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Fabrication, Designing & Performance Analysis of Solar Parabolic Trough

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Abstract
A parabolic trough solar collector uses a parabolic cylinder to reflect and concentrate sun radiations towards a receiver tube located at the focus line of the parabolic cylinder. The receiver absorbs the incoming radiations and transforms them into thermal energy, the latter being transported and collected by a fluid medium circulating within the receiver tube.This method of concentrated solar collection has the advantage of high efficiency and low cost, and can be used either for thermal energy collection, for generating electricity or for both, This paper focused on the fabrication and designing of solar parabolic trough, The designing of trough is depend upon the following parameters : Aperture of the concentrator , Inner diameter of absorber tube, Outer diameter of absorber tube, Inner diameter of glass tube, Outer diameter of glass tube, Length of parabolic trough, Concentration ratio, Collector aperture area, Specular reflectivity of concentrator, Glass cover transitivity for solar radiation, Absorber tube emissivity/emissivity, Intercept factor, Emissivity of absorber tube surface and Emissivity of glass. The performance analysis will be based on the Experimental data collection and calculations with reference to: Thermal performance calculations, Overall loss coefficient and heat correlations. Heat transfer coefficient on the inside surface of the absorber tube and Heat transfer coefficient between the absorber tube and the Cover.
Keywords: absorber tube, aperture, receiver, solar parabolic trough

I. Introduction

A parabolic trough solar collector uses a mirror or aluminum foil sheet in the shape of a parabolic cylinder to reflect and concentrate sun radiations towards a receiver tube located at the focus line of the parabolic cylinder. The receiver absorbs the incoming radiations and transforms them into thermal energy, the latter being transported and collected by a fluid medium circulating within the receiver tube. This method of concentrated solar collection has the advantage of high efficiency and low cost, and can be used either for thermal energy collection, for generating electricity. Therefore it is an important way to exploit solar energy directly. Parabolic trough is the most mature technology for large scale exploitation of solar energy. Several power plants based on this technology have been operational for years, and more are being build trough solar trough collector temp increase up to 100°C to 400°C [02].

The greatest advantage of solar energy as compared with other forms of energy is that it is clean and can be supplied without any environmental pollution. Over the past century fossil fuels have provided most of our energy because these are much cheaper and more convenient than energy from alternative energy sources, and until recently environmental pollution has been of little concern

Initially, an analysis of the environmental problems related to the use of conventional sources of energy is presented and the benefits offered by renewable energy systems are outlined. A historical introduction into the uses of solar energy is attempted followed by a description of the various types of collectors including flat-plate, compound parabolic, evacuated tube, parabolic trough, Fresnel lens, parabolic dish and heliostat field collectors. This is followed by an optical, thermal and thermodynamic analysis of the collectors and a description of the methods used to evaluate their performance. Typical applications of the various types of collectors are presented in order to show to the reader the extent of their applicability. These include solar water heating, which comprise thermosyphon, integrated collector storage, direct and indirect systems and air systems, space heating and cooling, which comprise, space heating and service hot water, air and water systems and heat pumps, refrigeration, industrial process heat, which comprise air and water systems and steam generation systems, desalination, thermal power systems, which comprise the parabolic trough, power tower and dish systems, solar furnaces, and chemistry applications. As can be seen solar energy systems can be used for a wide range of applications and provide significant benefits, therefore, they should be used whenever possible [03].

The conversion of solar energy into heat energy, an incident solar radiance is concentrated by concentrating solar collectors. For many applications it is desirable to deliver about 1 to 60 m2 and with widths ranging from 1 to 6 m, [01]. energy at temperatures higher than those possible with flat-plate collectors. Energy delivery temperatures can be increased by decreasing the area from which heat losses occur. Generated heat is used to heat the thermic fluids such as oils, air or water/steam, acts as heat carrier and as storage media. The hot thermic fluid is used to generated steam or hot gases, which are then used to operate a heat engine. Concentration ratios of this type of concentrator are quite high. Increasing ratios mean increasing temperatures at which energy can be delivered. Maximum energy collection orientation of the concentrator relative Concentration ratios range from 10 to 80, and rim angles from 70 to 1200to the direction of propagation of beam radiation is needed and 'sun tracking' in some degree, will be required for focusing systems. Various type of collectors are available which has aperture areas from

The absorber tube is either made of stainless steel or copper or iron coated with a heat resistant black paint. Generally tube is surrounded by a concentric glass cover and the space between the tube and the glass cover is evacuated. The reflecting surface is linear parabolic curved shape. It is fixed on a light-weight structure usually made of aluminium sections. The structure is are such that it should not distort significantly due to its own weight and that it should be able to withstand wind loads.

II. LITERATURE REVIEW

Sagade et al [04], conducted experiment on prototype parabolic trough made of fiberglass-reinforced plastic with its aperture area coated by aluminum foil with a reflectivity of 0.86 From Indian conditions, there is a large potential available for low-cost solar-concentrating technologies for domestic as well as industrial process heat applications. This line-focusing parabolic trough with mild steel receiver coated with black proxy material has been tested with and without glass cover. Instantaneous efficiency of 51% and 39% has been achieved with and without glass cover, respectively. From Indian conditions, low-cost FRP parabolic trough system can prove to be beneficial for industrial heating applications as well as domestic heating. With the system described in this paper, the following conclusions are drawn:

1. Instantaneous efficiency of the collector has been increased by 13%. Instantaneous efficiency of 51.67% has been achieved with the glass-covered receiver.
2. Useful heat gained by the receiver increases by 22% with the glass-covered receiver throughout the day, and the average receiver temperature increased by 23%.
3. It has been observed that, with glass-covered receiver, outlet water temperature and temperature gradient increase by 29% and 68%, respectively.
4. It has been observed that the average decrease in heat loss coefficient is 70% when the receiver was covered with glass.

Ruby, Steve[05] (American Energy Assets, California L.P.),This project researched the viability of producing high temperature industrial process heat from the sun's energy. The installation of a large scale industrial solar thermal system provides an opportunity to evaluate the technical and economic hurdles of similar systems in California. The research was performed through the design, construction, operation, and analysis of a high temperature solar thermal system at a Frito-Lay snack food plant located in Modesto, California. In this installation, high temperature water in excess of 232°C (450°F) is produced by a concentrating solar field, which in turn is used to produce approximately 300 pounds per square inch (20 bar) of process steam. The solar thermal system is intended to improve plant efficiency with minimal impact on day-to-day production operations. Process steam in the plant is used for cooking, which includes heating edible oil for frying, and heating baking equipment. Steam is also converted into hot water for cleaning and sterilization processes.

Xiao Gang [06] describes a closed parabolic trough solar collector which a hermetic box with a transparent cover and the parabolic reflector forming the back parabolic trough concentrated solar collector. And the tracking of the sun is done by rotating (swinging) the box around the receiver tube which is fixed with respect to the ground. The absorber is build by two concentrating tube such that outer glass tube and an evacuated annular space between the working fluid and outer glass tube, for the purpose of thermal isolation with a steel inner tube conducting the HTF, and an outer tube for air tightness. The interior of the boxes can be filled to a slight overpressure (50Pa or so), with air or gas supplied by a central equipment due to prevent the dust from the surroundings and subsequent damage to the optic surfaces. Active carbon can be used to remove most of the gaseous pollutants. Accepting an optical loss of a few percentages due to reflections by the cover, this design offers several advantages over the current open model, in particular a potential of significant cost reduction

Ming Qu et al. [07] devloped linear tracking parabolic trough reflector focused on a surface-treated metallic pipe receiver enclosed in an evacuated transparent tube, and obtained fundamental radiative and convective heat transfer and mass and energy balance relations. The experiment is shows that when hot-water at 165°C flows through a 6m by

2.3m Parabolic Trough Solar Collector with 900 w/m^2 solar insulation and 0 incident angles, the estimated collector efficiency is about 55%. In this work engineering equation solver (EES) is used to solved the equations involve. The main advantage of EES is automatically identifies and groups equations that must be solved simultaneously. Second, EES provides many built-in mathematical and thermo physical property functions useful for engineering calculations. The inside of receiver tube is the absorber tube coated with selective blackened nickel because of high absorption of short length solar radiation and low emissivity for long wave energy spectrum to reduce thermal radiation losses. The efficiency of PTSC is 0.5529. The outlet temperature of Parabolic Trough Solar Collector is 181◦C.

S.D Odeh et al. [08] conducted experiment on parabolic trough collector to obtain the effect of the vacuum space between the steel tube and the glass tube on the reduction of the total thermal loss. Synthetic oil is working fluid. Calculation is down to measure the main thermal loss from the absorber tube outer wall to the evacuated glass tube (surrounding the absorber) occurs by radiation. The heat loss from the glass cover tube occurs by radiation to the sky and by convection to the surrounding air by wind or natural convection. The second part of the loss from the collector takes place between the absorber tube and the ambient via the vacuum bellows and supports. The temperature increase by this experimental setup is about 250- 400 °C. The thermal cycle uses a heat transfer fluid (synthetic oil) to transfer energy from the collector field to a Rankine steam cycle via a heat exchanger.

Joshua Folaranmi [09] reported the designed, constructed and testing of a parabolic solar steam generator works on solar energy and made concentrating collector, heat from the sun was concentrated on a black absorber located at the focus point of the reflector in which water is heated to a very high temperature to form steam. It also describes the sun tracking system unit by manual tilting of the lever at the base of the parabolic dish to capture solar energy. The whole arrangement is mounted on a hinged frame supported with a slotted lever for tilting the parabolic dish reflector to different angles so that the sun is always directed to the collector at different period of the day. On the average sunny and cloud free days, the test results gave high temperature above 200°C. The testing of the parabolic dish solar steam generator was done in the month of January 2009 for three days. The whole set was placed in an open space in the sun from 9:00am in the morning to 5:00 pm in the evening each day for three days. Resistance thermometer placed at the focal point was used to obtain its maximum obtainable Temperature. The results obtained for hourly reading of 8hours every day.

Brooks, M.J et al. [10] conducted experiment to measure and testing the performance of components of parabolic trough solar collector and development in a solar energy research programme. Low-temperature testing was performed at Mangosuthu Technikon’s STARlab facility using water as the working fluid. Both an evacuated glass shielded receiver and an unshielded receiver were tested, with which peak thermal efficiencies of 53.8% and 55.2% were obtained respectively. The glass-shielded element offered superior performance at the maximum test temperature, Experiment contain also tracking system. Pumping system provided for feed control quantity of fluid. In this study only low-temperature testing was conducted with receiver inlet temperatures from 20°C to 85°C.

M. Halil [11] conducted experiments in which one-dimensional heat transfer model for the thermal analysis of the receiver subsystem was presented to reducing the optical errors. It is also useful for analysis the geometry of collector. It was shown that this model could be used to calculate a heat-loss parameter of receiver surface area to characterize the thermal behavior of the receiver. It was shown that the presented thermal analysis could be used to size the annulus gap size. The method developed in which can be used in a comprehensive design and optimization method.

Garcıa A. Fernandez et al. [12] presents paper in which an overview of the parabolic trough collectors that have been built and the prototypes currently under development. It also presents a survey of solar system to supply thermal energy up to 400 0C, which is especially for steam power cycles for electricity generation. First commercial collectors used in U.S. Government’s Sandia National Laboratories and Honeywell International Inc. Both collectors were quite similar in concept and were prepared to work at temperatures below 250°C. They studies Luz collectors, Euro Trough collector and discuss their application in the field of Steam production for sterilization, Dairy, Steam production for silk printing, Steam production for pharmaceutical chemicals, Cold generation, Refrigeration in isolated areas etc.

Singh B.S.M. et al. [13] conducted experiment of solar parabolic trough collector of equilibrium achieved between the increasing thermal losses with the increasing aperture area, and the increasing optical losses with the decreasing aperture area for the optimization of the long-term performance. Three different types working fluid is used with maximum theoretical concentration ratio are reached to 212. It is found that with increasing concentration ratio, decreasing heat removal factor and efficiency.

Gregory J Kolb [14] developed the time-dependent performance of the proposed storage system was evaluated with a new model of the plant based on the TRNSYS simulation system. Results indicate that the proposed system should work well at Saguaro. The paper describes the TRNSYS model and the engineering insights gleaned from annual performance simulations of the plant. A TRNSYS model of the 1 MW Saguaro solar trough plant has been developed. In the TRNSYS model with storage it is assumed that the solar field will be expanded from the current size of 10300 m2 to 18800 m2. During daytime the solar field directly powers the ORC, as before, but excess energy collected by the solar field is stored in the thermocline for later delivery to the ORC after sunset The model is capable of predicting the time-dependent flows and temperatures within the solar field and proposed thermocline storage system, as well as the power produced by the organic Rankine cycle power block. Analysis conducted with the model indicates that the proposed thermocline energy storage system should work well and only small annual performance improvements are possible through changes to its design and operation.

III. Basic Terminology

1) The aperture (W):-Aperture is the plane opening of the concentrator through which the solar radiation passes. It is characterized by the diameter or width of the opening.
2) Concentration ratio(C):- The ratio of the effective area of the aperture to the surface area of the absorber. Values of the concentration ratio vary from unity to a few thousand. This quantity is also referred to as the geometric concentration ratio or simply concentration ratio.
3) Intercept factor (γ):- The fraction of the radiation, which is reflected or refracted from the concentrator and is incident on the absorber. The value of the intercept factor is generally close to unity.
4) Acceptance angle ($2\square_a$):- The angle over which beam radiation may deviate from the normal to the aperture plane and yet reach the absorber. Collectors with large acceptance angles require only occasional adjustments, while collectors with small acceptance angles have to be adjusted continuously.

- Advantages of Concentrating Collectors

1) Reflecting surfaces require less material and are structurally simpler than flat plate collectors.
2) The absorber area of a concentrator system is smaller than that of flat plate system for same solar energy collection.
3) Heat lost to the surrounding per unit of solar energy collecting area is less than that of flat plate.
4) Working fluid can attain higher temperature in concentrating collector.

- Losses in Collectors

1) **Conductive losses**: Heat transfer takes place through adjacent surfaces by conduction; this can be minimized by placing insulating materials in place of good conductors of heat.
2) **Convective losses**: Heat losses due to carry of heat by some medium like air from the surface can take place in these kinds of devices. This can be minimized by closing all the air gaps.
3) **Radiative losses**: Radiative losses from the absorber can be prevented by the use of spectrally selective absorber coatings. Such coatings have a high absorption of about 0.9 in the solar spectrum and a low emittance usually of the order of 0.1, in the infrared spectrum, in which the absorber radiates to the environment. Selective absorber coating, therefore decrease heat losses and increase collector efficiency.

IV. Solar Trough

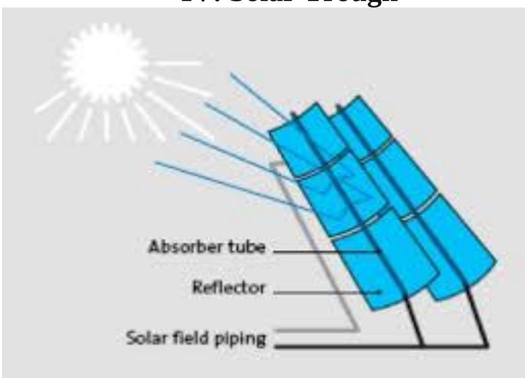

Fig 1: A diagram of a solar parabolic trough system

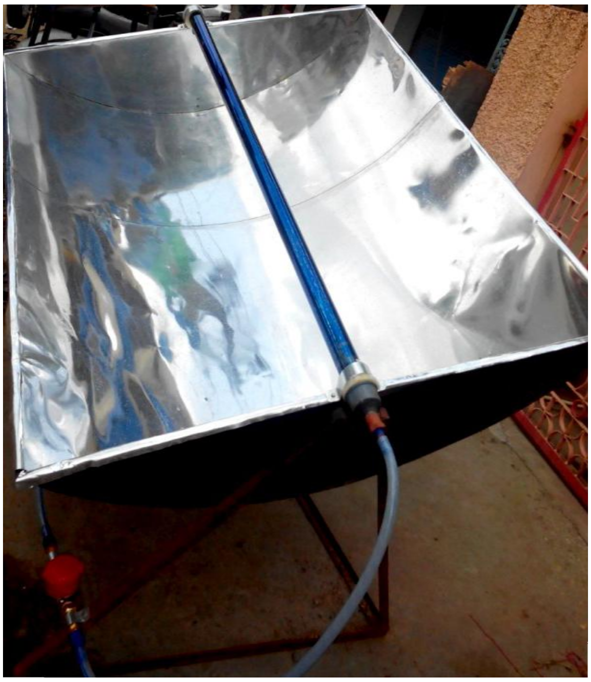

Fig 2: Fabricated model of solar parabolic trough system

The main components used in the parabolic trough -

1) Absorber tube
2) Reflector
3) Solar Field Piping

1) Absorber tube: - It is a metal tube through which working fluid is transfer and gain the heat from solar energy.
2) Reflector: - Solar reflectors are classified by how they collect solar energy. The three most common types are parabolic troughs, parabolic dishes, and power towers. Parabolic troughs and dishes use mirrors shaped like parabolas to focus incoming radiant energy onto a fluid-filled pipe that runs down the center of a trough. Heat from the fluid is used to boil water.
3) Solar Field Piping:- In Solar parabolic trough the field piping and measuring instruments are required for transporting high-temperature fluid (HTF) from the solar field.

V. Thermal performance calculations:

The useful energy delivered from the concentrator can be given by Equations 1 and 2

$$q_u = mc_p(T_o - T_{in}) \tag{1}$$

$$q_u = mc_p\left[\frac{CS}{U_l} + T_a - T_{in}\right]\left[1 - \exp\left\{-\frac{F'\pi D_o U_l L}{mc_p}\right\}\right] \tag{2}$$

Where, qu is the useful energy delivered from the concentrator (W); m, mass flow rate(kg/s); To, outlet fluid temperature (°C); Tin, inlet fluid temperature (°C); Cp, specific heat of water (kJ/kg°C); C, concentration ratio; S, incident solar flux absorbed in the absorber plate (W/m2); Ul, overall heat loss coefficient (W/m2°C); Ta, ambient temperature (°C); F', collector efficiency factor; Do, outer diameter of the tube (m); and L is the length of the concentrator (m). The useful energy gain per unit of the collector length can be expressed by Equations 3 and 4 in terms of the local receiver temperature Tr [2].

$$q_{u'} = \frac{q_u}{L} \tag{3}$$

$$q_{u'} = \frac{q_u}{L} = F'\left[S - \frac{U_l}{C}(T_r - T_a)\right](W - D_o) \tag{4}$$

where qu0 is the useful energy gain per unit of the collector length; Tr, mean receiver surface temperature (°C); W, width of the parabolic reflector (m), and where F0 is the collector efficiency factor defined by Equations 5 and 6

$$F' = 1/U_l\left[\frac{1}{U_l} + \frac{D_o}{D_i h_f}\right] \tag{5}$$

$$q_u = F_R(W - D_o)L\left[S - \frac{U_l}{C}(T_{in} - T_a)\right] \tag{6}$$

where Di is the inner diameter of the tube (m); hf, heat transfer coefficient on the inside surface of the tube
(W/m2°C); and FR is the collector heat removal factor. Heat removal factor is given by Equation 7

$$F_R = \frac{mc_p}{\pi D_o L U}\left[1 - \exp\left\{-\frac{F'\pi D_o U_l L}{mc_p}\right\}\right] \tag{7}$$

and collector efficiency can be obtained by dividing qu by Ib WL. The instantaneous collection efficiency can
also be calculated by Equation 8

$$\eta_{in} = \frac{q_u}{IbrbWL} \tag{8}$$

Where, nin is the instantaneous collection efficiency.

Overall loss coefficient and heat correlations

The calculations of overall loss coefficient were based on convection and re-radiation losses. Heat loss rate
per unit length can be given by Equations 9 and 10 [2].

$$\frac{q_l}{L} = h_{pc}(T_r - T_c)\pi D_o + \sigma\pi D_o\left(T_r^4 - T_c^4\right)/\left\{\frac{D_o}{\frac{1}{\varepsilon_p} + D_{ci}\left(\frac{1}{\varepsilon_c} - 1\right)}\right\} \tag{9}$$

$$\frac{q_l}{L} = h_w\,(T_c - T_a)\pi Dco + \sigma\pi Dco\varepsilon c\left(T_r^4 - T_a^4\right) \tag{10}$$

where Tc is the temperature of the cover; hw, wind heat transfer coefficient(W/m2-K); εp, emissivity of absorber
surface for long-wavelength radiation; and εc, emissivity of the cover for long-wavelength radiation. Heat transfer coefficient between the absorber tube and the cover The heat transfer coefficient hpc for the enclosed annular space between a horizontal absorber tube and a concentric cover is calculated by Equations 11, 12, and 13

$$\frac{K_{eff}}{k} = 0.317(Ra^*)^{0.25} \tag{11}$$

$$(Ra^*)^{0.25} = \frac{\ln\left(\frac{D_{ci}}{D_o}\right)}{b^{0.75}\left(\frac{1}{D_o^{0.6}} + \frac{1}{D_{ci}^{0.6}}\right)}Ra^{0.25} \tag{12}$$

where Ra* is Rayleigh's number.

$$h_{pc} = \frac{2K_{eff}}{D_o \times ln\left(\frac{D_{ci}}{D_o}\right)}. \quad (13)$$

Heat transfer coefficient on the inside surface of the absorber tube

The convective heat transfer coefficient hf on the inside surface of the absorber tube can be calculated. For

Reynolds number greater than 2,000, the flow is turbulent and the heat transfer coefficient may be calculated from Equation 14

$$Nu = 0.023 \mathrm{Re}^{0.8} P_r^{0.4} \quad (14)$$

VI. Conclusion

In conclusions, The Fabrication and designing of a solar parabolic trough using locally available materials is possible hence low temperature trough will be a better solar thermal device for the rural area. This research has its own special features Maintenance cost is minimum and hence economical, Running cost is nil, The labour cost is minimized on account of its simple design. As other forms of energy are fast depleting and polluting the atmosphere, non-conventional energy resources like solar energy are best suited to use. The solar Parabolic Trough is among the best way to use solar energy efficiently due to its advantages to convert abundantly available solar energy into effective and convenient form of heat energy which can be used for various purposes. several applications like solar water heating, which comprise thermo syphon, integrated collector storage, space heating and cooling, service hot air and water systems and heat pumps, refrigeration, industrial process heat and steam generation systems. Solar concentrating collector allows us to use solar heat energy for various purposes without using any external power source and avoids using separate devices for each individual purpose.

References

[1]. Sukhatme S.P. (2007) *principles of thermal collection and storage*. McGraw Hill, New Delhi

[2]. Administration, U. E. I., 2010. International energy outlook. Tech. Rep. DOE/EIA-0484(2010), *Office of Integrated Analysis and Forecasting*, U.S. Department of Energy, Washington, DC.

[3]. Kalogirou S. *The potential of solar industrial process heat application*. Appl Energy 2003;76:337-61

[4]. Sagade et al., "*Performance evaluation of low-cost FRP parabolic trough reflector with mild steel receiver*", International Journal of Energy and Environmental Engineering, pp 3-8, 2013

[5]. Ruby, Steve (*American Energy Assets, California L.P.).* 2012. Industrial Process Steam Generation Using Parabolic Trough Solar Collection. California Energy Commission. Publication number: CEC-500-2011-040.

[6]. Xiao G. (2007) *A closed parabolic trough solar collector*. Version 2 Page 1-28

[7]. Qu.M., Archer D.H. and Masson S.V. (2006) A linear Parabolic Trough Solar Collector Performance Model. Renewable Energy Resources and a Greener Future, Vol.VIII-3-3, USA

[8]. Odeh S. D., Morrison G. L. and Behnia M. *Thermal analysis of parabolic trough solar collectors for electric power generation*. Australia

[9]. Folaranmi, J. (2009) *Design, Construction and Testing of a Parabolic Solar Steam Generator*. Journal of Practices and Technologies ISSN 1583-1078. Vol-14, page 115-133, Leonardo

[10]. Brooks, M.J., Mills, I and Harms, T.M. (2006) *Performance of a parabolic trough solar collector*. Journal of Energy in Southern Africa, Vol-17, page 71-80 Southern Africa

[11]. Halil M. G. and Richard B. B. (1984) *Optical and thermal analysis of parabolic trough solar collectors for technically less developed countries*. Technical report, USAID Project Grant No. 386-0465, Texas

[12]. Garcıa A. F., Zarza E., Valenzuela L. and Perez M. (2010) *examination of Parabolic-trough solar collectors and their applications*. Vol-14, page 1665-1721, Spain

[13]. Singh B.S.M. and Sulaiman (2003) *Examination of designing a solar thermal cylindrical parabolic trough concentrator by simulation*.

[14]. Gregory J Kolb, " *PERFORMANCE ANALYSIS OF THERMOCLINE ENERGY STORAGE PROPOSED FOR THE 1 MW SAGUARO SOLAR TROUGH PLANT*" Proceedings of ISEC 2006 ASME International Solar Energy Conference July 8-13, 2006, Denver, COISEC2006-99005