Synthesis of steam through parabolic trough collector - A review

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ABSTRACT

KEYWORDS

Parabolic Trough Collector (PTC), Steam Generation System, Concentrated Solar Power (CSP).

From the early days of ancient Egyptians, human has known the power of the Sun. Solar energy is innocuous, and due to increasing enervation of fossil fuels, it has become essential for having alternate sources of energy. Over the years, researchers and technocrats have advanced in the technology of converting solar energy, obtained from sunshine to heat energy. This paper reviews the practical development of solar steam generation system through Parabolic Trough Collector (PTC), using concentrated solar power, and making all this happen in an economically feasible way. This paper reviews the design, construction, and optical proficiency of Solar Parabolic Trough Concentrator (PTC) with different reflector surfaces.

1.Introduction

The modern era has been dealing with the deficiency of energy, and the introduction of renewable energy sources is the need of the hour. Energy crisis and increased demand for energy have also spiked the energy costs. The current situation has compelled the industries, to use conventional fuels and for paying high prices to generate the same amount of heat that could be generated by a simple setup of renewable sources of energy. Solar energy is one such renewable, high exergy, radiant, and adaptable form of energy. With modern devices and techniques, the use of solar energy is made possible and economically feasible not only at industrial scale but also at small scale for the use at homes and commercial places in the form of solar heaters, boilers, and air heaters and also generate steam which is further used in cooking and for other purposes.

The primary requirement of most of the industries, i.e., thermal energy, which used to drive a range of simple and complex industrial processes, is called Industrial Process Heat (IPH).

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The thermal energy demand for IPH is generally below 300°C. According to Stadjuhar [1], 37.2% of the total IPH demand is utilized in the temperature range of 92-204°C.

The solar thermal collector works as a heat exchanger that transform solar radiation energy into internal energy of the transport medium. The significant component of any solar system is the solar collector. A collector is a device that absorbs the incoming radiation of solar energy and transmits or concentrates this energy onto a receiver. Solar collectors are either concentrating or non-concentrating type. In non-concentrating collectors, the collector area is much larger than the absorber area.

Among the two, concentrated plate collectors are more efficient and are capable of achieving high temperatures. There are various designs of concentrated collectors available currently like - parabolic trough collector, power tower, Fresnel concentrator, and parabolic dish collector. Among these, the parabolic trough collector is the most efficient.

The very first working module of a parabolic trough collector was developed by a Swedish engineer John Ericsson with a total collector surface of 3.25m2 and was able to drive the small steam engine of 373W. Later, in 1913, the

American engineer, Frank Shuman, designed and built a parabolic-trough collector solar plant in Egypt that produced 0.1 MPa saturated steam to drive a steam engine for pumping irrigation water for the farming community in Meadi, near Cairo.

In a parabolic trough collector system, a reflective surface made in the shape of a parabola, called collector, is placed to collect and reflect the incident solar radiation to the receiver or absorber, which is made in the shape of a tube and is placed at the point of focus of the parabolic trough. The tube or absorber gets heated up due to continuous and focused incident radiation from the collector, and this heat is transmitted to the fluid inside the tubes. The reflective surface of the collector must be highly polished to get better results.

The absorber tube is placed at the focal point of the parabolic surface to receive concentrated radiation. Also, different types of reflecting surfaces are used to get desired heating level. Material with high reflectivity is preferred to transmit most of the radiation to the absorber tubes. Fig. 1 shows the schematic diagram of a parabolic trough collector.

There are various advantages of parabolic trough collector over other flat plate collectors such as: -

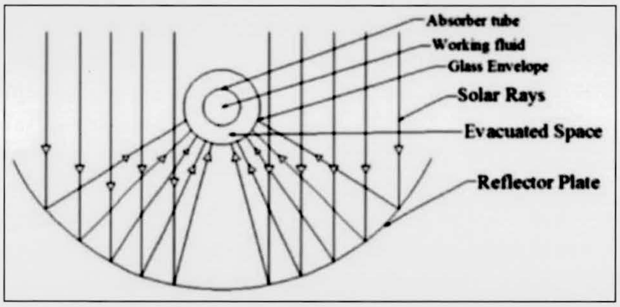

Fig. 1. Schematic diagram of a parabolic trough collector [3].

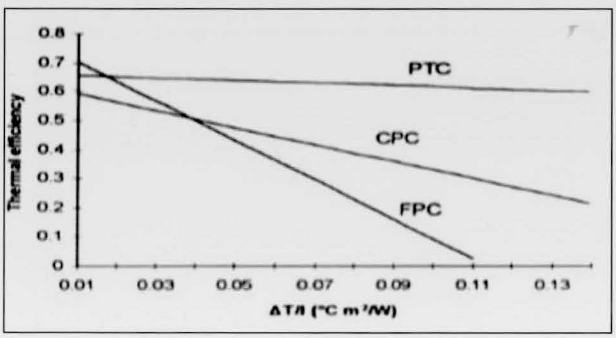

Fig. 2. Collector performance curve [5].

1. Higher temperature is achieved by the working fluid in concentrated systems such as a parabolic trough collector as compared to other flat plate collector systems.
2. These systems are thermally more efficient due to the smaller heat-loss receiver area.
3. The PTC systems have higher energy quality as compared to FPC systems [4].
4. The PTC technology has proved to be robust and delivers excellent performance in commercial power industry which also proves its reliability. [15]

From Fig. 2, it is comprehensible that the efficiency of PTCs remains very high as compared to FPCs and other concentrated plate collectors (CPC). At 100 °C, that corresponds to a ΔT/I value of 0.1, the working efficiency of PTC is about 62%, CPC is about 32%, and the efficiency of FPC is about 10 %. Therefore, from the collector-performance curve it is clear that PTCs are a better and more efficient option as compared to other solar plate collectors [5].

Further generation of steam from the parabolic trough collector system involves other devices and techniques which are discussed in this paper.

2. Description of Parabolic Trough Collector

A parabolic trough collector is such kind of solar collector that has one curved reflective surface in the shape of a parabola and an absorbing surface, which is generally the outer surface of the horizontal absorber tube placed on the focus of the parabola. The incident sun rays fall on the reflector surface parallel to the plane of symmetry of reflector. In this very plane, only the focal point lies, which is at the intersection of all such planes which are perpendicular to the reflector surface.

For steam production purposes, a collector tube containing fluid is placed at the focus of the parabolic reflector surface. The sun rays are focused on the tube, and the fluid inside the collector is heated by the thermal energy of the sun. The heated fluid is then carried away through the pipes. The heat transfer fluid can be air, water, or synthetic oil. The reflective surface of reflector is desired to have high reflectivity and the absorber tube is required to have very low reflectivity or emissivity but high absorptivity.

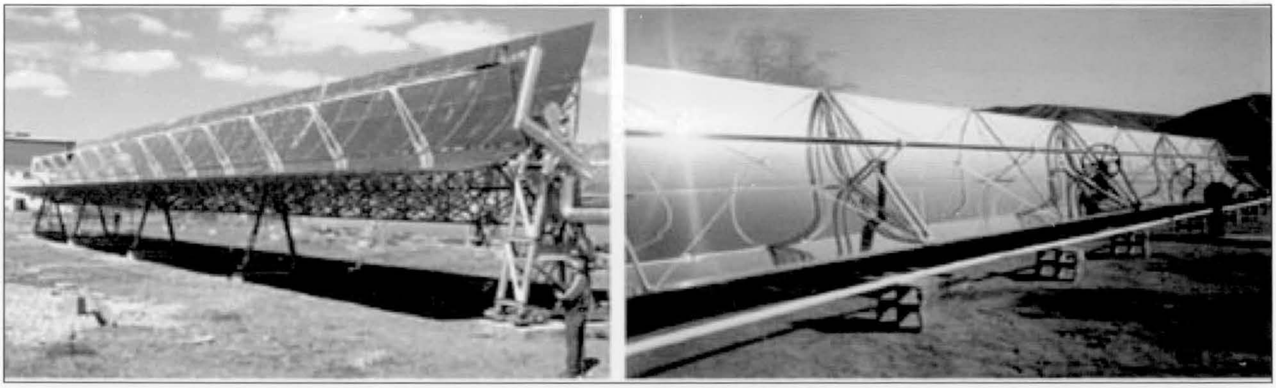

Fig. 3. Parabolic trough collector.

2.1 Mirror material

Silvered polymer reflectors, Aluminium mirrors, Silvered mirrors and Aluminium–silver alloy reflector mirror [6] are some common mirror types used as reflectors in parabolic trough collectors. Although there are various other materials used on reflector surface and various reflectors made of different materials with different properties are available.

2.2 Receiver tube

The stainless steel receiver tube are used for low temperature operations as in high temperature these tubes show frequent deformation and the glass envelope tends to rupture as observed by Fuqiang et al. [19] therefore the solution this problem was proposed by Almanza and Flores [20-22], where a compound tube made of copper and steel was used instead of normal steel tube receiver. Also, an eccentric receiver tube was proposed by wang et al. for reducing the thermal stresses [9]. The recent advancements in receiver or absorber tube material show that glass tube made of low iron-borosilicate glass, developed by Morales et al. increases transmittance for solar radiation [23]. A study shows that stainless steel and silicon carbide materials have much higher temperature gradient and effective stresses as compared to aluminium and copper materials [19]. High absorptance and low reflective material coating could also serve the purpose as 98% of incoming solar radiation is below 3μm wavelength [26].

2.3 Tracking system

A tracking system is used to ensure that the sun-rays falling on the reflector surface is always at the right position for maximum efficiency of PTC. Various kinds of tracking system are available these days ranging from programmed or software-controlled tracking system to timer controlled motorized system. Also, among single axis tracker and rotatable axis tracking system, the rotatable axis tracker system is more efficient and better than the single axis tracker system as shown by the study of Peng et al [24]. He demonstrated that the annual solar-field efficiency of the rotatable axis tracking system could reach about 59% whereas an efficiency of 55% is achieved with single axis tracer system.

3. Application of Parabolic Trough Collector

Parabolic trough collector serves as the medium to convert the solar energy to thermal or heat energy and it is the application which decides the design and integration of the collector with other devices for making the setup specific situation. Thermal energy has immense application and so do parabolic trough collector. Here some of the important applications of PTC are discussed below.

3.1 Air conditioning and refrigeration

The air conditioning is one of the most important industrial processes. These systems also find applications in the commercial and domestic arena in hot-weather conditions where the electricity demand and prices increase drastically. Although, the main reasons for this growing energy demand are the increased thermal loads, improved living standards and occupant comfort demands, and architectural characteristics and trends, such as an increased ratio of transparent to opaque areas in the building envelope [7]. The refrigeration requirements in the food processing industry and the improved conservation of pharmaceutical products in developing countries has led to the development of air-conditioning and refrigeration systems. These systems are powered by renewable energies, especially solar thermal energy, which works efficiently, and in some instances, approaches competitiveness with conventional cooling systems. In addition to being green energy and environmentally friendly, Solar energy is very suitable for air-conditioning and refrigeration demands because solar radiation availability and cooling requirements usually coincide seasonally and geographically. Solar air-conditioning and refrigeration facilities can also be easily combined with space heating and hot-water applications and with passive solar techniques, increasing the yearly solar fraction of buildings. The Coefficient of Performance (COP) is higher for a LiBr–H2O double-effect than for a single-effect absorption chiller. Still, it requires thermal energy at temperatures of 140–160 °C [7], at which the performance of conventional collectors is not good enough. As PTCs are highly efficient at these temperatures, the combination of these two systems is of great interest [9]. Connection of NH3–H2O absorption chillers to a solar system requires solar collectors able to work efficiently at temperatures above 95 °C [7], such as the PTCs or high-efficiency stationary collectors. Air-conditioning and refrigeration facilities driven by a PTC solar field are still infrequent.

3.2 Power generation

Power production is also one the main applications of PTC, where steam produced from PTC is used to turn the fins of turbines. The classical method of production of electric power by burning fossil fuels for producing steam and then feeding this steam produced by PTC into the turbine. In solar steam method, the driving force of the steam is used to rotate the turbine blades which drives the generator for production of electricity.

3.3 Humidifier

Many large commercial and industrial facilities, especially in colder climates, use low pressure saturated steam as the predominant heat source for indoor seasonal heating. HVAC coils, often combined with steam humidifiers, are the equipment used for conditioning the air for indoor comfort, preservation of books and records, and infection control. When the cold air is heated by the steam coils, the relative humidity of the air drops, and it must then be adjusted to normal levels with addition of a controlled injection of dry saturated steam into the downstream air flow.

3.4 Pre-heater

The classical furnace oil boiler used for the production of steam uses fossil fuels such as wood, for the production of steam but the steam production causes lots of capital and a lot of natural fossil fuel is burned, especially in mass steam production. This can be improved by integrating a PTC system as a pre-heater for feed water boilers. The incoming supply of water to the boiler is fed into the PTC system where water is pre-heated and then it is fed into the boiler. This method can save a large amount fuel which is burnt away and the capital invested in the production of steam. Also, the overall boiler efficiency is improved and the scaling of boiler is reduced causing increased life of the boiler.

3.5 Desalination

The process in which the sea water is converted into fresh water is referred to as the desalination process. Generally, desalination is done through a reverse osmosis method. Toluene and water as heat transfer fluids showed better performance at super heated temperature compared to butane and hexane [10]. The various working fluids like dodecane, nonane, octane, and toluene are examined using parabolic trough collectors for the extraction of heat from solar energy. Minjur sea water desalination plant is the biggest desalination plant in India and is working with reverse osmosis Process. The application of PTC in a desalination process makes it more economical and cost-effective compared to an electrical operation that requires numerous electrical grids etc. Solar energy for desalination purposes finds good applications in making fresh water. Jafari et al. designed and manufactured a new desalination system that purified water using a PTC with a copper tube as the absorber tube [29].

4. Literature Review

4.1 Performance analysis

The work on solar parabolic trough collector had been carried by a number of researchers over a period of time. Here is a short literature review of solar parabolic trough collector. PTC consists of a reflective surface and a collector surface and is placed on a rigid structure. According to

Bellos et al., the two parameters i.e. absorber geometry and working fluid type became increasingly effective in increasing the thermal efficiency by enhancing the heat transfer between the working fluid and receiver tube and resulted an overall increase in the thermal efficiency by 4.55% [31]. Garcia-Cortes et al. [11] observed that the weight of the solar collector itself is the reason for its deformation. A study carried by Naeeni et al. [25] shows that adjusting the collector orientation with wind flow decreases the pressure field around the collector 15-20 times than at the collector aperture area. The coupling issue of solar thermal power with the coal-based thermal power plant was resolved by Kalogirou and it saved 24% of coal consumption [13]. These researches have paved the way for modern developments in PTC. Zarza et al. [17] studied the direct steam generation system through PTC and concluded that direct steam generation is feasible and cost-effective way of steam production with appropriate design and technology.

Aerodynamics also affects the thermal efficiency of PTC. Hachicha et al. studied the improvement of thermal efficiency by observing the aerodynamic aspect of the PTC and the heat transfer phenomenon associated with it.

4.2 Thermal efficiency

The improvements in thermal efficiency and thermal model of PTCs available, are an outcome of series of researches and experiments carried by the scholars to make solar energy more available in an efficient way. The solar tracking system is the most important in improving the thermal efficiency. It ensures that the sunlight always falls over the collector plate throughout the day. Euro trough 100 and Euro trough 150 are the PTCs developed by Michael and Eckhard, has a mirror reflectivity of 94% and weighs over 15 kg. The efficiency of the collector was higher if the incidence angle is higher than 30°[14]. A two-axis sun tracking system is designed by Bakos which has increased the thermal efficiency by 46.46%. The absorbers are made of metal pipe but a better coating around the absorber improves both the solar absorption ability and also the emittance is also less.

Temperatures up-to 400° have been achieved by Price et al. using synthetic oil as working fluid [15]. Yaghoubi et al. have presented experimental analysis of heat loss in the absorber tube showing that heat loss in lost vacuum tube is about 40% higher than in the vacuum jacket tube which results in a 3–5% decrease in the collector efficiency [16]. Insulation also plays a vital role in improving the efficiency of the collector. According to Thomas et al. the heat loss from pipes and valves left uninsulated is about 0.5 to 1 m of uninsulated piping. The solar field piping can be improved by using by-passes as suggested by Zarza at al. during the start-up of the system to reduce time required to achieve a particular temperature and pressure for operation [17]. A thermal model of direct steam generator was developed by Saad SE. et al. and it was found that reducing the absorber tube diameter for a given collector area increases the collector efficiency due to reduced heat loss [18].

To increase the thermal efficiency, one major step is to reduce the thermal losses. The heat takes place via three modes of heat transfers namely, conduction, convection and radiation. Among them, the convection heat loss is due to fluid movement from one place to another. Hence, better geometrical structure would result in reduced heat losses [27]. According to Vasquez et al. [12] who analysed the one-dimensional heat transfer and concluded that 41.8% of convection heat loss results in an improvement of performance. Also, for better heat transfer within fluids, Waghole et al. utilized twisted tape inserts and silver Nano fluid inside the absorber tube of PTC to enhance heat transfer [28].

5. Conclusion and Future Scope

CSP Technologies offer many advantages over conventional plate collectors and are associated with higher operating temperatures, greater system efficiencies. This also reduces the usage of non-renewable and exhaustible energy sources. The present review paper provides a comprehensive review of steam generation through a parabolic trough collector. This paper covers the know-how, applications of solar parabolic concentrator, the material used in its construction and method of manufacturing. It is very clear from this paper that PTC is an inexpensive technology and do not require complex manufacturing techniques. The parabolic trough collector used for generation of steam is a very viable technology. Over the years, the researches carried over PTC have improved the modelling and overall efficiency up-to such level that commercialization of PTC has become possible. For effective and efficient industrial processes, integration of PTC for using solar power has proved the practicality of PTCs. Also, direct steam generation with high pressure is also one of the important scopes of PTC.

6. Acknowledgement

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