IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X,
PP 17-20
www.iosrjournals.org

Solar Parabolic Trough - A Review of Performance Analysis

Kavya Dwivedi[1], Prashant Jain[2]
[1]*M.Tech. Scholar, Mechanical Dept., K J Somaiya College of Engg., Mumbai.*
[2]*Assistant Professor, Mechanical Dept., K J Somaiya College of Engg., Mumbai.*

Abstract: *Solar technology offers great potential in terms of supplying the world's energy needs. However its contribution to the energy market is very limited. The main factor for it is its high initial cost and low efficiency of system. Thus, in order to encourage and facilitate studies about the solar concentrator this paper is concerned with the detail study of parabolic trough collector. Working principle as well as performance analysis is discussed further. Using the energy equations, thermal efficiency of the system can be predicted.*
Keywords: *Solar energy, energy market, solar concentrator, parabolic troughcollector, thermal efficiency.*

I. Introduction

Energy and water are the two main issues in this century. All efforts are done to tap the solar energy and make it viable. In current scenario, a need exists to develop alternative energy sources which can fulfill the increasing energy needs of the world. The primary sources of alternative energy which have potential in future are as classified as follows:

1. Solar energy
2. Nuclear energy
3. Biomass energy
4. Other sources like geothermal energy, tidal energy etc.[1]

Solar energy is a very, inexhaustible source of energy. The power from the sun received by the earth is approximately 1.8x 10^{11} MW which is many times more than the present consumption rate[2] . Thus in short, it can supply all the future energy needs of the world on a regular basis. In addition, the two main advantages of solar energy are, unlike nuclear and fossil fuel it is an environmentally clean source of energy and the other is it's availability in adequate amount all over the world. However there are issues related with it because of which we cannot utilize it to it's fullest. Various methods are used to convert solar energy into useful heat energy directly or indirectly. In this paper we will discuss about the solar- thermal conversions. Solar high temperature designs need concentration systems, such as parabolic reflectors. Solar thermal power plants with concentration technologies are important thing for providing the bulk solar electricity needed within the next few decades.

Four concentrating solar power technologies are developed:

1. Parabolic trough collectors (PTC)
2. Linear Fresnel reflector systems (LF)
3. Dish engine systems (DE)
4. Power towers or central receiver systems (CRS) [3]

In PTC, sun's image is formed on the focus of the parabola. Many commercial versions of this type are now available.

Concentration can also be achieved by the use of lenses. The most common one is Fresnel lenses. It is basically a thin sheet, flat on one side and with the fine longitudinal grooves on the other. The angles of them are such that radiation is brought to line focus.

In order to achieve higher concentration ratio and temperature it becomes necessary to have a point focus than linefocus. Such collectors can have concentration ratio from 80 to few thousands and have yielded a temperature up to 2000^{o}C[1]

To accumulate larger amount of energy at one point, the central receiver concept has been established. In this case, beam radiation is reflected from a no. of independently controlled mirror called heliostats to central receiver located at the topmost of a tower.

II. Working Principle of PTC

Parabolic troughs currently represent the most cost-effective solar technology for developing large utility-scale solar electric power systems. These systems are also one of the most mature solar technologies, with commercial utility-scale plants that have been operating for over 20 years.[4]

Solar line concentrators are primarily installed parallel to the ground and have rotating focus. These are mostly used for power generation through steam route. A parabolic trough is a type of solar thermal collector that is straight in one dimension and curved as a parabola in the other two. It has a lined with a polished metal mirror. The energy of sunlight which enters the mirror parallel to its plane of symmetry is focused along the focal line, where objects are positioned which are intended to be heated. For example, food may be placed at the focal line of a trough, which causes the food to be cooked when the trough is kept, so the sun is in its plane of symmetry. For other application, there is often a tube, which runs the length of the trough at its focal line. The mirror is focused so that sunlight which it reflects is concentrated on the tube, which contains a fluid which is heated to a high temperature by the energy of the sunlight. It is then is sent to a heat exchanger to generate high-pressure superheated steam. The steam is used to power a conventional Rankine cycle steam turbine/generator, which produces electricity. The trough is generally aligned on a north-south axis, and rotated to track the sun as it travels across the sky each day. A parabolic trough is made of a number of solar collector modules (SCM) fixed together to move as one solar collector assembly (SCA).As the lengths of these solar concentrators are very long, it is almost mandatory to have these solar concentrator mounted on ground with axis parallel to the ground. Such concentrators have following limitations:

- Such concentrators suffer from high cosine losses.
- These concentrators need recirculation pump for thermic fluid or pressurized water, which also consumes auxiliary power.
- Conventional systems also need multiple rotary jointsand complex sensor based tracking system.
- Secondary heat exchanger or flash tankis required for generating steam. Direct steam generation is not possible.

Parabolic trough power plants use concentrated sunlight, in place of fossil fuels, to provide the thermal energy required to drive a conventional power plant. These plants use a large field of parabolic trough collectors that track the sun during the day and concentrate the solar radiation on a receiver tube located at the focus of the parabolic shaped mirrors. A heat transfer fluid passes through the receiver and is heated to temperatures required to generate steam and drive a conventional Rankine cycle steam power plants. As of 2014, the largest solar thermal power systems using parabolic trough technology include, the 354 MW SEGS plants in California, the 280 MW Solana Generating Station that features a molten salt heat storage, the 250 MW Genesis Solar Energy Project, that came online in 2014, as well as the Spanish 200 MW Solaben Solar Power Station, the 200 MW Solnova Solar Power Station, and the Andasol 1 solar power station, using a *Eurotrough*-collector.[5]

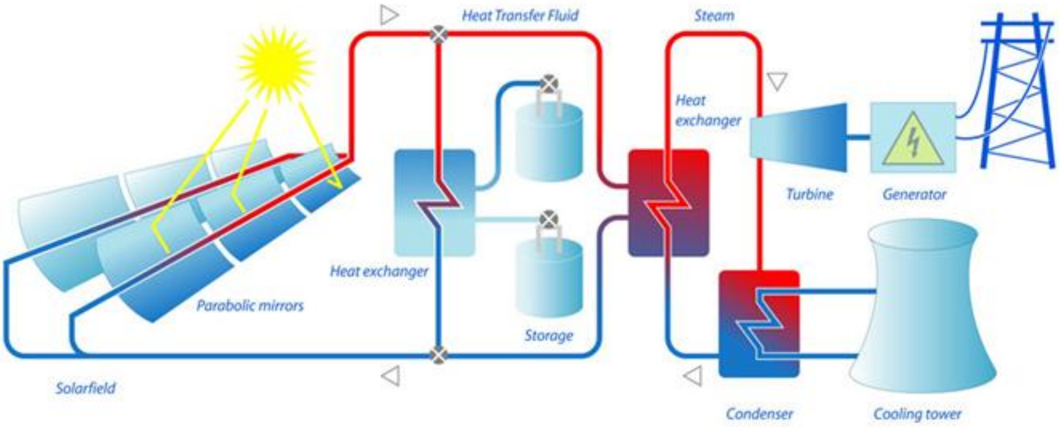

Figure 1: PTC Solar Power Plant

III. Performance Analysis of PTC

The solar radiation falling on the concentrator is reflected to the receiver (absorber tube) located at the focal line through which working fluid runs and which is covered by concentric-transparent glass cover. As the temperature in the receiver rises, heat transfer processes starts. Energy in transition under the motive force of a temperature difference between components of the collector forms the basis for the determination of heat gained and heat losses to and from one component to other.

The elementary components for thermal analysis of the PTC are as follows:

- The concentrator or reflecting surface.
- A receiver assembly consists of a circular receiver tube with selective coating, enclosed inside a concentric-transparent glass-cover.
- The working fluid.

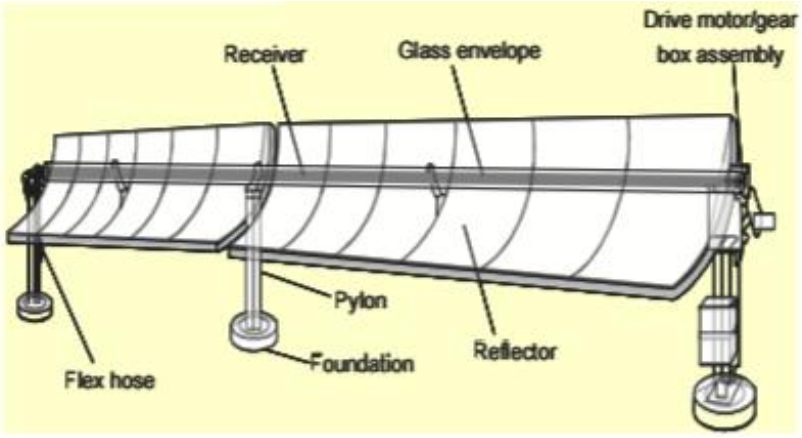

Figure 2: Parabolic Trough Collector.

\Energy balance equations for a PTC by Egbo [6] considered the heat-energy-gain, the heat energy-loss and the heat-energy-transfer between the components, i.e. the reflecting surface, the glass-cover and the absorber-tube, the thermal properties of the materials of the components and geometric dimensions of the PTC. The equation for the enveloping glass-cover temperature developed by Egbo[6] is given as follows:

➢ **Energy Equations for the Enveloping Glass-Cover:**

The energy balance equation for the enveloping glass-cover can be written as follows

$$2\alpha_g RL\left[(I_{beam} * R_b) + I_{diff}\right] + \rho_c \alpha_g \left[\frac{(W-D)\,L}{\pi}\right](I_{beam} * R_b) + \frac{A_t \sigma\left(T_t^4 - T_g^4\right)}{\frac{1}{\varepsilon_t} + \frac{A_t}{A_g}\left[\frac{1}{\varepsilon_g} - 1\right]} - \sigma \varepsilon_g A_g\left(T_g^4 - T_{sky}^4\right) - A_g h_c\left(T_g - T_{sur}\right) = m_g c_{p_g}\, dT_g/dt$$

The ratio of the beam radiation flux falling on a tilted surfaces to that falling on horizontal surface is called tilt factor for beam radiation. It is denoted by r_b and it is given by:[1]

$$R_b = \frac{\cos(\phi-\rho)\cos\delta_t \cos h_t + \sin(\phi-\rho)\sin\delta_t}{\cos\phi\cos\delta_t \cos h_t + \sin\phi\sin\delta_t}$$

➢ **Heat Gained and Heat Lost by the Absorber-Tube**:

The energy balance for the absorber-tube can be written as in equation as follows:

$$\alpha_t \tau_g\left(\frac{2RL}{\pi}\right)\left[(I_{beam} * R_b) + I_{diff}\right] + \alpha_t \tau_g \rho_c\left[\frac{(W-D)L}{\pi^2}\right]\left[I_{beam} * R_b\right] - \frac{A_t\sigma\left(T_t^4 - T_g^4\right)}{\frac{1}{\varepsilon_t} + \frac{A_t}{A_g}\left[\frac{1}{\varepsilon_g} - 1\right]} - \frac{A_{in}\left(T_t - T_f\right)}{\left[\frac{1}{h_f} + \frac{A_{in}\ln\left(\frac{r}{r_i}\right)}{2\pi KL}\right]} = m_t c_{p_t}\, dT_t/dt$$

➢ **Energy Equation for the Working Fluid**:

The equation for the fluid temperature established by Egbo et al,[10] is given as follows:

$$\frac{A_{in}\left(T_t - T_f\right)}{\left[\frac{1}{h_f} + \frac{A_{in}\ln\left(\frac{r}{r_i}\right)}{2\pi KL}\right]} - \frac{2A_c\left(T_f - T_{surr}\right)}{\frac{1}{h_c} + \frac{1}{h_f}} = m_f c_{p_f}\, dT_f/dt$$

Where mass of the working fluid (m_f), specific heat capacity of the working fluid (C_{pf}) and temperature gradient of the working fluid, (dT_f/dt)

- **Thermal Efficiency of the Parabolic-Trough Collector**

The hourly heat given to the receiver tube (Q_{input}) is as follows:

$$Q_{input} = [(I_{beam} * R_b) + I_{diff}][WL]$$

The total heat losses in the system (Q_{losses}) are considered as the sum of the radiative heat-loss from the surface. The total heat losses in the system (Q_{losses}) is considered as the sum of the radiative heat-loss from the surface of the enveloping glass-cover to the surroundings (q_{r2}), the convective heat loss from the surface of the enveloping glass-cover to the surroundings (q_c) and the conductive/convective heat loss from the fluid to the surroundings (q_1). This can be expressed as follows:

$$Q_{losses} = q_{r_2} + q_c + q_1$$

The thermal efficiency of the Parabolic-trough Collector is given by:

$$\eta_{th} = 1 - \frac{Q_{losses}}{Q_{input}}$$

IV. Conclusions

Advantages like use of clean fuel, ease of availability of sun light, use of simple system, desired high concentration ratio etc. makes PTC more approachable and user friendly. Despite of so many advantages, its contribution to the world's energy market is still very limited. Solar concentrator can bring down the total cost and thus make the solar technology cheaper and affordable. Even if there are many PTC design available losses like cosine losses, end loss effect, heat losses from the HTF are common[7] which have the potential in improvement of the design and hence increase in the efficiency of the whole system.

References

[1]. Sukhatme S. P. (2007), Principles of Thermal Collection and Storage, McGraw Hill Publication.
[2]. Duffie and Beckman (2005), Solar Engineering of Thermal Processes, Fourth edition,
[3]. https://www.researchgate.net/publication/228348640_Solar_Concentrators.pdf
[4]. http://www.nrel.gov/docs/fy07osti/41424.pdf [Accessed February 2017]
[5]. NREL.gov Concentrating Solar Power Projects in the United States, 17 February 2014
[6]. Alvarez M.R. and Zarza E., 'Concentrating Solar Thermal Power', Hand Book of Energy Efficiency and Renewable Energy, pp. 212 - 216,
[7]. http://www.greenworldinvestor.com/2011/07 [Accessed March 2017]