DESIGN OF SOLAR PARABOLIC TROUGH WATER HEATER

S. S. Pawar[1], Chinmay Karandekar[2], Gaurav More[3], Shubham Khule[4], Raj Bansode[5]

[1] *Professor in the Department of Mechanical Engineering, Terna Engineering College, Navi Mumbai, India.*
[2,3,4,5] *Students in the Department of Mechanical Engineering, Terna Engineering College, Navi Mumbai, India.*

---***---

Abstract - *Renewable energy technology is one of the prospective sources which can meet the energy demand and can contribute to achieve sustainable development. Concentrating collectors absorb solar energy and convert it into heat for making hot water,steam at demanded temperature which can be further used for solar thermal operations. In India where solar energy is abundantly available. There is a need to develop technology for employing solar energy for power products. But the main problem associated with concentrating solar power technology is the high cost of installation and low effectiveness. This paper includes a literature review of 25 journal papers and subsequently the experimental study of parabolic trough for water heating technology. A design of solar parabolic trough water heater which is further effective with lower cost is proposed.*

Key Words: **Renewable energy, concentrating collectors, solar power technology, solar thermal operations, parabolic trough.**

1.INTRODUCTION

Energy plays a vital part to represent a country, because it's related to poverty reduction, profitable development and security also. Bangladesh has high demand for electricity and to meet up this demand- coal, gas, diesels are being used to produce electricity. The main source of energy is natural gas which is going to run out veritably soon. The only use of natural gas or non-renewable sources for ménage use isn't a good sign for the future and also the massive use of reactionary energy in the last century has caused climate change through the greenhouse effect and produced large scale environmental pollution. A huge energy demand, reliance on natural gas clearly creates an extremity in future. Among numerous renewable energy sources, solar energy is the most suitable for this country. Solar energy sources made their way into the homes of millions of people throughout the world through solar photovoltaic(PV) and solar thermal energy. By the development of better materials and technologies with dwindling cost, solar energy systems are getting popular day by day. Solar PV generates electric power for use in the home or marketable places, while solar thermal energy systems are used to produce hot water, cuisine or other purposes. But numerous marketable places and hospitals need a huge quantity of hot water for the whole time. For this purpose, solar thermal application can be a great action for environmental protection and conventional energy saving. Solar collector is the major element of any solar system. Solar collectors are special kind of heat exchangers that transfigure solar radiation energy into heat and transfer this heat to a fluid(generally air, water etc.) flowing through the collector. There are different kinds of solar collectors which are used worldwide for domestic or artificial water heating. The most common concentrating technologies are parabolic trough collector(PTC), direct Fresnel glass, solar dish, and solar palace, where, parabolic trough collector is one of the most notorious technologies. This technology uses parabolic shaped mirrors to concentrate the incident radiation onto a receiver tube which is placed at the focal line of the trough. Parabolic trough collector(PTC) is having colorful advantages similar as in artificial brume generation and hot water products. The advantage of solar trough is that it's clean, cheap and can be used to supply thermal energy. This paper presents a simple model of a Solar Parabolic Trough Water Heater. The model proposed has a trough collector of aluminium with mirrors and a copper tube receiver.

2.LITERATURE SURVEY

[1]Madan designed a cylindrical solar water heater and manufactured it. It consisted of a cylindrical tube made from high quality glass and a copper coil tube in the shape of spiral rings, painted black, served as a collector to the incident solar energy on the cylinder wall. A profitable analysis was done which revealed that the cylindrical solar water heater compared with the flat plate collector is cost effective. A maximum temperature difference of 27.8 °C between inlet and outlet of the solar water heater at a mass flow rate of 9 kg/h was achieved. The effectiveness of the cylindrical solar water heater was found to be 41.8. [2]Helal et al. created an integrated collector stack (ICS) consisting of a single cylindrical horizontal tank placed in a reflector composed of three parabolic branches, and the geometrical characteristics were determined. A comparison of this system was made with two other solar water heater systems, consisting of a tank with an

asymmetric CPC and a symmetrical CPC. [3]Mohammed worked on design and development of a parabolic dish solar water heater for domestic hot water operation. For effective performance of the design, an automatic electronic control circuit was designed and developed. In order to reduce space demand, the heater was designed in such a way that it'll heat about 10 litres of water only at a time. An automatic linear actuator (SuperJack) typical of the one in use in the satellite dish assiduity was selected over the manual tracking mechanism. The Superjack gave a slow, steady motion to the parabolic dish as it turned on its axis from East to West. Solar energy radiation detectors fitted on the aperture of the dish transferred electric signals to the motor which, in turn, acclimated the position of the dish until maximum solar radiation intensity is received at the aperture.[4]Pei et.al. experimented and did a comparison of rig of evacuated tube solar water heater systems with and without a mini-CPC reflector was set up, with a series of trials done in Hefei, China. The first and second laws of thermodynamics were used to analyze and differ their thermal performance. Two types of solar water heater systems were used, and the data gathered for two days were compared. From the results attained it can be noted that when attaining low temperature water, the evacuated tube solar water heater system without amini-CPC reflector has higher thermal and exergy edge than the system with amini-CPC reflector, including the average and immediate values. On the other hand, when attaining high temperature water, the system with amini-CPC reflector has a higher thermal and exergy edge than the other one.[5] Singh et al. studied the potential of a solar-thermal system for hot water production. The parabolic trough concentrator (PTSC) was made of an aluminum sheet that was covered with a cloth to which rectangular mirror strips were glued. Two different absorber tubes were taken and the efficiencies of the PTSC without the glass cover on the absorber tubes were compared. The tracking system used was manual where the trough moved 10° from E to W every 30 minutes. [6]Oggy Et.al. designed and constructed a solar water heating system for domestic using locally available materials. Solar energy is received by a flat- plate collector consisting of a thin absorber plate, integrated with underneath grids of fluid carrying tubes, and placed in an insulated covering with a transparent glass cover having a cold and a hot water tank integrated in the system. [7]Pachkawade Et.al. designed and fabricated solar water heater at comparatively low cost and high capacity by the use of material like plastic lateral tubes, HDPE pipe, old glasswool, thermocol, plastic barrel,G.I. sheet collect or boxes replacing the material as copper tube, stainless steel water tank, thick expensive PUF insulations, toughened glass etc. further the " Pebbles " are used as a medium of heat storage so as to increase the capacity of solar water heater rather than using an electric heater. [8]Macedo- Valencia et.al. presented a paper in which the stages of design, modeling, and evaluation of a parabolic trough collector(PTC) for heating water as a demonstrative prototype were bandied. The design was done using computer- aided design and manufacturing. The water flows from the container, passes through the absorber pipe where it's heated, and then recollected by a glass baker to measure the flow rate. The water flow is induced through the system by gravity. The solar concentrator was oriented with a slope of 18 ° depending on the latitude of the position.[9]Khan et.al. developed a novel loop- heat- pipe based solar thermal heat- pump system for small scale hot water production for ménage purposes. They developed a prototype solar water heating system for an experimental test. They reported the investigation of solar thermal conversion effectiveness in different seasons which is 29.24 in summer,14.75 in winter, and 15.53 in rainy season. This paper also discusses the DC heater for backup system and the current by using thermoelectric generator which are 3.20 V in summer, 2.120 V in winter, and1.843 V in the rainy season. This solar water heating system is substantially suited for its ease of operation and simple maintenance.[10] Zou and Dong et.al. an experimental disquisition on a small- sized parabolic trough solar collector for water heating in cold areas was done. It can be noted that under the condition of fluid temperature below 100°C, the thermal effectiveness of the proposed PTC increased with the increase of fluid temperature. [11]Senthilkumar et.al. presented the performance study on single axis solar Parabolic Trough Collector(PTC) with solar tracking for varied flow rate of working fluid. trials were conducted on PTC with and absence of tracking mechanism at different flow rates of water. The experimental results such as fluid temperature rise, incident solar radiation and thermal effectiveness of PTC were analysed. [12]Jayakanth designed a flat plate collector solar water heater. The purpose was to make a water heater for the bathroom. The required operating temperature range of 55°C to 65°C was achieved. The solar water heater was tested while circulating water at different flow rates. SWH efficiency was up to 60%. A flow rate comparable to 0.2 l/min was found to be the best for heating. [13]Rajamohan presented a literature in which the conical absorber tube directly absorbs solar radiation from the sun and the parabolic dish concentrator reflects the solar radiations towards the conical absorber tube from all directions, thus both radiations would significantly improve the thermal collector effectiveness. The working fluid water was stored at the bottom of the absorber tubes. The absorber tubes get heated and increases the temperature of the working fluid inside of the absorber tube and causes the working fluid to partially evaporate. The partially vaporized working fluid moves in the upward direction due to buoyancy effect and enters the heat exchanger. When fresh water passes through the heat exchanger, temperature of the vapor decreases through heat exchange. This leads to condensation of the vapor and forms liquid phase. The working fluid returns to the bottom of the collector absorber tube by gravity. Hence, this continues as a cyclic process inside the system. [14]Sagade et al. evaluated the thermal performance of a parabolic trough water heater for small industrial process heat using a spiral wound truncated cone that is coated with black chrome as a selective coating. It was seen that when the receiver was coated black and covered with a glass cover, the performance of the system increased. The system efficiency achieved at a significant flow rate of 0.0056 kg/s was 63%.[15]Vadher and Adroja experimented on a solar parabolic trough collector with some changes in the receiving tube. In the first case, the spherical ball was filled into the receiving tube without any attachment. In the second case, the receiver was filled with uniform aluminum chips. In the third case, the iron 2mm roll of netting was completely filled in the receiver. The 2 mm iron mesh showed the highest performance evaluation criteria value at low fluid velocity. [16]Vaghasia and Ratnadhariya prepared an experimental setup in which they prepared PV supported Automatic Sun Tracking System mounted with parabolic trough collector to track sun from E to W during sun hours for increasing energy collection by PTC which leads to increasing energy effectiveness of collector. The design mechanism holds the solar concentrator and allows the concentrator to perform an approximate hemispherical rotation to track the sun's movement during the day. This solar tracking system consumed some quantity of power so gross energy gained is someway reduced.[17]Bhakta et.al. reports the overall thermal performance of a cylindrical parabolic concentrating solar water heater(CPCSWH) with inserting nail type twisted tape(NTT) in the copper absorber tube. The tracking mechanism consists of an embedded electronic control system. The electronic control system is equipped with a Light Dependent Resistor(LDR), to move the collector with the apparent movement of the sun, so that solar radiation reaches the collector aperture at a 90 ° angle. The PCR rotates around the vertical north – south axis, to track the sun as it moves through the sky during the day. Firstly, the test was conducted with a plain copper absorber tube and the succeeding experimentations were conducted by inserting the NTT into the absorber tube, one by one, with varying nail twist pitch proportions(4.787,6.914 and9.042). [18]Beattie presented an investigation paper in which the design of solar trough was made such that the temperature of water at the outlet will be 20 °C more than the normal temperature attained. A heat transfer analysis on square and circular cylinders were done to decide the shape of the focal line. It was discovered that the square pipe had a total heat transfer resistance that's nearly 20 times that of the circular one, which means that the circular pipe will transmit more solar energy to the water than the square pipe would. The tracking system used an Arduino to control a motor which rotates the parabolic trough about the focal line. Photoresistors were used to follow the sun's position. [19]Tabassum el.at. did an experimental study of parabolic trough collector for water heating technology. It focuses on the performance of concentrating solar collector by changing the reflector materials(aluminium sheet, aluminium foil and mirror film). It was found that the mirror film had the highest durability and can give higher outlet water temperature compared to other reflectors. [20]Isravel el.at. conducted a trial for empty tube, conventional twisted tape, Rings attached twisted tape and modified Rings attached twisted tape and a comparison of heat transfer rate was done. Rings attached twisted tapes show higher heat transfer rate than empty tube and conventional twisted tapes condition but it also augments the pressure drop.[21]Panahi el.at. did an experimental study involving the design, manufacturing and testing of a prototype integrated collector storage(ICS) solar water heater(SWH) in combination with a compound parabolic concentrator(CPC) was done. The advanced system was intended to supply hot water for a family in remote pastoral areas. A 6- month experimental study was accepted to probe the performance of the ICS SWH system.[22]Ibrahim presented a modified parabolic trough solar collector to control the outlet temperature and protect the glass enclosure from rain damage. The design focused on the incorporation of a polymer cover. The design takes into account the position of the collector focus; therefore, the cover slider was placed at a point above the absorber tube. [23]Majeed el.at. developed a new dual solar tracking system for CPU parabolic trough water heater using a novel biaxial tracking system based on Algorithms chronological tracking system. A two-axis solar tracking system microcontroller was used, which consists of an Arduino Uno R3 microcontroller. It was observed that the proposed tracking design increased the energy efficiency by 3.43% compared to the PV panel tracking technology. [24]Hameed and Ibrahim proposed a new designed multistage solar parabolic trough collector and its thermal performance was investigated in this study. The modified PTC consisted of five channels or PTC buses. Each channel had the same dimension. Six k-type thermocouples were placed on the test section. One thermocouple at the water inlet feeds the other at the water outlet. The remaining four thermocouples were deployed at the end of each receiving tube bus to measure temperatures. An automatic controller with a servo motor was connected to the base structure for moving the test section according to the sunlight sensor signal. It was observed that the amount of heat absorbed by the collector increased.[25]Gogoi et.al. presented a study on a parabolic trough collector with absorber and different reflecting surfaces and also with different flow rates to predict the best form of efficient source. The structure of the absorber is copper tubes, while the reflecting surfaces are taken as one aluminum and the other as a reflecting mirror. A 33% reduction in flow resulted in a 50-70% increase in efficiency.

From the above literature it can be seen that: The performance of a solar water heater mainly depends on the fluid flow rate, the materials used for the components and the tracking system. The specular reflector provides optimal performance. It has been observed that the efficiency of the parabolic trough collector varies inversely with the efficiency of the flow rates. The solar tracking system plays an important role in improving the efficiency of the system. If the correct material is used for the absorption tubes, the efficiency of the system can be increased. A receiver made of copper pipes is more suitable. There is a possibility of reducing the cost of manufacturing the system and simplifying it.

3. METHODOLOGY

3.1 Design Parameters and Experimental setup

The geometric parameters of a PTC are its aperture width and length, rim angle, focal length and diameter of the receiver. The parabolic equation in Cartesian coordinates system can be represented as, $x^2 = 4fy$ ....(1)

Using equation (1), the height of the parabola (h) can be calculated in terms of the focal length (f) and aperture diameter (D). $(D/2)^2=4fh$........(2)

The rim angle is defined as the angle subtended by the edges of the reflector at the focus. The rim angle Ψ is given by $\tan(\Psi/2) = (D/4f)$ .... (3)

From the selected values of aperture diameter and concentrator height, the focal length, rim angle of the concentrator was calculated from equations. The selected data of the designed model has the following values as given by table 1.

Table -1: Different parameters and their values for the fabricated PTC

Item	Notations	Value
Aperture length	L	900 mm
Aperture diameter	D	508 mm
Rim angle	Ψ	100^o
Focal length	f	104 mm
Receiver diameter	d	13 mm
Concentrator height	h	152 mm

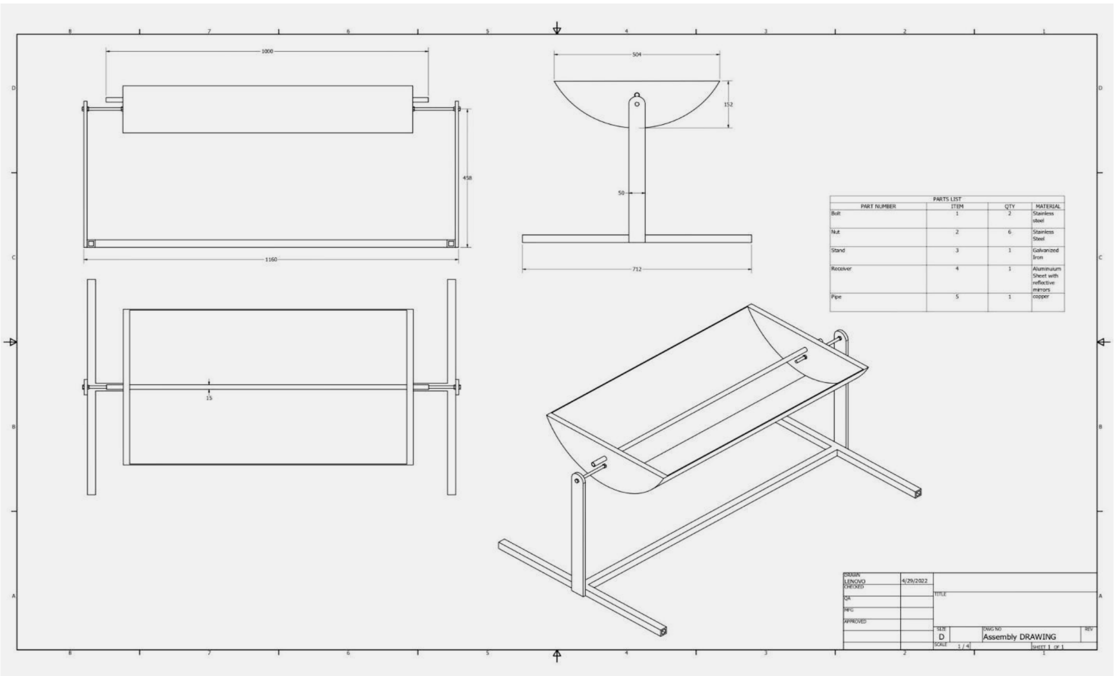

Fig -1: Design sheet

Fig-2 describes the design proposed by our group for Solar Trough Water Heater. The design was made on AutoDesk Inventor 2022.

Materials: Receiver tube- Copper, Trough sheet- Aluminium sheet with reflecting mirror, Stand- Stainless Steel

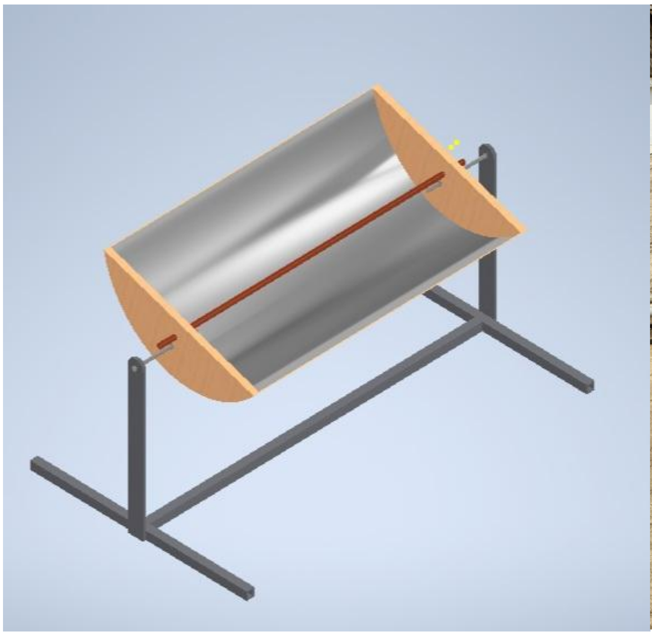

Fig -2: Cad Model

Fig -3: Solar Parabolic Trough water heater

3.2 Testing

The collector's reflecting surface is curved in a parabolic shape so that the solar radiations which are colliding are getting reflected most of all the radiations to the receiver tube. In our study, as a reflecting surface, the type of reflector material used is mirror film to evaluate the performance of the parabolic trough collector. A copper pipe was chosen because of its higher thermal conductivity than aluminium tube or any other plastic tube. a copper tube of 0.013m internal diameter was used at the focal axis. All the components of the receiver tube and parabolic reflector were mounted on a stand which was basically a supporting structure. The structure frame supports the rotation axis of the parabolic reflecting surface. To reduce cost, the structure was made from galvanized iron rods which were welded together. A plastic pipe connected the inlet with the storage tank. The outlet fluid temperature was recorded with the help of a thermometer. The flow rate was set at 0.3lpm. The table below shows the inlet and outlet temperature obtained at 0.3 lpm on 12^{th} of April at Terna Engineering College, Navi Mumbai.

Table -1: Temperatures obtained

Sr.No.	Time	Inlet temperature (°C)	Outlet temperature(°C)
1.	9 am	30	41.2
2.	10 am	30	41.6
3.	11 am	34	44.5
4.	12 pm	37	51
5.	1 pm	37	50.3
6.	2 pm	35	49
7.	3 pm	35	48.3

4. Result Analysis

The solar thermal efficiency of the PTC and useful heat gain by the circulating water during flow through the absorber tube are estimated by equations

Solar thermal efficiency: $\mu_C = (Q_u/I_bA) = mc_P(T_o-T_i)/I_bA$…………(4)

Heat gained by water: $Q_u = mc_P(T_o-T_i)$……………(5)

Where, Q_u= Useful heat gain-W, Ti & T_0= Inlet and outlet water temperature respectively -°C, m=Mass flow rate of water - kg/s, Cp= the specific heat of water - J/(kg-K), I_b= direct solar beam radiation - W/m², A= aperture area of the collector - m²

According to formula, we know that

Heat Gain(Q_u)=$mc_P(T_o-T_i)$

Mass flow rate of water = 0.33 × 0.012 = 0.00396 kg/s

Cp of water is 4.18 KJ/(kg-K)

Hence, Q_u = 0.00396 × (4.187×1000) × (51-37) = 232.127W

Solar thermal Efficiency(μ) = $(Q_u/I_bA) = mc_P(T_o-T_i)/I_bA$=232.127/957×0.9×0.508=0.53

%μ = 0.53 × 100 = 53%

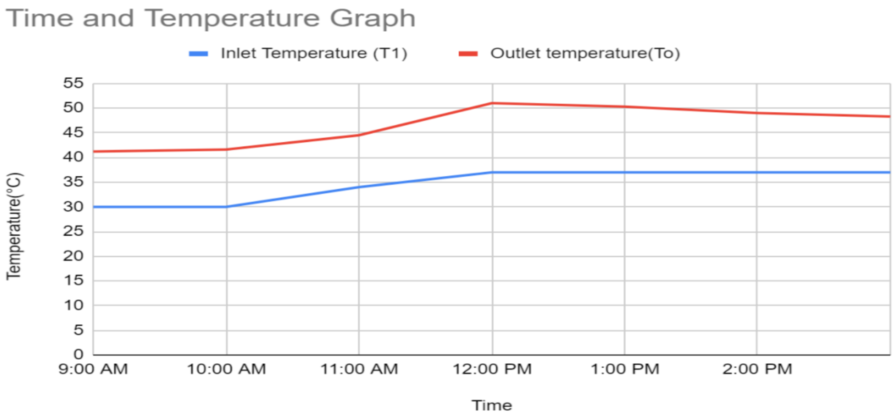

Chart -1: Time vs temperature graph showing the outlet temperature

3. CONCLUSIONS

In the present work a solar parabolic trough water heater was designed by using a software Autodesk Inventor 2022. The materials for the components Receiver tube- Copper, Trough sheet- Aluminium sheet with reflecting mirror, Stand- Stainless Steel were decided after reading a number of research papers. The performance is high in the mid noon because of the high solar intensity at that time. The heat gain was increased depending on time and solar intensity. The efficiency of the solar water heater is 53% for 0.3lpm. The total cost to make the solar water heater is less than Rs. 2000.So, this low-cost parabolic trough water heating system can be beneficial for domestic heating.

REFERENCES

[1] Al-Madani, H.,"The performance of a cylindrical solar water heater. Renewable Energy", October 2005, pp.1751-1763. doi: 10.1016/j.renene.2005.09.010

[2] Helal O., Chaouachi B., & Gabsi S.,"Design and thermal performance of an ICS solar water heater based on three parabolic sections", Solar Energy, August 2011, pp.2421-2432. doi: 10.1016/j.solener.2011.06.021

[3] Ibrahim Ladan Mohammed ,"Design And Development Of A Parabolic Dish Solar Water Heater", vol.2, Jan-Feb 2012,pp.822-830

[4] Pei, G., Li, G., Zhou, X., Ji, J., & Su, Y. ,"Comparative Experimental Analysis of the Thermal Performance of Evacuated Tube Solar Water Heater Systems With and Without a Mini-Compound Parabolic Concentrating (CPC) Reflector". Energies,April 2012, pp. 911-924. doi: 10.3390/en5040911

[5] Santosh Kumar Singh, Arvind Kumar Singh, and Santosh Kumar Yadav,"Design and Fabrication of Parabolic Trough Solar Water Heater for Hot Water Generation",IJERT ,vol.1,Dec.2012

[6] Ogie, N., Oghogho, I., & Jesumirewhe, J. ,"Design and Construction of a Solar Water Heater Based on the Thermosyphon Principle", Journal Of Fundamentals Of Renewable Energy And Applications, vol.3,Jan.2013,doi: 10.4303/jfrea/235592

[7] Pachkawade M.,Nimkar P.,Chavhan B.,"Design And Fabrication Of Low Cost Solar Water Heater",Science,vol. 6, Nov.2013, pp.2249-6149

[8] Macedo-Valencia, J. & Ramírez-Ávila, J. & Acosta, R. & Jaramillo, O.A. & Aguilar, J." Design, Construction and Evaluation of Parabolic Trough Collector as Demonstrative Prototype", Energy Procedia,vol.57,Dec.2014,doi: 10.1016/j.egypro.2014.10.082.

[9] Khan, M., Al-Mamun, M., Sikdar, S., Halder, P., & Hasan, M.,"Design, Fabrication, and Efficiency Study of a Novel Solar Thermal Water Heating System: Towards Sustainable Development.", International Journal Of Photoenergy,Dec.2015, doi: 10.1155/2016/9698328

[10] Zou, B., Dong, J., Yao, Y., & Jiang, Y. ,"An experimental investigation on a small-sized parabolic trough solar collector for water heating in cold areas.", Applied Energy, vol.163, Jan.2016,pp.396-407. doi: 10.1016/j.apenergy.2015.10.186

[11] Senthilkumar S*, Durai Kumar S, D. R. S. Raghuraman,"Performance Enhancement of Solar Parabolic Trough Collector by Fluid Flow Control and Solar Tracking System",Journal of Chemical and Pharmaceutical Sciences,August 2016

[12] Jayakanth, J., Ramasubramanian, S., Chandrasekaran, M., & Manavalan, S.,"Investigation of solar water heater by using flat plate collector and evacuated tubes." IOP Conference Series: Materials Science And Engineering,vol.183, March 2017, doi: 10.1088/1757-899x/183/1/012035

[13] Rajamohan G., Kumar P., Anwar, M., & Mohanraj T.,"Analysis of solar water heater with parabolic dish concentrator and conical absorber",IOP Conference Series: Materials Science And Engineering,vol.206,June 2017, doi:10.1088/1757-899x/206/1/012030

[14]Atul A. Sagade , Satish Aher , Narayani Sagade,"Thermal performance of parabolic dish water heater with helical coiled receiver",June 2017,doi: 10.1007/978-3-319-53556-2_85

[15]Rahul Vadher, Falgun Adroja,"Improvements of Water Temperature in Solar Parabolic Water Heater",vol. 6,2018

[16]Jignesh G. Vaghasia, Jayesh K. Ratnadhariya,"Design and Development of Self-Sustainable Solar Energy Operated PV Assisted Sun Tracking Mechanism for Parabolic Trough Collector",vol.13,2018,pp.9260-9266

[17] Bhakta, A., Panday, N., & Singh, S.,"Performance Study of a Cylindrical Parabolic Concentrating Solar Water Heater with Nail Type Twisted Tape Inserts in the Copper Absorber Tube.",Energies,,January 2018 ,doi: 10.3390/en11010204

[18]Beattie Audrey, "Parabolic Solar Trough Design Report", Engineering Undergraduate Publications, Presentations and Projects, 7,April 2019

[19] Tabassum, S., Sharmin, L., Bashar, M., Rahaman, M., Debnath, S., & Khanam, M.,"Design and Analysis of Parabolic Trough Solar Water Heating System.", Journal Of Architectural Environment &Amp; Structural Engineering Research,vol.2,July 2019, doi: 10.30564/jaeser.v2i3.1034

[20] Suresh Isravel, R., Raja, M., Saravanan, S., & Vijayan, V. "Thermal augmentation in parabolic trough collector solar water heater using rings attached twisted tapes.", Materials Today: Proceedings, vol.21,July 2019 pp.127-129. doi: 10.1016/j.matpr.2019.05.375

[21] Panahi, R., Khanjanpour, M., Javadi, A., Akrami, M., Rahnama, M., & Ameri, M.,"Analysis of the thermal efficiency of a compound parabolic Integrated Collector Storage solar water heater in Kerman, Iran.", Sustainable Energy Technologies And Assessments,Oct.2019, doi: 10.1016/j.seta.2019.100564

[22]Idowu David Ibrahim."Development of Smart Parabolic Trough Solar Collector for Water Heating andHybrid Polymeric Composite Water Storage Tank." Automatic Control Engineering. Université Paris Saclay; Tshwane University of Technology, 2020.

[23]Majeed, M., Alwan, N., Shcheklein, S., & Matveev, A."Electromechanical solar tracker system for a parabolic dish with CPU water heater.", Materials Today: Proceedings,vol.42,Jan 2021. doi: 10.1016/j.matpr.2020.12.326

[24] Hameed V., & Ibrahim M."An Experimental Study on New Multistage Solar Parabolic Trough Collector.",IOP Conference Series: Materials Science And Engineering, vol.1094,Feb.2021, doi: 10.1088/1757-899x/1094/1/012103

[25]Amitabh G.Kartik Kamal S.,Rishikesh R.Monmayuri D.,"Performance Analysis Of A Solar Parabolic Trough Collector For An Absorber And Different Reflective Surfaces And Flow Rates", unpublished