International Journal of LNCT
Volume-5 Issue-26 October -2021
ISSN: (Online):2456-9895

STUDY OF PARABOLIC TROUGH TYPE SOLAR THERMAL COLLECTOR

Nishant Kumar Jha
M.Tech Scholar
Dept. of Mechanical
Engineering, LNCT BHOPAL

Dr.Shailendra Dwivedi
Dept. of Mechanical
Engineering
LNCT BHOPAL

ABSTRACT

The solar parabolic trough collector technology is one of the most reliable technologies in the field of solar thermal. This is due to the fact that temperatures as high as 300^0 C can be achieved using this technology. This technology is used for Solar thermal applications such as hot water production, process steam requirement, power generation and many more. Fabrication and performance analysis on a solar parabolic trough collector is performed and designed is done in this present study. To evaluate the performance of the system, different parameters of the system such as material of the receiver tube is chosen for the study. Some Area of Applications of the produced hot water in this campus is figure out.

INTRODUCTION

In today's world of crisis of energy while fossil fuels are the main fuels for thermal power there is a fear that their existence will be limited and it will get exhausted ultimately in the coming years. Therefore, many countries are trying other systems based on non-conventional and renewable sources. These are solar, wind, sea, geothermal and biomass. These are called renewable or alternative sources of energy.
Solar energy has the greatest potential of all the sources of renewable energy and it will become one of the most important sources and supplies of energy if only a small amount of this form of energy could be used, mainly when the rest of the sources are getting depleted in the country.
The amount of depletion of solar radiation depends upon the amount of dust particles, water vapor, ozone content, atmospheric pressure, cloudiness, etc., and on solar altitude. Areas lying on the earth between 35° N to 35° S latitudes receive maximum solar radiation. India is among countries that are blessed to have sufficient amount of solar radiation. It is located north of the equator between 8°4' to 37°6' latitude.
Solar energy collection requires a certain kind of setup by which the available energy can be trapped and utilized effectively. To collect solar radiation and transfers the energy to a fluid passing in contact with it is known as a solar collector.
Various solar energy collection and conversion systems like water heaters, air heaters, solar air-conditioning and water distillation systems, green houses, solar stills, solar cookers, solar dryers and solar furnaces, etc., have been developed.
Solar thermal systems have been found to be economically most attractive in actual applications. In all such systems, a solar collector is the most important element. A solar collector is a special kind of heat exchanger that transforms solar radiation into heat energy. Several designs of the solar collectors have been developed.
These are general of two types:

1. Non concentrating or flat plate type solar collector
2. Concentrating type solar collector

FLAT PLATE COLLECTORS

Where temperatures below 90°C are adequate, flat plate collectors are particularly convenient. Flat plates can absorb both direct and diffuse solar radiation. It consists of transparent cover, tubes, fins or channels are integral with the collector absorber plate, which carry the water. Standard insulating materials such as fiber glass or styro-foam are used for this purpose. A flat-plate collector is installed at a fixed position facing the sun at an optimum inclination to the horizontal depending on the latitude of the location. Water heating is its major application which can be used for different purposes like domestic use (cleaning of utensils, clothes and bathing), industrial use (coloring, heating of secondary fluid), etc. As shown in Figure, a flat plate collector consists of five components as follows:
Cover plate: Its work is to entrap short-wave solar radiation falling on it by transmitting and converting them into long wave radiations. For the long wave radiations, it works as an opaque surface. Glazing is done on it, to increase its efficiency. Toughened glass and transparent plastic covers are used as cover plate.
Absorber plate: Its work is to absorb all the solar radiation falling on it and transmitting it to the tubes. It is mainly made up of Copper (Cu). Selective coating of black chrome, nickel black, copper oxide, etc., is being done on it to increase its efficiency.
Flow tubes: Its work is to transmit the energy taken from absorber plate to the fluid flowing through it. It is also made up of Copper (Cu). These are connected to the storage tank where hot water is being kept, through header pipes.

Insulation: Its work is to stop transmission of the heat energy through the bottom and side surfaces. Mainly made up of glass wool, Rockwool and so on.

Enclosure: Its work is to support the above-mentioned components and is made up of iron sheet, wood.

Sun Tracking Systems

1. Point Focus Mounting

Point focus solar concentrators are mounted in a fully tracking mode. This to the fact that the image formed is very small and to keep the image focused on the absorber requires accurate adjustment of the reflecting or refracting surface.

The maximum amount of available solar radiation as a function of season for latitudes 30° and 45° for tracking mounting is shown in Fig. The maximum amount of solar flux as a function of time as a day is shown in Fig. These two sets of curves are, in general, used as reference curves for concentrator mountings.

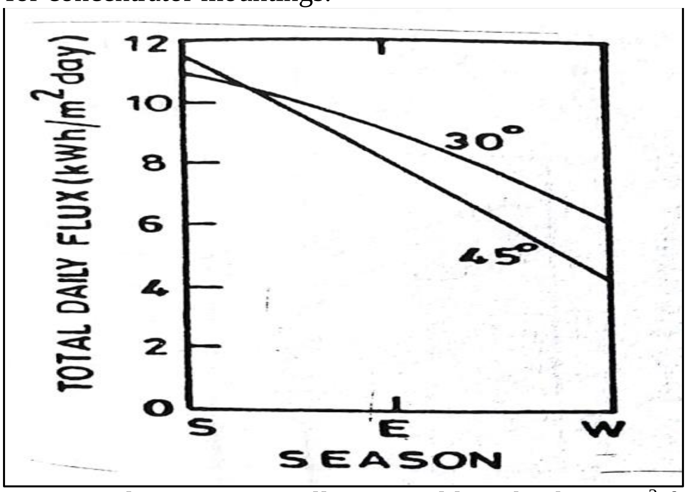


Fig 9. Daily maximum collector Yields in kWh per m^2 for 30 and 45-degree latitude

Fully tracking mounting can have several geometries. The polar mounting Fig., is the simplest of all mountings. In this, one axis of the on contractor is kept parallel to the earth's axis and the second axis is orthogonal to it. In such a case the daily solar motion requires tracking about the polar axis only. In order to account for the seasonal motion of the sun in declination, adjustments can be made in the alignment of the axis of the concentrator at infrequent times during the day.

Non-polar mounting generally require motion about two axis which is non-linear in nature. The common non-polar mounting is the altitude azimuth mounting in which one axis is vertical while the other is horizontal. This type of mounting is particularly advantageous because of the least engineering complications in the design of its support.

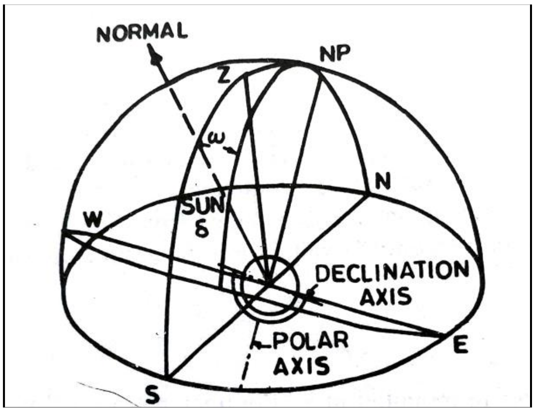


Fig Diagram of the polar mounting For a fully tracking collector

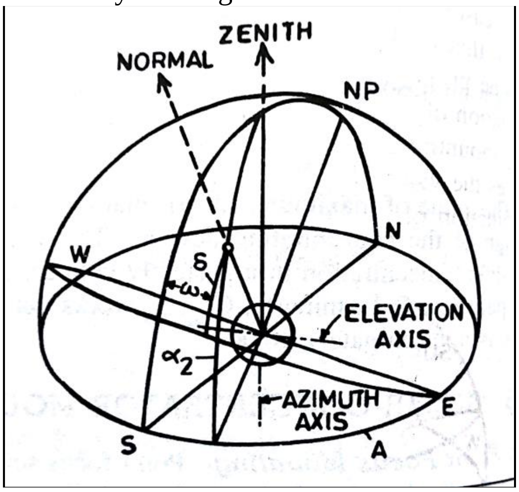


Fig 12. Diagram of the altitude azimuth mounting for a fully tracking collector

2. Line Focusing Mountings

Line focusing solar concentrator systems require one axis tracking only and therefore a variety of mounting geometries are possible. Three important configurations are given below:
(i) **Polar Mounting**: Fig. shows the basic geometry of the polar mounting. The axis of rotation of the system is pointed towards the pole of the earth. Due to seasonal variation in declination, the sun is 23.5 degree north or south of the normal to the mirror at noon. The minimum value of the cosine projection factor is only about 0.92 and therefore, the difference between winter, summer and equinox performances will be small. The variation of seasonal output for the polar mounting is shown in Fig.

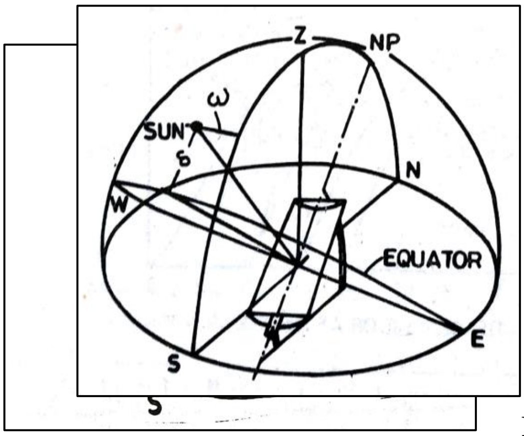


Fig.Schematic diagram of a polar Mounting of a cylindrical mirror.

(ii) **N-S Horizontal-EW Tracking**: The north-south horizontal mounting with east-west tracking to follow the sun is shown in Fig In this case the seasonal performance is considerably different from that of a polar mounted concentrator as the cosine projection factor for winter is small. The variation of seasonal output for the NS-EW tracking mounting is shown in Fig.

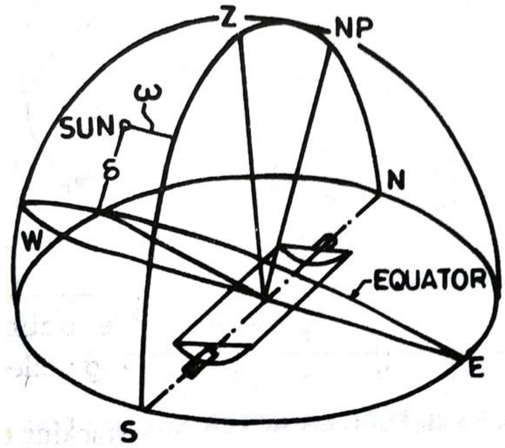


Fig A NS horizontal tracking

(iii) **EW Horizontal - NS Tracking**: Fig. shows the basic geometry of the east-west horizontal mounting with north-south tracking. This mounting mode provides better performance in winters in comparison to NS horizontal configuration. However, its diurnal energy collection shows a peaked noon time performance similar to a stationary horizontal flat plate collector instead of nearly flat diurnal performance of a fully tracking collector. The seasonal variation of output for this configuration is given in Fig.

LITERATURE REVIEW

Parmpal and Cheema 1976 researched an examination of the execution of a barrel shaped parabola authority with respect to the measure of vitality gathered, improvement of its different parameters and that the utilization of opening of a tube-shaped parabola gatherer as a quality's measurement is by all accounts more sensible than the utilization of the central length. The warmth balance on the safeguard demonstrated that the dimensionless temperature (proportion of the safeguard temperature to the stagnation temperature) totally predicts the execution of the authority. The greatest temperature achieved by the safeguard for zero vitality extraction, called stagnation temperature.

Ramsey and Gupta 1977 assessed the execution of the PTSC by utilizing three unique safeguards; a dark painted cylinder intended to work close surrounding temp, a warmth pipe which had a particular sun powered safeguard covering connected to its surface, and a warmth pipe which had it surface covered with nonselective dark paint. The pinnacle productivity for the gatherer without warmth misfortunes is around 62% when the approaching sun powered vitality is typical to the authority gap. The misfortunes which happened at raised temperatures (300 ^{o}C) diminished the pinnacle efficiencies to half and 30%, separately, for the specifically covered and dark painted cylinders.

Derrick 1979 dissected and thought about between the compound allegorical and basic explanatory sunlight-based gatherers for their capacity to acknowledge non-coordinate radiation and for their separate reflector bend lengths. For fixation proportions more prominent than around 10, the basic allegorical concentrator has the favorable position, on the grounds that the compound explanatory reflector cost is more than 4.4 occasions as costly. In any case, the straightforward explanatory trough might be more financially savvy than the compound illustrative concentrator.

Clark 1982 concentrated the guideline configuration factors that impact the execution of a PTSC. Factors, for example, unearthly directional reflectivity of the mirror framework, the mirror-recipient tube block factor, the episode edge modifier, the end misfortune, impact of following blunders and collector tube misalignment were considered for examination.

Jeter 1983 concentrated geometrical impacts on the execution of PTSC, it focused on end-impact. The outcomes demonstrate the essentialness of end-impacts especially increments when short troughs are considered and end of this impact is critical in acquiring test results.

The American organization Luz International Ltd., established in 1979, structured three age of PTSC, called LS-1, LS-2 and LS-3, introduced in Solar Electric Generating System (SEGS) plants. The initial two ages of gatherers, LS-1 and LS-2, comprised of comparative congregations, mounted on a structure of comparable length, yet the opening width of the LS-2 authority was twice that of the LS-1 authority. The structure depends on an inflexible basic help tube, called the torque tube, which underpins the steel profiles to which the explanatory mirrors are joined. In the LS-3, the torque tube is supplanted by a metal grid system, the opening width is 14% more extensive than the LS-2 and authority length is multiplied.

Thomas 1994 built up an example structure of PTSC to think about its avoidance and optical attributes under different load conditions. In the nonappearance wind burrow offices, the test gives adequate data about the impact of twist stack on the optical execution of a PTSC.

Odeh et al. 1998 did the execution investigation of PTSC with manufactured oil and water as working liquids. The definitions for proficiency of sunlight based explanatory trough gatherers have been produced dependent on safeguard divider temperature to foresee the execution of the framework with any working liquid. The warm misfortunes from the trough gatherer have been portrayed in wording safeguard, emissivity, wind speed, safeguard divider temperature and radiation level of the mirror framework, the mirror-recipient tube capture factor, the episode edge modifier, the end misfortune, impact of following mistakes and beneficiary cylinder misalignment were considered for investigation.

Umamaheswaran 2005 displayed think about points of interest of the development, testing and examination of PTSC for little scale local reason water refining application. Ground water is warmed by the sun powered radiation as it flows along the sun based authority inside a safeguard pipe with the end goal to produce steam straightforwardly into the safeguard pipe.

Miguel and Javier 2006 built up the plan of a PTSC called (SENER) and the point of the exploration was to lessen cost of development of the concentrators. Two model modules of SENER trough have been mounted and tried at the CIEMAT-PSA offices. A first model of SENER illustrative authority was mounted and tried in CIEMAT-RSA offices in October 2005. The reason for existing was to get mounting knowledge and to have a general thought of the operational conduct looking at it against different authorities. This first model was made out of a torque cylinder and cantilever arms made of welded tube profiles. The 28 cantilever arms were amassed to the torque tube utilizing a manual jeg. A second model of SENER allegorical authority is mounted in February 2006. This second structure incorporates the ideal answer for the cantilever arms. The experience obtained with the principal model in mounting techniques is connected to this second model. The equivalent optical and warm tests are played out, these tests have demonstrated that this model progressively a precise structure has come about to additionally enhance execution and option of these stepped cantilever arms diminish the conceivable mistakes in the situation of the mirror bolster focuses.

Valan and Samuel 2006 built up another PTSC for boiling water age. The variety of authority water outlet temperature and the capacity tank water temperature is expanded from 36° C to 73°C.

Kassem 2007 anticipated regular convection warm move in an annular space between a round beneficiary cylinder and a glass envelope of a PTSC.

Dirk et al. 2008 explored the sun oriented warm illustrative trough authorities called solitem PTC-1800 to give warmth to desalination, cooling and power age. The outcomes demonstrated that warm testing of the gatherer has uncovered similarly low warm misfortunes and still noteworthy optical misfortunes. Inside and out the gatherer is well relevant for medium temperature applications in the scope of 150° to 190°C.

At 2002 **Falah Abed AlhasanM** explored the execution of the Parabolic Trough Solar Collector (PTSC), the aftereffects of this authority were generally worthy, taking into account that it is the primary endeavor to create such gathered locally and assessed in Iraq condition. The specialized attainability of utilizing PTSC results in the warm vitality at temperatures up to 150 ^{o}C for sun oriented irradiance around 400-500 W/m^2.

SOLAR CONCENTRATING COLLECTOR

Solar concentrators increase the amount of incident energy on the absorber surface as compared to that on the concentrator aperture. Temperatures as high as 3500 °C have been achieved with such devices. Solar concentrators are used for thermal as well as photovoltaic conversion of solar energy. Solar concentrators have the following advantages:

(i) Thermodynamic efficiency will be better due to higher temperature.

(ii) By reducing heat loss area, losses will be reduced.

(iii) As compared to flat plate solar collector systems, because of less material requirement it will reduce cost.

(iv) The storage cost is reduced due to storing heat at higher temperatures.

PARAMETERS CHARACTERIZING SOLAR CONCENTRATORS

To specify concentrating collectors, different parameters are used. Their brief descriptions are given below:

The aperture areaA_a is the area through which the solar radiation is incident.

The acceptance angle defines the angular limit to which the incident ray may deviate from the normal to the aperture plane and still reach the absorber/receiver. A concentrator with large acceptance angle needs only seasonal adjustment while to track the sun continuously, a concentrator with small acceptance angle is required.

The absorber areaA_{abs} is the total area of the absorber surface that receives the concentrated radiation. The beneficial energy is received by this area.

PERFORMANCE ANALYSIS OF CYLINDRICAL ARABOLIC COLLECTOR

The cylindrical parabolic collector also called parabolic trough concentrator (PTC) is one of the best know commercially available solar concentrators and has been studied extensively both experimentally & hypothetically. Basically, it is made up of

(i) A parabolic reflector of about 1–5 m^2 aperture area.

(ii) An absorber tube made of steel or copper with diameter 2.5-5 cm and coated with selective coating.

(iii) A concentric tubular glass covers surrounding absorber with a gap of about 1-2 cm which is evacuated.

A section of a cylindrical parabolic collector is shown in figure below.

The cylindrical parabolic reflector focuses all the incident sunlight onto a metallic tubular or flat absorber placed along its length in the focal plane. The heat transfer fluid is allowed to flow through the absorber or receiver. The parabolic reflector is defined by its (1) aperture diameter D, (ii) rim angle e, and (iii) absorber shape and size.

SOLAR CONCENTRATING RECEIVER TUBE

ANALYSIS OF PARABOLIC TROUGH RECEIVER

Fig. shows the graphic diagram of parabolic trough solar receiver. The solar receiver has a metal absorber & a glass envelope. To improve the heat absorption of absorber, there is a selective coating on the outside wall of absorber which also reduces the heat loss because of radiation. [8]. The energy balance equations for the solar receiver as shown in Fig. 1can be written as [9]:

Absorber materials and their choice are depending on several factors which are:

(i) Physical properties, such as the modulus of elasticity, the melting point, thermal inertia and the yield strength

(ii) cost of material

(iii) ease of fabrication

(iv) heat transfer fluid, corrosion resistance of the outer & inner surfaces to environment respectively

(v) resistance to stagnation temperature conditions

(vi) Energy effectiveness in use of material, for example, energy consumed to produce steel has been estimated to be 16500 kJ/kg, for aluminum 141,000 kJ/kg and for copper 93,000 kJ/kg. In short, durable, strong and energy economic absorber materials must be used. Some candidate materials are copper, steel and aluminum.

ABSORBER COVER MATERIALS

The factors on which the choice of absorber cover materials depends are:

(i) Optical properties such as the transmittance for visible light and opacity to infrared radiation.

(ii) Physical properties such as the coefficient of expansion and the melting or softening point.

(iii) Durability including degradation due to ultraviolet radiation.

ABSORBER SURFACE COATING MATERIALS

Higher absorptivity for solar radiation, durability when exposed to weathering, sunlight and high stagnation temperatures, cost effectiveness and protection to the base material are the desirable characteristics of an acceptable coating for absorber used with solar concentrators. Moreover, it is also desirable to use a selective coating which combines high absorptivity for sunlight with low emissivity for the reradiated infrared energy.

CASE STUDY

INTRODUCTION

Using a parabolic trough solar collector in a local enterprise has settled up to produce thermal energy. Around the country this collector having modular characteristics has been installed in some industries to lessen the usage of fossil fuels and to meet the thermal load for the processes. Further to this type of solar collector a local university has made a computational program that shows the energy output of system. This dissertation presents the results of two systems installed, comparing the results with computational and experimental data.

1. Solar collector

Table 1 shows the principal data about the collector. Due to its dimensions and materials; one of their major characteristics is its modularity. As it does not require special machinery for transportation or maintenance, these characteristics make the collector practicable. It also covers a wide range of industrial applications that use temperatures in their processes and that's why the collector is designed for working temperatures between 60ºC and 180ºC.

2. Tracking system

To maximize its efficiency; the device is used so as to make the collector follow the sun during the day. Its working is based on the sensors and signals are sending to the electronic board that controls the movements of the collector which determine the position of the Sun. With thermal or electric output, the tracking system also can be installed in other solar systems for one or two axis controls. Solar trackers are highly efficient installations. The operating costs are extremely low once the initial investment of building a solar power plant has been spent. As solar tracker is directly exposed to solar rays, they can generate more electricity compared to their stationary counterparts. Solar trackers continuously direct photovoltaic panels towards the sun, maximizing the investment on photovoltaic systems.

3. Monitoring device

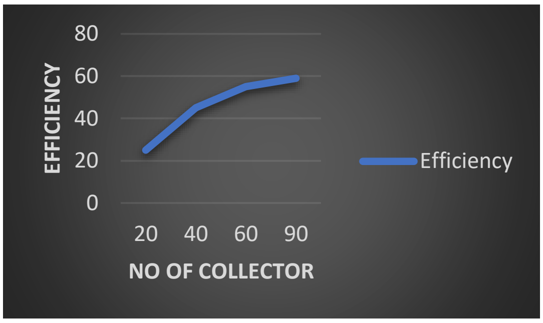
Due to that the cost of energy is not the same through the day, the monitoring device reduce the demand of the system in high-cost schedules. Besides this, it measures electric parameter such as active and reactive power and energy, voltage and amperage used.
SolarEdge monitoring device used in this experiment.

Cases of study

Two different systems are described below for this study, which are installed and analyzed; both systems are for water-heating purposes. With water heated up to 95ºC, the main purpose of these installed systems is the pre-heated water for boiler, cleaning machinery, pasteurization and other processes. The results are obtained and the weather conditions and general data of the systems were also shown. These are based on input and output data from the computational model.

1. Chicken Production Industry A

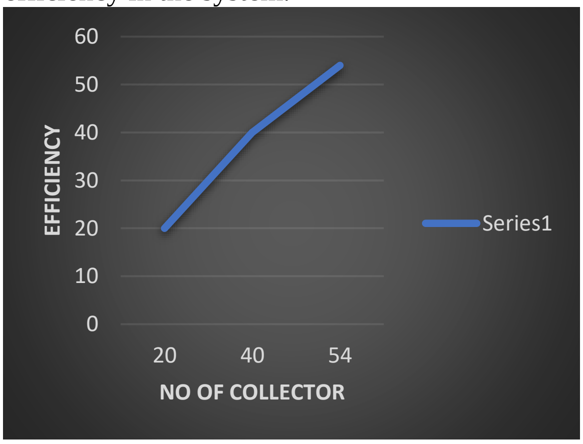
A food production industry A has a factory that produces food mainly chicken. It needs approximately 12150 /day vapor in this factory. And to meet the need for the load a common boiler is used with LPG as a fuel. Below table shows the principal data before installing the system about the needs of the factory and the proposed solar collector system. This data shows that approximately 6h of sun was simulated on the system to an estimation of 920W/m^2 of mean solar radiation. Under these conditions, containing 140kW as maximum thermal output with a mean net efficiency of 58%, the system is capable of heating the water up to 85º and the results are shown accordingly. Figure shows how temperature and efficiency varies through each collector in the system.



Efficiency v/s Collector Number for industry A

2. Shrimp Food Production Industry B

A factory is shown in food production industry B who is dealing with shrimps where they the amount of heated water they used to meet the production needs is of 11000 /day in their process. A fuel oil is used as a fuel in this case as a boiler. Similar to previous case, the principal data about the needs of the factory is shown in below table taken before installing the system and the proposed solar collector system. Using approximately 6h of sun and a mean solar radiation of 1000W/m^2 was simulated for this case. This system is capable of heating water up to 90ºC giving a maximum output of 103kW and a net thermal efficiency of 57% is shown in the results. Figure 3 shows the variation of temperature and efficiency in the system.



Efficiency v/s Number of Collectors for industry B

Results and Discussion

The results show that the model predicts the thermal output with around 10% of error in accuracy, this with weather data taken from internet to simulate the system in the model (due to a lack of weather data acquisition system on the site). Through each collector in the system, the behavior of the thermal efficiency and temperature is also depicted by this model. Also, to get a better performance, the computational model and the collector both can be improve by these results. Overall, we can say that total power will increase according to no. of solar collector using in industry and efficiency of A, and B are 58%, and 57% respectively.

APPLICATIONS

Solar Troughs find a wide variety of applications in various fields where heating is essential. The application of PTC's divided into two groups:
1. The parabolic trough solar power generation needs temperatures from 300ºC to 400ºC range which is the most important application of the concentrated solar power (CSP) technology.
2. The temperatures ranging from 100-250ºC is required by the industrial process heat applications for refrigeration, space heating, cooling and drying.
The one of the different applications are water heating parabolic solar trough. To produce high pressure steam for power generation, this type of technology can be used on a commercial scale as well on small scale industries and residential applications. For small factories dealing with food canning, paper production, air conditioning, refrigeration and sterilization, a medium temperature ranging from 100ºC to 250ºC is needed.

REFERENCES

1) Use of parabolic trough solar collectors for solar refrigeration and air-conditioning applications (F.J. Cabrera, A.Fernandez-Garcia , R.M.P.Silva , M.Perez-Garcia)
2) Parabolic-trough solar collectors and their applications (A. Fernandez-Garcia, E. Zarza, L. Valenzuela, M. Perez)
3) An Application of Parabolic Trough Collector (PTC) System to a Hospital Building (AtillaDönük, Selman Sağlam, Çığır Diner, Yunus Çerçi1, YunusÇengel, OnurGünduru, Francesco Orioli, YaseminSomuncu, M. Pinar Mengüç)
4) Challenges and Prospect for the Development of Parabolic Trough Solar Collectors (PTC's) in Malaysian Environment (Ibrahim MagajiKotorkoshi, Dr. zulistianabintizulkifli, Prof. Dr. Karsono Ahmad Dasuki)
5) H.P. Garg, Advances in Solar Energy Technology, Vol. 1, D. Reidel Publishing Co., Holland, 1987.
6) Solar Energy by S. P. Sukhatme
7) R. Forristall Heat Transfer Analysis and Modeling of a Parabolic Trough Solar Receiver Implemented in Engineering Equation Solver. Technical ReportNREL/TP-550-34169, 2003.
8) J.A. Duffie, Solar Engineering of Thermal Processes, John Wiley & Sons, Inc, Hoboken, 2013.
9) V. Gnielinski, New equations for heat and mass transfer in turbulent pipe and channel flow, Int. Chem. Eng. 16 (1976) 359–368.
10) A.C. Ratzel, C.E. Hickox, D.K. Gartling, Techniques for reducing thermal conduction and natural convection heat losses in annular receiver geometries, J. Heat Transfer 101 (1979) 108–113.
11) F.P. Incropera, D.P. DeWitt, T.L. Bergman, A.S. Lavine, Fundamentals of Heat and Mass Transfer, John Wiley & Sons, New York, 2006.
12) V.E. Dudley, G.J. Kolb, A.R. Mahoney, et al. Test Results SEGS LS-2 Solar Collector. SAND 94-1884, the Sandia National Laboratires, 1994.
13) R. Petela, Exergy of undiluted thermal radiation, Sol. Energy 74 (6) (2003) 469–488.
14) J.E. Parrott, Theoretical upper limit to the conversion efficiency of solar energy, Sol. Energy 21 (3) (1978) 227–229.Suzuki, General theory of exergy-balance analysis and application to solar collectors, Energy 13 (2) (1988) 153–160.
15) J.F. Guo, M. Xu, L. Cheng, Thermodynamic analysis of waste heat power generation system, Energy 35 (7) (2010) 2824–2835.