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Modeling and Performance Prediction of Solar Parabolic Trough Collector for Hybrid Geothermal Power Generation: A Case Study of Dholera, Gujarat, India

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ABSTRACT

Geothermal energy is worldwide accepted as clean renewable energy and has trivial impact on environment. The research and development on renewable energies are constantly increasing in today's era, due to breakthrough demand and cost of energy. The availability and efficiency are defined because of limited resources. This study illustrates the efficient generation of electricity using hybrid solar and geothermal resources. The research was carried out in Swaminarayan temple located in Dholera village of Gujarat. The heat pump transfers the heat around 60°C - 75°C in terms of primary fluid which was considered as input heat to parabolic trough collector (PTC). Duratherm 450 was taken as primary fluid due to its non toxicity, organic nature, economic viability and thermal stability and longer service life. When the primary fluid passes from PTC the temperature of fluid rises drastically, to control the temperature of primary fluid thermostat is placed. After getting desired output around 110°C - 120°C the primary fluid is passed to evaporator which is connected with organic rankine cycle (ORC) and efficient electricity is generated (around 20 KW). This paper discusses about the design and performance calculations of PTC according to standard dimensions on CREO software.

1. INTRODUCTION

Electricity is the most sought after commodity in the world. More than 70% of the world fuel demand is based on non renewable source of energy like coal, oil etc. Additionally these fuels are depleting at a fast rate and also are putting adverse effects on the environment. The global environmental protection concepts and concerns have been widely excited and several new forms of renewable energy resources such as solar, geothermal, wind systems are examined to supplement the fossil fuels, integrate and develop for the energy needs.(annual report of ministry of non conventional energy sources).Since the oil crisis of 1970, utilization of alternative source of energy has become increasingly significant, attractive and cost effective.

The utilization of geothermal energy has been carried out since thousands of years. It has been used since roman times for bathing and cooking and to heat buildings and used in spas (Martha Mburu,2009).The direct applications of geothermal energy are many such as space heating, agriculture, industrial uses, spas(Dickson and Fenelli,2004). But the indirect usage in electricity production has been experimented only in few parts of the world such as Iceland, USA etc. The shortcomings of a standalone system is that the overall efficiency of the system is very less (approximately 48%) (www.energyhomes.org). The solution to this can be hybridization with solar energy. Solar energy is a non-depleating, site based, non-polluting and future alternative energy source. However renewable energies like solar and wind are unpredictable in nature. Due to their dependence on sunshine hours, weather conditions etc results in under utilization of the capacity (Elhadidy and Shaahid). The initial cost of solar system is higher but operations and maintenance costs are always lower.

The present paper aims at predicting the performance of a Solar parabolic trough collector for hybrid geothermal power generation. This is accompanied by a summary of the research that several writers published. Paper also discusses the need of future consideration in the design of hybrid solar and geothermal energy.

2. STUDY AREA

A standalone Geothermal plant is located at Dholera which is situated at 30 km in southwest direction from Dhandhuka village of Ahmedabad district and 60 km away in north direction from city of Bhavnagar (courtesy Centre of Excellence for Geothermal Energy, PDPU). The hot springs of Dholera lie along the Saurashtra Peninsula. They fall in the location of Western Marginal fault of Cambay Basin. Land in Dholera is covered by recent to alluvium and mud flats. The area is also occupied by quaternary soils deposited in subsiding area by the side of Cambay Basin to an extend of about 100 m over Tertiary sediments resting on Deccan Traps at a depth of about 500–600 m. A total of four springs were separated in a radius of 4 km Dholera, Uthan, Swaminarayan temple and Bhadiyad. The maximum Geothermal flow rate in Gujarat is located in Dholera. Crucial methods were applied during various stages of exploration and exploitation to evaluate reservoir characteristics. Studies from pre-existing wells and surveys have suggested the presence of a sizable low enthalpy geothermal resource base. Geochemical study shows that the geothermal waters in this region are rich with sodium, Potassium Chloride and Sulphate. The temperatures estimated from the cross-plots and the Geo-thermometric analyses did show that the springs were a part of low enthalpy geothermal reservoir system.(Manan shah et al ,2017). Deccan basalt province revealed that there is high heat producing granites under basalt cover. Artificial thermal reservoir can be created at depth > 1 km in these granites (Chandrasekhar V. and Chandrasekharam D., 2008).

3. METHODOLOGY

Procedure followed to Design the Parabolic Trough Collector :

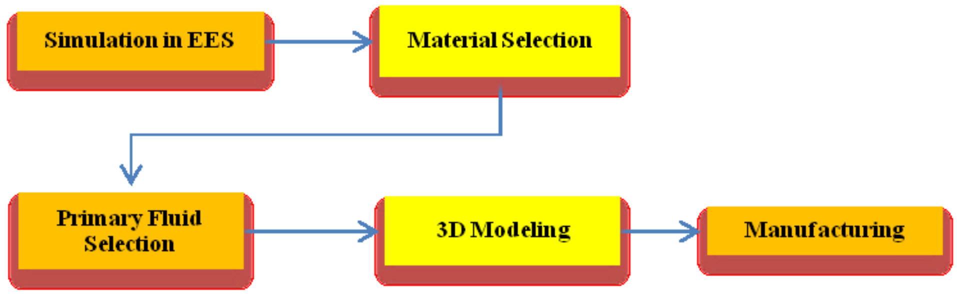

Figure 1: Parabolic Trough collector designing steps

3.1 Material Selection

3.1.1 Reflector

Reflector helps to absorb sunlight on absorber pipe to transfer solar heat to HTF. According to that materials were selected. Following data is represented in Table 1 and Table 2.

Glass Mirror	
Shape	Parabolic
Thickness	3 to 4 mm
Reflectivity Coating	Silver
Specular Reflectivity	≥ 93%
Strength & Durability	Applicable standards ISO 6270-2:2005; ISO 9227:2012.

Table 2: Glass mirror specifications for reflector, UNDP and GEF (2015)

Silver Reflective Film	
Material	Aluminum Substrate
Thickness	0.38 mm to 0.50 mm
Reflective Coating	Solar grade 0.1 mm to 0.12 mm thickness
Edge Sealing	Edge tape /caulk
Specular Reflectivity	≥ 94%
Strength & Durability	EN 485-2: 2008; ASTM D882; ISO 9227:2012

Table 2: Silver reflective film specifications for reflector, UNDP and GEF (2015)

3.1.2 Support Structure

As per ambient conditions support structure data was selected, following data is represented in Table 3.

Support Structure	
Material	Structural Steel
Corrosion Resistance	Galvanization or Polyurethane paints

Durability	Designed as per IS 800/IS 875

Table 3: Specifications for Support Structure, UNDP and GEF (2015)

3.1.3 Receiver

According to HTF temperature, solar radiation and flowrate of fluid, material selection was done and it is represented in Table 4.

Absorber	
Material	Stainless Steel grade 304
Thickness	1 to 2 mm
Diameter	25 to 35 mm
Absorber Coating	
Material	Solar grade absorber paint
Absorptivity	0.9 to 0.95
Emissivity	0.09 to 0.15
Glass Cover	
Material	Borosilicate Glass
Transmitivity	≥ 95%
Thickness	2-3 mm
Diameter	50-80 mm

Table 4: Receiver specifications, UNDP and GEF (2015)

3.2 Primary Fluid

According to thermal specification of our designed system, Duratherm 450 was selected as heat transfer fluid (HTF) due to its characteristic specification. Non toxic and non hazardous in nature (Beitelmaland Fabris,2015). Working condition of fluid in very high and very low temperature (-49°C to 233°C). viscosity of primary fluid is declined by pre-heating method. Due to which Reynolds number rises and it is identified and maintained above 10,000 (turbulent flow) (Alaric C. Montenon et al,2016).

3.3 Designing Formulas

Focal length, (Modified after kalogirou,2013):

$$f = \frac{a^2}{16h} \tag{1}$$

Where f = focal length,a = aperture area (m^2),h = height (m)

Aperture width, (Modified after kalogirou,2013):

$$W_a = 4f \tan\left(\frac{\varphi_r}{2}\right) \tag{2}$$

Where W_a = Aperture width,f = Focal length,φ_r= Rim angle,

Rim angle, (Modified after k. lovegrove,2012) :

$$\tan \varphi_R = \frac{4f(\frac{W_a}{2})}{4f - (\frac{W_a}{2})^2} \tag{3}$$

φ_R = Rim angle

Length of parabola, (Modified after kalogirou,2013):

$$L = \frac{H_p}{2}\{\sec\left(\frac{\varphi_r}{2}\right)\tan\left(\frac{\varphi_r}{2}\right) + \ln[\sec\left(\frac{\varphi_r}{2}\right) + \tan\left(\frac{\varphi_r}{2}\right)] \tag{4}$$

Where L = Length of parabola, H_p = latus rectum of parabola, and $H_p = W_a$

Concentration Ratio, (Modified after kalogirou,2013):

$$C = \frac{W_a}{\pi d} \tag{5}$$

Where C = Concentration ratio,W_a= Aperture width,d = Outer diameter

3.4 Section Diagram

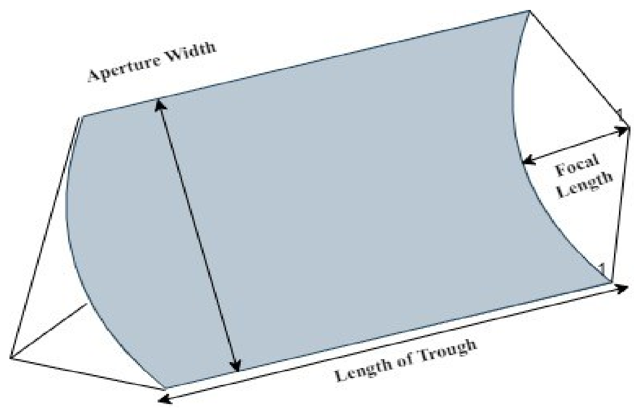

Figure 2: Geometric sketch of Parabolic Trough collector

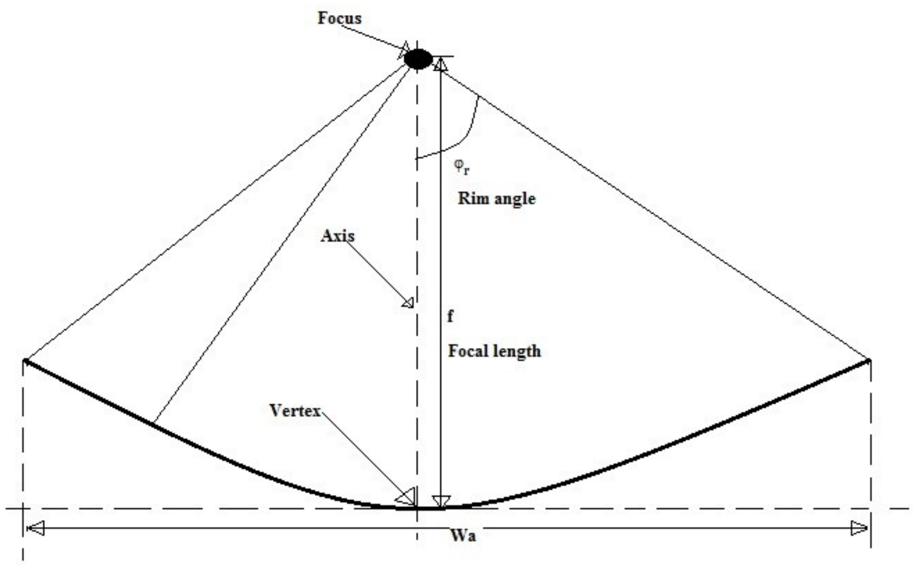

Figure 3: Detailed sketch of Parabolic Reflector (modified after k. lovegrove, 2012)

3.5 Simulation Result

Based on the above equations results were simulated and 3D modeling was done.

Rim angle(phi_r)	70
Aperture width (m)	3
Focal length (m)	1.071
Height (m)	2.1
Length of parabola (m)	2
Concentration ratio	68.20
Aperture area (m^2)	6
Diameter	14 mm
Velocity	52 m/sec.
Receiver material	Stainless Steel

Table 5: EES Results

3.6 3D Modeling

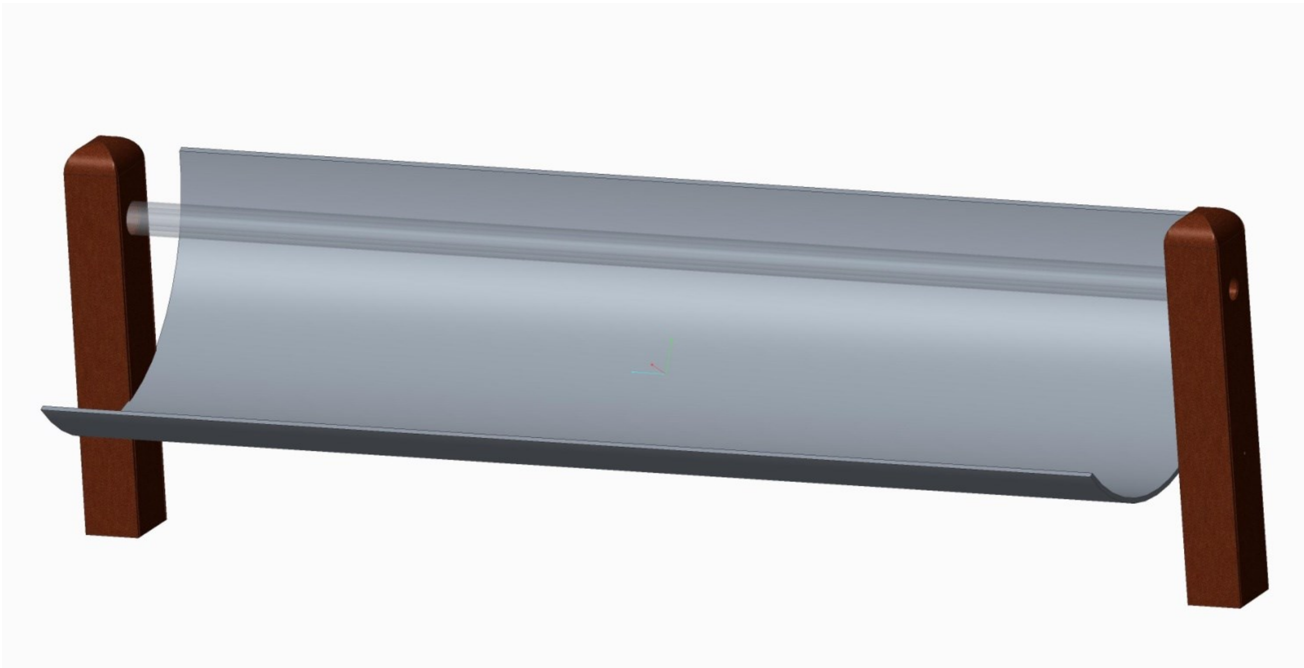

Figure 4: Front View of PTC

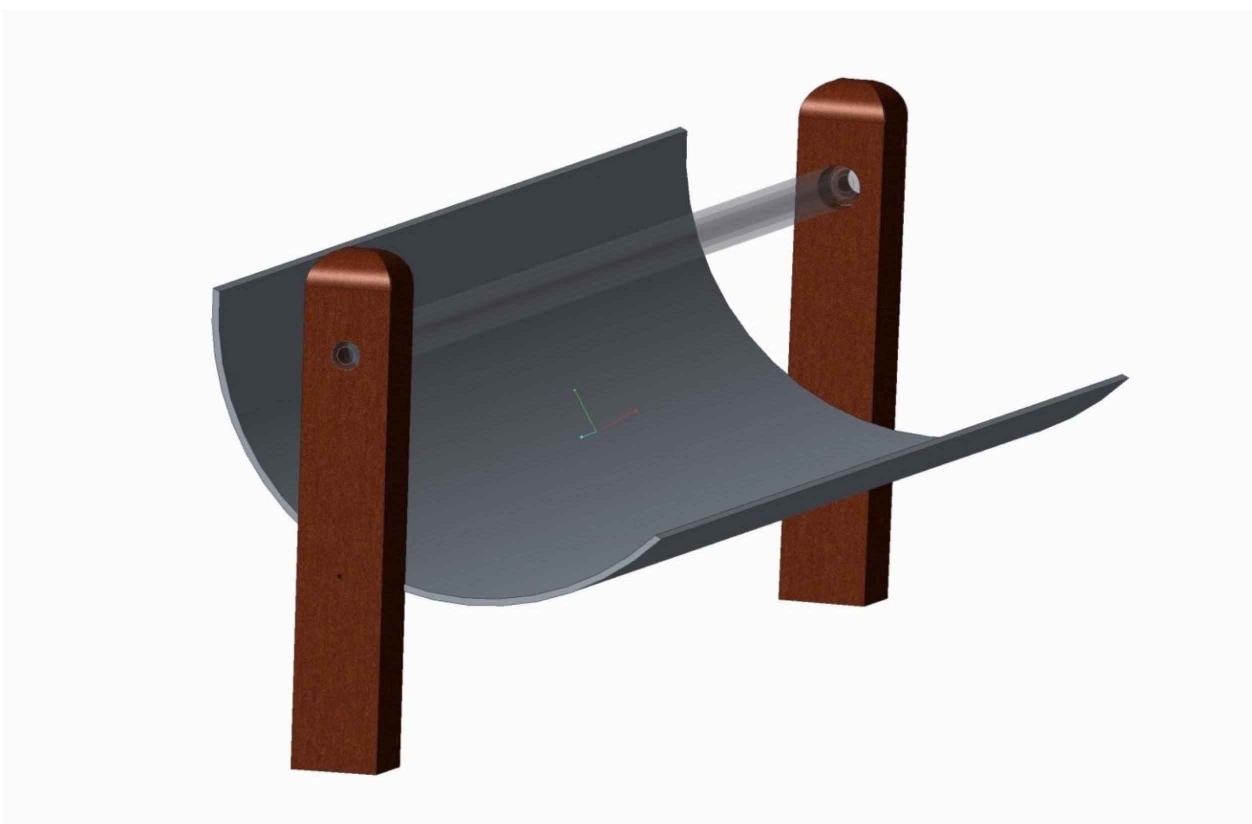

Figure 5: Side View of PTC

4. CONCLUSION

The paper describes about utilization of geothermal water for power generation, by hybridizing with PTC. It also showcases the designing procedure of PTC to elevate the temperature of heat pump and pass on to ORC. The Designing calculations were carried out in mathematical modelling software Engineering Equation Solver (EES) and with help of that 3D modelling was done in parametric Creo. Duratherm 450 was selected as primary fluid due to its thermal specifications and on this basis material selection was done. Moreover, the performance of PTC is dependent on calculation and materials that are used to manufacture it. This project is still in designing stage and the authors are hopeful that it will be implemented in field by the end of 2020.

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