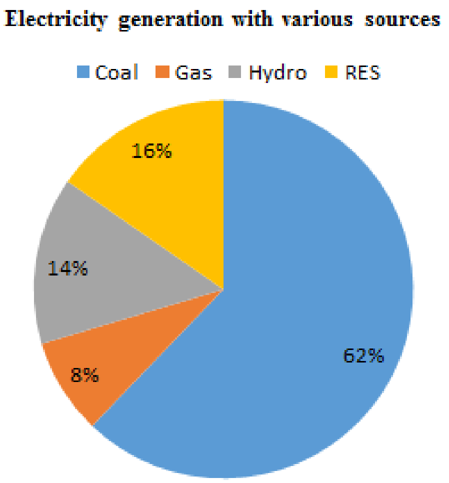

Fig.1(a) all india power installed capacity(MW) [8]

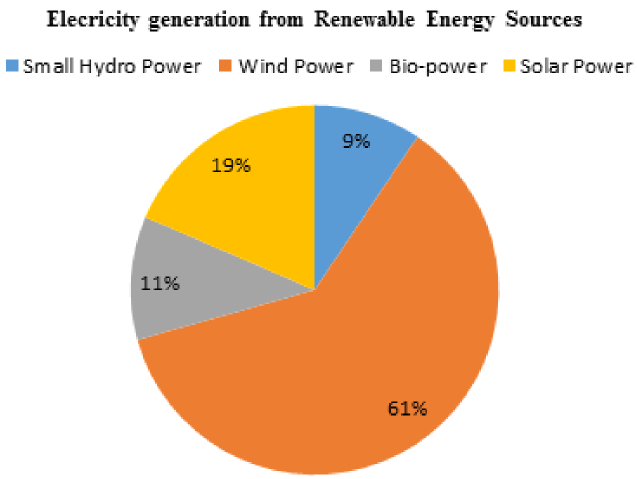

Fig.1(b) all india renewable power capacity(MW) [8]

Very large amounts of energy are spent for industrial heat generation in many countries. In India 100 million tons oil used annually, of which 40% is consumed in industries. 60 – 70% of this use is in the form of thermal energy, out of which 70% is used for applications below 250°C. With solar concentrating collectors we can meet 30% of this requirement, leading to savings of about 4.5 million tons of furnace oil, LDO or diesel [9]. India has a large number of small and decentralized industrial units, where this technology can be used, at the same time we can meet reduction in oil imports. The development of solar thermal systems for industrial heat, solar cooling and other applications is a thrust area of the Ministry of New and Renewable Energy, Government of India [8].

With low and medium temperature heat accounting for 45% of total industrial process heat use, solar thermal systems have a large potential. Solar thermal technology can also provide an alternative to cooling processes in sectors, such as the food and tobacco sector where most products cooling is currently done by electric chillers. Almost all industrial process heat demand requires heat in temperature ranges that can be provided by a solar thermal system. There are several potential fields of application of solar thermal energy in the temperature range of 80°C to 240°C, as identify in TABLE 1 [10].

TABLE 1 Temperature required for various industrial processes

Industry	Process	Required temperature(°c)	Industry	Process	Required temperature(°c)
Meat industry	Washing and sterilization	60-90	Beverages industry	Washing and sterilization	60-80
	Cooking	90-100		Pasteurization	60-70
Bricks and blocks industry	Curing	60-140	Flours and by-product industry	Sterilization	60-80
Dairy industry	Pressurization	60-80	Timber and by-product industry	Thermo diffusion beams	80-100
	Sterilization	100-120		Drying	60-100
	Drying	120-180		Pre-heating water	60-90
	Concentrate	60-80		Preparation pulp	120-170
	Boiler feed water	60-90	Chemical industry	Soaps	200-260
Tinned food industry	Sterilization	110-120		Synthetic rubber	150-200
	Pasteurization	60-80		Processing heat	120-180
	Cooking	60-90		Pre-heating water	60-90
	Bleaching	60-90	Paper industry	Cooking and drying	60-80
Plastic industry	Preparation	120-140		Boiler feed water	60-90
	Distillation	140-150		Bleaching	130-150
	Separation	200-220	Textile industry	Bleaching and dyeing	60-90
	Extension	140-160		Drying and	100-130

				degreasing	
	Drying	180-200		Dyeing	70-90
	Blending	120-140		Fixing	160-180
				Pressing	80-100

All the processes temperature required is less than 260°C. The heat required for all the industrial processes is obtained from solar energy. The solar PTC has the ability to capture temperature of about 400 °C [11]. Solar energy is being used for industrial processes in various developing countries [12, 13]. Each square meter of collector surface can reduce 250-400 kg CO_2 emission per year [14].

The solar collectors absorb the solar radiation and convert it into heat, and transfer it to the working fluid. The working fluid may be air, water, oil or any organic solvents. The heat energy which is in the form of thermal energy in the working fluid of the solar collector can directly be utilized for different applications [15, 16]. Solar collectors are of various types as shown in Table 2[10].

TABLE 2 Different solar collectors

Name of Collector	Type	Operating Temperature(°C)	Heat transfer medium	Application Area
Flat plate	Non concentrating	30-80	Water or air	Air heating and water heating
Evacuated tube	Non concentrating	50-200	Water or air	Water, oil and air heating
Parabolic trough	Line focusing	60-300	Air, thermal oil	Power generation, water and air heating
Linear fresnel reflector	Line focusing	60-250	Water, air, thermal oil	Water and air heating
Dish type	Point focusing	100-500	Water, thermal oil	Steam generation, parabolic dish engine
Power tower	Point focusing	150-2000	Thermal oil	Power generation

The evacuated tube collector receives diffuse light that the concentrating collector cannot do. However, the evacuated tube collector has a much greater thermal loss ratio, so the extra heat collection is more or less lost. The amount of diffuse energy collected by flat-plate collectors in most regions is not sufficient to compensate for the tracking capability of the troughs. Flat plate collectors have a lower thermal efficiency in comparison to the parabolic trough collectors. The parabolic trough collector has a much less internal heat capacity for the fluid circulating in it and hence very small heat loss when the system turns on at every morning. Dish type and power tower is used for very high temperature range more than 400°C.

The temperatures at which energy is required below 100°C conventional solar collectors with suitable efficiencies (FPC, CPC or evacuated tube collectors) could be employed. However, when a large amount of hot water is demanded, a large collection area, which sometimes becomes excessive, must be installed. In this case, PTCs might be of interest, because they supply thermal energy at higher temperatures than those required by the load and, therefore, higher demands can be covered by mixing the hot solar fluid with another cooler [17].

The advantages of PTCs over other solar collectors used in water heating facilities are their lower thermal losses and, therefore, higher efficiency at higher working temperatures reached, smaller collecting surface for a given power requirement, and no risk of reaching dangerous stagnation temperatures, since in that case, a control system sends the collectors into off-focus position and reduce risk.

Today factories are usually located in industrial areas where land is limited and expensive, therefor installing the solar field on roofs should be a real possibility. PTCs should therefore be modular to cover the wide range of thermal power required for many different applications. Differences between PTCs used for industrial applications and for power generation are that they are smaller, have fewer absorber tube selective coating requirements due to the lower working temperature, and use first surface reflectors instead of silvered glass mirrors, which are only marketed for PTCs developed for power generation applications [11].

II. HISTORY OF PARABOLIC TROUGH COLLECTOR

Archimedes (214–212 BC) was first to invent a techquines to reflect sun energy on parabolic reflector to burn ships attacking Syracuse. Later on Anthemius of Tralles mentions burning-glasses as Archimedes' weapon which was also sometimes called as the "Archimedes heat ray"[18]. Still in the early’s attention on solar concentrating technology was negligible for many years. However in 70’s, the oil crisis in many countries and growing environmental impact has made mandatory to find some alternative option of fossil fuel for sustaining the world and that causes development of a number of solar collector. The beginning of PTC was carried out by an engineer named John Ericsson (1870), for running an engine with the help of steam in which air was used as working fluid [10]. Later in 80’s, this technology has managed to enter the market, and some American companies, Acurex Solar Corp. (models Acurex 3001 and Acurex 3011), Suntec Systems Corp.–Excel Corp. (models IV and 360), Solar Kinetics Corp. (models T-700 and T-800), General Electric Co., Honeywell Inc. and Jacobs Del. Corp., manufactured and marketed a number of PTCs[19]. Further, application of parabolic trough collector was divided into categories on the basis of temperature requirement. For generating temperature range from 300 to 400ºC, which can be directly or indirectly can be used in steam power plant and further, for medium temperature range from 100 to 250ºC, which has wide variety of application in industrial process heating, space heating, swimming pool etc [11].

III. APPLICATIONS AND CASE STUDIES OF PARABOLIC TROUGH COLLECTOR IN INDUSTRIES

S. A. Kalogirou studied PTCs for industrial process heat generation in Cyprus. The optimum collector area is 300 m^2, the optimum collector flow rate is 54 kg/m^{2}h and the optimum storage tank size is 25 m^2. The system covers 50% of the annual load of the system and gives life cycle savings of about £6200. This amount represents the money saved from the use of the PTC system against paying for fuel. The optimum system can deliver a total of 896 GJ/year and avoids 208 tons of CO_2 emissions to the atmosphere. It was found that the bigger the load the bigger the collector area required, the greater the first year fuel savings and the greater the life cycle savings of the installation. This means that it is good to apply solar industrial process heat to higher energy consumption industries [20].

Pablo D. Tagle et al. studied the application of PTCs in two different industries namely Chicken food production industry in Morelia (Michoacan state), Shrimp food production industry in San Miguel Zapotitlan (Sinaloa state). The vapor needs for chicken food industry were estimated in 12150 l/day. For meet this load, they use a common boiler with LPG as fuel. An estimation of 920W/m^2 of mean solar radiation during approximately 6h of sun was simulated on the system. Under this condition the system can heat the water up to 85ºC obtaining 140kW as maximum thermal output with a mean net efficiency of 58%. In shrimp food industry the process they need an amount of 11000 l/day of heated water to meet their production. In this case a boiler is also used but with fuel oil as fuel. Similar to previous case, for this case, a mean solar radiation of 1000W/m^2 during approximately 6h of sun was simulated. Under this condition the system can heat water up to 90ºC with a maximum output of 103kW and a net thermal efficiency of 57% [21].

F. J. Cabrera et al. Studied application of PTCs for solar refrigeration and air - conditioning. The performance of PTC in air conditioning applications have been compared to other solar thermal collectors on the basis of the SACE methodology. The PTC solar fraction is higher than other collectors, the ETC and CPC have low inter-mediate fractions, and the FPC have the lowest. Solar cooling installations should be designed with a specific area of collector range of 0-3m^2/kW for single-effect absorption chillers and 0-2 m^2/kW for double-effect absorption chillers. The PTC has a similar solar fraction when connected to a single- effect or double-effect absorption chiller, while other collectors have lower solar fractions with double-effect chillers, for the same specific area collectors [22].

Ricardo Silva et al. studied the use of a parabolic trough solar plant to generate process heat steam for a food processing application. The food processing industry, afforded to vegetables preservation by thermal treatment and canning, is situated in the Southern Spain region and demands saturated steam at 7 bar with total annual consumption of 148MWh. From this energy production approximately 64% are consumed by processes in industry, and the remaining 36% are thermal losses. Therminol 55 is used as heat transfer fluid (HTF) and steam generator is used to connect solar plant with industrial process. Average annual solar fraction obtained is 34.9% and annual overall efficiency is 30.4%. Use of heat exchanger increases thermal efficiency of the solar field by lowering its inlet temperature, and increases the energy storage density, so reducing its specific losses [23].

M. J. Tierney studied that the Coefficient of Performance (COP) is higher for a LiBr-H_2O double-effect than single-effect absorption chiller, but it requires thermal energy at temperatures of 140-160°C, at which performance of conventional collectors is not good enough. As PTCs are highly efficient at these temperatures, the combination of these two systems gives good results. Connection of NH_3-H_2O absorption chillers to a solar system requires solar collectors able to work properly at temperatures above 95°C, such as the PTCs or high-efficiency stationary collectors [24].

S. A. Kalogirou studied use of PTCs for hot water production for two types of applications, Hotels and Domestic. When PTC installed for domestic purpose it saves 379 cyprus pounds and it's payback period is 7.3 years for 4 m^2 collector area. When PTC installed in hotels it saves 4692 C.P. for 120 m^2 collector area [25].

P. Nandi et al. examined the production of tinned rosogolla at the Food Processing Division of MPS Food Products Private Limited in its factory at Dighisole village, Jhargram subdivision of West Midnapore district in the State of West Bengal, India. For cooking rosogollas, 101°C temperature is required and these rosogollas, after being canned, have a 6 months of shelf life. The total fuel consumption is about 60 litres per 250 cans of rosogollas. Setting up of PTC systems costs about 20000 Rs per system. The use of 60 litres of diesel fuel results in the emission of 162 kg of CO_2 per day at the factory of the company which was reduced by PTC system. The payback period of the system was analysed as 4.5 months [26].

B. Sadhana et al. applied cylindrical parabolic concentrator to sterilize medical equipment in remote area. For this application water was raised upto 100°C to achieve boiling point temperature and produce steam. In order to remove all bacteria related with various disease, saturated steam at least 121°C temperature needed to sterilize the equipment. This process must have to continue at least 15-30 minutes for proper sterilization of equipment. Autoclave is a device to sterilize the equipment. Currently, many electrical autoclaves are used which are operated by electricity. Unfortunately, in many rural area use of these type of technology is a challenge. To overcome this challenge parabolic concentrator is best option to produce saturated steam in autoclave to sterilize equipment and reduce risking the spread of infection [27].

Vivek Mahajan did a case study on installation of PTC at Zytex Biotech Pvt. Ltd. The company requires air at 180°C for spray drying process. This heat was generated by heating ambient air with steam produced by an LDO fired boiler. The system has been designed to serve 75% of the heat requirement for this process. The solar thermal heating system is fully integrated with the existing air heating process. This is done by installing a solar air heater before the existing steam based air heater. The two air heaters are placed in series, thus ensuring maximum utilization of solar thermal energy for the process. Thermic fluid circulated through the OptiTrough 300 collectors is heated up to 180°C using solar energy and flows through the solar air heater, thereby heating the air required for the process. The air is effectively pre-heated before entering the steam based air heater, thus reducing steam consumption for the process. By integrating the solar thermal system in this way, closely with the air heating process, its operating efficiency is maximized. The cost of the system to the client was 27 lakh, supported with MNRE subsidy of 6.48 lakh and a support of 2.0 lakh under UNDP–GEF project. The payback of the system was analysed to be less than four years [28].

Dr. R. P. Goswami did case study in Emmi Group, Switzerland. A 630 m^2 PolyTrough-1800 collector field has been installed at Emmi Group, the largest Swiss milk processor. The system is used for hot water generation at 130°C for process heating and cleaning at the Tete de Moines Cheese factory at Saignelegier, Switzerland. The system has been fully operational since then. The tracking system for the collector field includes brushless DC motors, GPS based guidance system and an in-built software for tracking the sun throughout the day. Reflectors are made out of Aluminium reflectors and are fabricated with foam and backsheet. The average optical efficiency for the collector field is around 65%. Since the weather is clean and it often rains, the cleaning frequency was analysed once a year. The PTC system uses water glycol mixture as a heat transfer medium and steam is produced indirectly through the heat exchanger. The overall system design and thermal storage is optimized for winter condition, and therefore storage size is limited to 1-2h storage only. The system therefore produces excess heat during peak summer days. The annual solar fraction for the system is around 15%. The average annual thermal efficiency is found to be 36%. The system can also be used for air-conditioning and power generation using ORC (Organic Ranking Cycle) turbine technology [29].

Klemens Jakob did a case study in the ham factory, Fleischwaren Berger Gesmb H& CO KG is located near Vienna. The factory requires hot water (at 70°C) and steam (at 4 bar, 140°C) for the ham production process. The heat was generated exclusively by oil fired boilers. It was estimated that 36 parabolic trough collectors would be sufficient for the requirement. The installation of SmirroTM parabolic trough collectors was started by Solera in July 2015. The first challenge was the rough terrain. One collector-line with ten collectors in series is 33 m long. These 10 collectors must be on the same level so that they can be tracked together by one motor. The use of parabolic trough collector not only increases the energy efficiency competitiveness of the process but also improves its ecological footprint with the significant reduction of CO_2 emissions. The use of solar thermal system will also make the company more immune from the price fluctuations of the fossil fuels. The installation of parabolic troughs in the company, Berger, is an important model for those industries with process heat applications. This installation shows to the entire food processing industry as well as other industries in Austria, a country which has moderate availability of solar radiation, that there is enough energy from the sun to support the energy consumption in the country [30].

Geetanjali Patil Choori did a case study on installation of PTC in Siddharth Surgicals at Valsad, Gujarat. Company have commissioned 263 m^2 accumulated area of concentrated solar at an investment of Rs 45 lakh. The solar field will produce 4.02 lakh kcal/day of energy displacing an average 40 kg of LPG on a normal sunny day. It is in hybrid mode with the existing LPG burner. The company is manufacturing surgical cotton, absorbent cotton wool, and soft cotton roll for use in pharmaceutical industry. A closed loop system is used to deliver heat to the process application. The hot water is allowed to pass through a heat exchanger tank containing the synthetic heat transfer fluid 'HTF Therminol 55'. This is then stored for short period until the surgical plant starts its operations at noon. Majority of thermal energy is consumed in the process of making surgical cotton. With the use of PTC, company saves LPG 40 kg/day, 3600 Rs/day and 100 tonnes of CO_2 per year. Payback period of the system was analyzed 2 years. The project has qualified for 30% capital subsidy under MNRE scheme and 15% under the UNDP–GEF project on concentrated solar thermal [31].

IV. BARRIERS IN THE GROWTH OF PTC FOR INDUSTRIAL PROCESS HEAT

There are still major market barriers for the utilization of solar process heat in spite of the fact that several R&D efforts and commercialization activities are going on, and of the fact that solar process heat applications are assessed to represent a large and yet untapped market. Following barriers are noted from literature review:-[32]

a. Awareness - Relatively due to low marketing and lack of knowledge

b. System cost - Like most renewable energy technology, SHIP systems have typically higher investment costs, but save conventional energies throughout operation. With current technology, financial payback times are often beyond commercial requirements.

c. Lack of technology - Many industrial processes require higher temperatures than the typical solar thermal applications (domestic hot water, space heating, swimming pool heating). New designs, sometimes new materials, are needed to cater for these higher temperature demands.

V. CONCLUSION

Concentrating collectors can make an important contribution to future solar heat and electricity generation. Concentrating collectors have ability to support the industry in decreasing their dependency on fossil fuels. Decentralised combined heat, cooling and power can be an interesting future option. In order to establish these technologies globally, further demonstration projects are required, as well as research and development in the field of small-scale thermal engines, system integration and collector development customised for target markets, to develop concentrating collectors as an important technology in future. In the past when Archimedes invention was given name as Archimedes' weapon which was found to be a destroyer but in the modern era, similar devices have been constructed for wellness of human being to fight against the global warming for saving the earth, crisis of conventional fuel and many other supplementary needs of day to day life.

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