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Design and Operating Parameters Optimization for Solar Parabolic Trough Concentrator for Enhancement in Heat Transfer: A Review

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Abstract: **Solar energy is an adequate and enormous source of renewable energy. But the major drawback of this type of energy, it is scattered in nature, a device which concentrates solar energy at one point or line is called solar concentrator. The parabolic trough concentrator is widely used in industry and power plants to harness and concentrate the solar energy. The outputs of parabolic trough concentrator in terms of enhancement in heat transfer depends upon its various design and operating parameters. The different researcher observed the influence of different parameters to investigate the efficiency and enhancement of heat transfer by heat transferring fluild. An up to date reviews of these parameters and its effect on outcomes are summarized here to optimize the design and operating parameters to build a prototype.**

Keywords — Design parameters, Operating parameters, Parameter optimization, Solar energy, Parabolic trough concentrator, Heat transfer enhancement.

I. INTRODUCTION

The worldwide demand for energy has increased tremendously because of industrialization and the rapid increase in population. Whereas there is inadequate energy supply than the current requirement. The rate of oil production in the globe has declined due to limited resources and most of the oil reservoirs will be exhausted by this century. The production of natural gas is continuously increasing and it will reach its peak in about 10 years. Due to the scarcity of oil and natural gas burden on coal increased to compensate energy need where coal production is likely to be maximum by 2050. Government authorities, industrial bodies and educational institutions are applying tremendous effort to search viable energy sources and to increase energy efficacy.

Solar energy is one of the substitute energies having enormous prospective. As per assessment, it is found that the earth surface gets about 1000W/m2 quantity of solar insolation in the daytime. This energy has the potential to generate about 85,000 TW and estimates that the present world's energy usage is about 15 TW.

However, in spite of many exertions by the statutory bodies and private segments, the contribution of solar energy is hardly 1% of global energy need. Many collectors are used to harnessing and concentrating on solar energy. Parabolic trough concentrators are widely used in industry and plants to generated steam and hot water as per need.

II. THE BASIC OPERATIONAL PRINCIPAL OF PARABOLIC TROUGH SOLAR CONCENTRATOR

The parabolic collector is made by the 2 Dimensional design of a parabola. As per parabola, the sunrays are concentrated at a single focus point after reflected by reflecting materials. It is formed by truncated part of the parabola.

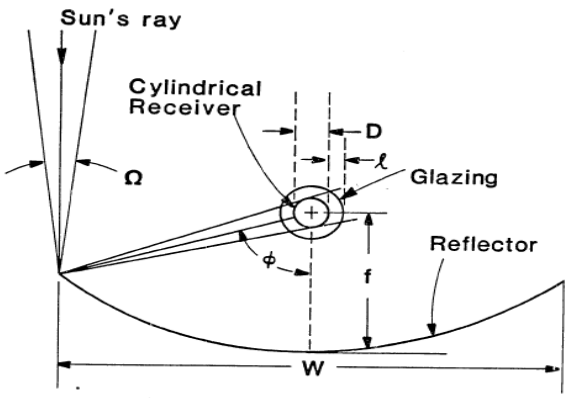

Fig. 2.1 Schematic of parabolic trough solar concentrator

The two types of parabolic concentrator design are available, the first type is formed by rotating the two dimensional design alongside the x-axis to form a parabolic dish having a single focal point with high concentrator ratio and the second type is with a parabolic trough with a single focal line to focus concentrated rays. Both concentrators are widely used in large solar power plant. To provide continues high concentration, it requires to track

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the sun by tracking system for maximum solar energy collection, which is quite expensive. The performance of the parabolic trough depends on the various design and operating parameters.

III. INVESTIGATIONS OF THE VARIOUS DESIGNED PARAMETERS OF SOLAR PARABOLIC TROUGH CONCENTRATOR

The performance of solar parabolic trough depends on various designed parameters. It depends on the design parameters like to set up a size, concentration ratio, type of reflecting material, rim angle, type of absorber open or evacuated, the material of absorber tube, length and diameter of the absorber tube, a coating of absorber tube etc.

3.1 Concentration ratio

The concentration ratio defined as the ratio of the aperture area to the the receiver area, it varies from unity for flat plate collector to 105 for point concentrator. Its important parameter to increase the intensity of solar radiation at a focal point or line.

Singh and Sulaimanet [1] have carefully developed the simulation procedures with the design specifications like fix diameter of 3 cm and the intercept factor γ has a maximum value of unity. It shows that concentrations ratio increase until its maximum theoretical value of 212, but the model's efficiency increased up to the concentration ratio reached 10 and then slowly reduced by at least 53 percent for all three heat transferring fluids flowing in the absorber.

Tyagi et al. [2] have observed that as the concentration ratio increases the performance factors like the stagnations temperature, exergetic output, inlet temperature, exergy & thermal efficiencies, ambient temperature etc. are found to be the increasing. Whereas concentration ratio decreases the optimum inlet temperature and exergetic outcome at higher solar intensity are decreases. Therefore, there will be an optimum concentration ratio.

Gharbi et al. [3] suggested that with more concentration ratio, more temperature achieved. However, in contrary the cost of the system increases due to the construction of the parabolic shape used in parabolic trough solar concentrator.

3.2 Rim angle

The breadth of the solar image at the focal plane increases with increasing rim angle. With an increase in rim angle, the concentration ratio as well as the proportions of the image increases.

Singh and Sulaimanet [1] observed an optimum Intercept factor gained at a rim angle of 90° and make the depth to be the focal point. The only value of the width required to calculate the focal point for the rim angle at 90°.

Mwesigye et al. in 2014 presented the influence of different concentration ratios, Reynolds numbers and rim angles on the heat flux and temperature spreading in the receiver for thermodynamic, entropy generation. The increase in receiver tube temperature gradients and entropy generation found to be insignificant at rim angles greater than 80o.

3.3 Reflecting surface material

Concentrating solar collectors need the reflecting surface materials to direct the beam component of solar radiation on a receiver. Thus reflecting surface require high specular reflectance for solar radiation with durability.

Kawira et al. [5] evaluated performance for deferent reflecting material and found that the efficiencies for Aluminium sheet reflector of 54.65 %, Car solar reflector of 53.16 % and Aluminium foil reflector is 49.26 % for the same size of Parabolic trough concentrator.

3.4 Absorber material

The receiver of parabolic concentrator where reflected energy is concentrated is called absorber. The estimation of the thermal performance of PTC requires information about solar energy absorbed by the absorber. The material with higher thermal conductivity and less thermal stress are preferred choice as an absorber.

Shuai et al. [6] performed the simulation for thermal stress analysis for concentric tube receiver with different materials. The stainless steel absorber having higher stress failure ratio compared to Aluminium and copper absorber tube. Absorber tube of copper material having a minimum failure rate comparatively.

Reddy et al. [7] found outcome from optimization of the process the absorber material was the strongest factor among the other parameters used on the multi performance characteristic and finally concluded the optimal material as the aluminium sheet.

3.5 Absorber surface coating

Energy absorbed by absorber depends upon its outer surface absorptivity, to enhance it, black colored coating is applied.

Kennedy and Price [8] successfully prepared a solar-selective coating comprised of materials stable at high using computer-aided design software and verify its accuracy by a round-robin experiment. Receiver tube with improved properties of selecting coating will increase the efficiency of parabolic trough collectors and reducing cost.

Valenciaa [9] developed PTC prototype for the design, construction and evaluation purpose. The efficiency gained was inferior to the reported findings due to the absorber pipe's coating; having absorptivity 0.90. Same way useful energy gain was not as expected due to some surface irregularities.

Keeffe et al. [10] suggested that for low temperatures, an uncoated system is higher efficient compared to generally

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suggested coating improves efficiency; they also provided discrimination to decide at what time coating is suitable. With using this discrimination, they showed that as the solar concentration ratio rises, an uncoated surface turns out to be further efficient than a coated surface less than 1500C Temperature.

3.6 Absorber tube length

The length of the receiver is generally considered the trough length. R. M. Muthusivagami [11] mentioned that in most of the concentrator, using tracking mode, the sunrays with some incident angle after reflection arise to focal line a slight away from the length of absorber tube. In order to intercept that reflected rays absorber tube required at least 10% extra length to intercept 95% of reflected solar insolation.

3.7 Absorber tube diameter

The diameter of the absorber tube used to determine concentration ratio and mass flow rate for a given setup. To allow high intercept factor absorber tube should have an appropriate diameter.

Kumar and Kumar [12] evaluated the variation in OHLC-Overall heat loss coefficient and an optimal air gap for different diameter of absorber pipe. It is observed that the 3.18-4.5 cm diameter range is effective. Among total heat loss, the influence of convective/conductive heat loss for the receiver is greater compare to radiation heat loss.

3.8 Evacuation of the absorber tube

The absorber tube receives concentrated solar insolation subsequently has a higher temperature at the outer surface of the absorber tube leads to higher convective losses to ambient air, this can be diminished by evacuating the absorber tube.

Brooks et al. [13] presented the baseline performance of a PTSC. In this study, the presence of an evacuated glass-shield reduced Ul by 50.2% and a 9.2% improvement in performance.

Kawira et al. [5] evaluated the performance of solar parabolic trough for various reflecting material and found that the maximum efficiencies for Aluminium sheet reflector are 55.52 % while using evacuated tube absorber.

Kawira et al. [14] had observed that the use of open parabolic trough systems, with exposed absorber, led to higher energy losses causing low operating efficiencies of the concentrating collectors prepared from various materials. A transparent medium like glass cover evacuated receiver would considerably improve the efficiencies of the system.

Ma et al. [15] observed that if the synthetically conductance rises from 5 to 40 W/m K, the thermal efficiency of solar collector increases by 10% and the fluid temperature increases by 16% with an increase in coating temperature up to 30° C.

Yaghoubi et al. [16] had noticed that the heat loss for the open tube is 40% higher than evacuated tube along with 3-5% reduction in the concentrator performance.

3.9 Modification of absorber tube

The absorber tube is an important parameter of the solar PTC that absorbed concentrated solar energy from surface area and transfer it to working fluid from the inner surface area of the absorber tube. To maximize collection and transfer of useful heat it required to increase in an area without effecting its concentration ratio.

Muñoz and Alberto [17] had done CFD analysis for internally finned tubes and noticed that as thermal losses and temperature gradients decrease this improves the thermal and exergetic performances of the system.

Shuai et al. [6] presented simulation for radiation transfer and thermal stress analysis for concentric as well as eccentric tube absorber. By implementing an eccentric tube as the tube receiver for PTC the thermal stress is greatly reduced up to 46.6% due to the impact of the oriented angle.

Table 3.1 Comparative study of various designed parameters of the parabolic trough collector.

Name of Researcher	Parameters studied	Optimum Parameters
Singh and Sulaimanet [1] Tyagi et al. [2] Gharbi et al. [3]	Concentration ratio(CR)	Up to 10
Singh and Sulaimanet [1], Mwesigye et. al [4]	Rim angle ø	Maximum 80^{0}
Kawira et al. [5],[14]	Type of reflecting material	Aluminium sheet
Shuai et al. [6] Reddy et al. [7]	The material used for absorber pipe	Copper tube compare to SS and Aluminium tube
Kennedy and Price [8], Valencia [9], O'Keeffe et al. [10]	Absorber coating	No coating required for low temp
Muthusivagami [11]	Length of the absorber tube	10 % Extended length, 0.03m
Kumar et al. [12]	The diameter of the absorber tube	0.03m provide maximum efficiency

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Brooks et al. [1], Ma et al. [15], Yaghoubi et al. [16], Kawira *et al.* [5],[14]	Evacuation of the absorber tube	The performance increase from 4 % to 15%
Muñoz and Abánades [17]	Internal fins type absorber	3% Efficiency Improvement, 5% increase cost
Shuai et al. [6]	Eccentric tube receiver	The thermal stress decreases up to 46.6%
Sangotayo and Waheed [18]	twisted tape factor	High pumping power due to more friction factor and pressure drop
Natarajan et al. [19]	Internal flow obstruction with the different shape	No appreciable changes in temperature.

Sangotayo and Waheed [18] concluded that the higher rate of heat transfer is observed with high twisted tape factor inserted in to the absorber tube. Its leads to higher pumping power due to the increases in the friction and pressure drop.

Natarajan et al. [19] performed the transient 3-D numerical analysis for the absorber tubes with and without insertions. Thermal stress for absorber tube with insertion is less than the without insertion tube and triangular insertion is found to be best compared to other but having a higher pressure drop.

IV. INVESTIGATIONS OF THE VARIOUS OPERATING PARAMETERS OF SOLAR PARABOLIC TROUGH CONCENTRATOR

The performance of solar parabolic trough depends on various operating condition parameters like with or without tracking, type of working fluid, the mass flow rate of the working fluid, the maximum temperature required, with or without storage of energy etc.

4.1 Mass flow rate of working fluid

The mass flow rate of heat transfer fluid is an important parameter to determine the temperature of the working fluid. As fluid mass flow rate through absorber tube is increased, the temperature increment of working fluid is decreased this causes lower average temperature of absorber leads to lower losses and higher useful energy gain.

Morrison et al. [20] outline the investigation on heat transfer performance for single ended all glass evacuated tubular solar collectors to determine the mass flow rate through the tubes. Primary results show that the flow rate through each tube for 1000 W/m^2 solar radiation found 20 kg/hr.

Tyagi et al. [2] seen that the prime aim of any thermal concentrator is to improve its thermal efficiency, for huge mass flow rates of the fluid, the fluid outlet temperature reduced very well and needs extra pumping power through the collector. Whereas for the low mass flow rates leads to high fluid outlet temperatures but it increases the energy losses due to the higher temperature deference, so there is a need for the optimum mass flow rate.

Manikandan et al. [21] presented an innovative system solar parabolic trough collector that combined with a residential type-cooling unit presented for the thermal energy. For the given value of the solar intensity the performance of the PTC shown to increases when the concentration ratio of the system and the mass flow rate of the fluid increases.
Yassen [22] has found that the efficiency starts with mass flow from zero, at zero mass flow rate there will be zero heat removal factor. The increasing mass flow rate will reduce the absorber tube temperature so that heat losses from the absorber tube will decrease and heat removal factor will improve. The efficiency reaches a maximum at a mass flow rate of 40 kg / hr, above which no more efficiency increase observed.

4.2 Tracking of the concentrator

Solar Parabolic trough has to trace the sun to get a continuous concentration of direct solar insolation. As concentration focus here on line absorber, parabolic trough required one axis mechanism to track the sun.

Valan and Sornakumar [23] are developed PTC having the maximum error for tracking mechanism was 0.18% merely and the precision of the tracking mechanism was amply advanced than the necessary 0.5%.

Dicorato et al. [24] analyzed the performances of a parabolic trough power plant to evaluate annual solar radiation two different types of one-axis solar tracking systems have been implemented, with the horizontal and tilted rotation axis. Moreover, the analysis shows a single inclined rotation axis on the horizontal plane has yielded better results, compare to biaxial sun tracking.

Sansoni et al. [25] have simulated ray tracing for optical characteristics and collector collection performance for the prototype geometry to regulate the errors. With reference to N-S positioning, there would be a huge loss of energy if not align properly and it depends on the sun's altitude and N-S positioning error.

Silverio et al. [26] advised that the Axis of the solar parabolic trough concentrator should keep facing N-S direction and solar tracking systems should track the the sun during a different time of day.
Wang et al. [27] presented an assessment of the optical performance for various tracking modes of PTC. The horizontal E-W tracking mode received higher energy than that of a horizontal N-S tracking, while the E-W tracking

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mode collects more energy in summer but a smaller amount in winter.

Keou et al. [28] assessed solar prospective for the four different tracking means and revealed that the one axis polar movement E-W provide 96% and horizontal E-W tracking provide 94% of full annually tracking mode.

4.3 Heat transfer fluid

The heat transfer fluid has the task to collect heat from the absorber and transfer to other working fluid or point of use. Pendalwar et al. [29] observed from Numerical and experimental investigations reveal that the heat transfer coefficient and Nusselt number increases with an increase in nanoparticle volume fraction.

Natarajan and Sathish [30] applied additives technique to enhance the heat transfer performance of base fluids. These nanoparticles alter the carrying and heat transfer properties of the base fluid, and reveal greater heat transfer ability in comparison with regular heat transfer fluids.

Yang and Lai [31] results indicate that with the increases of Reynolds number and particle volume concentration, the average Nusselt number increases and uniformity of fluid temperature distribution with nanofluid are more than that of pure water.

Moraveji et al. [32] [33] presented the effect of Aluminium oxide nanofluid for the thermal efficiency improvement of a heat pipe made of a straight copper tube on the different operating condition. Outcomes reveal improved thermal performances with the nanofluid for this heat pipe, due to decreases the resistance and wall temperature difference. Yousefi et al. [34] performances outcome shows that for 0.2 wt % of nano fluid leads to higher pumping power in comparison with water would increase the efficiency 28.3%.

4.4 Wind velocity

The wind speed variation affects the heat transfer outcome of a parabolic trough, as wind speed increase the convective heat losses from the outer surface of the glass cover is also increase for that instance.

Table 4.1 Comparative study of various operating parameters of the parabolic trough collector.

Name of Researcher	Parameters studied	Outcome of Research
Morrison et al. [20], Tyagi et al. [2], Manikandan et al.[21], Yassen [22]	The mass flow rate of fluid	40 kg/hr provide maximum efficiency
Valan and Sornakumar [23]	Tracking accuracy	0.18 against required 0.5 %
Dicorato et al. [24], Sansoni et al. [25], Silverio et al. [26], Wang et al. [27], Keou et al. [28]	Tracking and non-tracking	Tracking: In summer E-W direction tracking, In winter N-S tracking, The single axis E-W direction tracking provides 94% of full tracking performance
Pendalwar et al.[29], Natarajan and Sathish [30], Yang and Lai [31], Moraveji et al [32],[33], Yousefi et al. [34]	Heat transfer fluid water	Mostly water Water and Nano fluid Al_2O_3 Nano Particle
Tijani et al. [35], Shojaee et al. [36]	Wind velocity	The summative outcome of heat losses not significantly changed by variations of wind velocity

Tijania et al. [35] had found from a mathematical model that the summative outcome of radiation and convection heat losses not significantly changed by variations of wind velocity.

Shojaee et al. [36] presented the wind influence models for PTC for two main parts one-heat losses over receiver pipe due to wind flow and the second application of forces on the collector body. It was found that the maximum force occurs at +60 degrees. The receiver pipe covered for bigger incident angle, therefore the Nusselt number decreased.

V. CONCLUSION

This parametric review reveals the factor affecting on the outcome of the parabolic trough. The most important parameters are classified as designed and operating parameters. The effective performance of the parabolic trough depends on designed parameters likes Concentration ratio, Rim angle, Reflecting surface materials, Receiver surface specifications etc. Table 1 exhibits the summary of the designed parameters cited in this review. Where the concentration ratio vary from 1 to 212 but the system optimum efficiency found at concentration ratios of 10. The increase in absorber tube temperature gradients and entropy generation shown to be insignificant at rim angles greater than 80°. With an Aluminium sheet reflector found maximum efficiencies from the evaluated performance of solar parabolic trough for various reflecting material. An Absorber tube of copper material having minimum failure rate comparatively, and application of the selective coating on the external surface of absorber tube found ineffective for low temperature use, it is beneficial only in case of inlet temperature more than 150^0C. In order to intercept the reflected rays absorber tube required at least 10% extra length to intercept 95% of reflected solar insolation along with 3.18-4.5 cm absorber tube diameter range which is effective for useful heat gain. A transparent

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medium like glass cover evacuated receiver would considerably improve the efficiencies of the system.

Table 2 displays a summary of the operating parameters cited in this review. The aggregate outcome maximized at 40 kg / hr mass flow rate of the fluid, no further outcome increase beyond this. The horizontal E-W tracking mode received higher energy than that of a horizontal N-S tracking, while the E-W tracking mode collects more energy in summer but a smaller amount in winter. With the presence of nano fluid the average Nusselt number increases and uniformity of fluid temperature distribution is more than that of pure water. The productivity of solar PTC decrease with very high wind velocity but the summative outcome of total losses not significantly changed by variations of wind velocity.

The Selection of various design and operating for parabolic trough is difficult for given solar and environment conditions. The Various author have taken different parameters for their performance analysis and mentioned experimentally or analytically founded optimal parameters for best efficiency. The combination of these different optimal design and operating parameters for prototype development would provide more efficiency and effectiveness compare to one or two parameters considerations. These review have identified above mentions most favorable parameter solar parabolic trough.

REFERENCES

[1] Singh Balbir Mahinder Singh and Sulaimanet Fauziah, (2003), 'Designing a solar thermal cylindrical parabolic Trough concentrator by simulation', International Rio3 Congress, World Climate and Energy Event, Rio de Janeiro, 1-5 December, pp. 1-6.

[2] Tyagi S.K., Wang Shengwei, Singhal M.K., Kaushik S.C., Park S.R., (2007). 'Exergy analysis and parametric study of concentrating type solar collectors', International Journal of Thermal Sciences, Vol. 46, pp. 1304-1310.

[3] Gharbi Najla El, Derbal Halima, Bouaichaoui Sofiane, Said Noureddine, (2011),'A comparative study between parabolic trough collector and linear Fresnel reflector technologies', Energy Procedia, Vol. 6 , pp. 565-572.

[4] Mwesigye A., Le Roux, W.G., Bello-Ochende T. and Meyer J.P, (2014), 'Thermal and Thermodynamic Analysis of A Parabolic Trough Receiver At Different Concentration Ratios And Rim Angles', 10th International Conference On Heat Transfer, Fluid Mechanics And Thermodynamics, pp. 907-915.

[5] Kawira M, Kinyua R., Kamau J. N., (2011), 'Fabrication and characterization of a prototype parabolic trough solar concentrators for steam production', Department of Physics, Jomo Kenyatta University of Agriculture and Technology, Nairobi, pp. 1-7.

[6] Shuai Yong, Wang Fu-Qiang, Xia Xin-Lin, Tan He-Ping, (2010), 'Ray-Thermal-Structural Coupled Analysis of Parabolic Trough Solar Collector System' Solar Collectors and Panels, Theory and Applications, pp. 341-356.

[7] Reddy Sri P. Mohana, Venkataramaiah P., Sairam P., (2012), 'Optimization of Process Parameters of A Solar Parabolic Trough In Winter Using Grey-Taguchi Approach', International Journal of Engineering Research And Applications, Vol. 2(1), pp. 816-821.

[8] Kennedy C.E and H. Price, (2005), 'Progress in the development of high-temperature solar-selective coating', International Solar Energy Conference, NREL/CP-520-36997, pp.1-7.

[9] Valencia J. Macedo, Ávila J. Ramírez, Acosta R., Jaramill O.A. and J.O Aguilar O.A., (2014), 'Design, construction and evaluation of parabolic trough collector as demonstrative prototype', Energy Procedia, Vol. 57, pp. 989 – 998.

[10] O'Keeffe G.J., Mitchell S.L., Myers T.G., Cregan V., (2018), 'Modelling the efficiency of a nanofluid-based direct absorption parabolic trough solar collector', Solar Energy, Vol. 159, pp. 44–54.

[11] Muthusivagami R. M., (2011), 'The Impact of End Effects in Parabolic Trough Collector Pilot Set-Ups', IEEE, pp. 237-239.

[12] Kumar Devander and Kumar Shudir, (2016), 'Simulation anylisis of overall heat transfer coefficent of parabolic trough solar colletor at computed optimal air gap', Energy Procedia,Vol. 109, pp. 86-93.

[13] Brooks M J, Mills I, Harms T M, (2006), 'Performance of a parabolic trough solar collector', Journal of Energy in Southern Africa, Vol. 17(3), pp. 71-80.

[14] Kawira M., Kinyua R., and Kamau J. N., (2012) 'A prototype parabolic trough solar concentrators for steam production', JAGST Vol. 14(2), pp. 90-103.

[15] Ma Liangdong, Lu Zhen, Zhang Jili, Liang Ruobing, (2010), 'Thermal performance analysis of the 8 Glass evacuated tube solar collector with U-tube', Building and Environment, Vol. 45, pp. 1959 -1967.

[16] Yaghoubi M., Ahmadi F., Bandehee M.,(2013), 'Analysis of Heat Losses of Absorber Tubes of Parabolic trough Collector of Shiraz (Iran) Solar Power Plant', Journal of Clean Energy Technologies, Vol. 1(1), pp. 33-37.

[17] Muñoz Javier and Abánades Alberto, (2011), 'Analysis of internal helically finned tubes for parabolic trough design by CFD tools', Applied Energy, Vol. 88, pp. 4139–4149.

[18] Sangotayo Emmanuel O. and Waheed Mufutau A., (2011), 'Parametric Study of Heat Characteristics of Fluid in Cylindrical Parabolic Concentrating Solar Collector', The Pacific Journal of Science and Technology, Vol. 12(1), pp. 152-160.

[19] Natarajan M., Raj R. Thundil karuppa, Sekhar Y. Raja, Srinivas T. and Gupta Pranay, (2014),

 DOI : 10.18231/2454-9150.2019.0169

'Numerical Simulation of Heat Transfer Characteristics In The Absorber Tube of Parabolic Trough Collector With Internal Flow Obstructions', Arpn Journal of Engineering And Applied Sciences, Vol. 9(5), pp. 674-681.

[20] Morrison Graham L., Budihardjo Indra and Behnia Masud, (2002), 'Heat Transfer in Evacuated Tubular Solar Collectors', University of New South Wales. Pp. 1-5.

[21] Manikandan K. Senthil, Kumaresan G., Velraj R., Iniyan S., (2012), 'Parametric study of solar parabolic trough collector system' Asian journal of applied sciences, Vol. 5(6), pp. 384-393. Yassen Tadahmun Ahmed, (2012), 'Experimental and Theoretical Study of a, Parabolic Trough Solar Collector', Anbar Journal for Engineering Sciences, Vol. 5(1), pp. 109-125.

[22] Yassen Tadahmun Ahmed, (2012), 'Experimental and Theoretical Study of a, Parabolic Trough Solar Collector', Anbar Journal for Engineering Sciences, Vol. 5(1), pp. 109-125

[23] Valan Arasu A. and Sornakumar T., (2006), 'Performance Characteristics of Parabolic Trough Solar Collector System for Hot Water Generation', International Energy Journal: Vol. 7 (2), pp. 137-145.

[24] Dicorato Maria, Forte Giuseppe, Pisani Mariagiovanna, Tuglie Enrico De, (2010), 'One-axis tracking optimization of Concentrating Solar Power plant for electricity production', UPEC2010, pp. 1-6.

[25] Sansoni P., Fontani D., Francini F., Giannuzzi A., Sani E., Mercatelli L., Jafrancesco D., (2011), 'Optical collection efficiency and orientation of a solar trough medium-power plant installed in Italy', Renewable Energy, Vol. 36, pp. 2341-2347.

[26] Cortés Silverio Garcia, Garcia Antonio Bello, Ordonez Celestino, (2012), 'Estimating intercept factor of a parabolic solar trough collector with the new supporting structure using off-the-shelf photogrammetric equipment', Applied Energy, Vol. 92, pp. 815-821.

[27] Wang Cunxu, Zhang Hongli and Wang Shuqun, (2014), 'Track Mode Selection of Parabolic Trough Collectors', Advanced Science and Technology Letters, Vol. 73, pp. 52-59.

[28] Keou Charlain-Joel Ngangoum, Njomo Donatien, Sambou Vincent, Finiavana A. R. Andrianaharinjaka, Tidiane Ahmadou Diaby, (2017),'Two-Dimension Numerical Simulation of Parabolic Trough Solar Collector: Far North Region of Cameroon', Energy and Power Engineering, Vol. 9, pp. 147-169.

[29] Pendalwar S. P., Bhandarkar U. V. and Prabhu S. V., (2009), 'Experimental and numerical investigation on convective Heat transfer coefficient for the turbulent flow Through pipe using nanofluid', International journal of micro and nano systems, Vol. 1(1), pp. 9-14

[30] Natarajan E. and Sathish R., (2009), 'Role of nanofluids in solar water heater' International Journal of Advance Manufacturing Technology, Special Issue, pp. 1-5.

[31] Yang Yue-Tzu and Lai Feng-Hsiang, (2011), 'Numerical study of flow and heat transfer characteristics of alumina-water nanofluids in a micro channel using the lattice Boltzmann method', International Communications in Heat and Mass Transfer, Vol. 38, pp. 607-614.

[32] Moraveji Mostafa Keshavarz , Haddad Seyyed Mohammad Hossein, Darabi Mehdi, (2012), 'Modelling of forced convective heat transfer of a non-Newtonian nanofluid in the horizontal tube under constant heat flux with Computational fluid dynamics', International Communications in Heat and Mass Transfer, Vol. 39, pp. 995–999.

[33] Moraveji Mostafa Keshavarz and Razvarz Sina, (2012), 'Experimental investigation of aluminium oxide nanofluid on heat pipe thermal performance', International Communications in Heat and Mass Transfer, CHMT-02652, pp. 1-5.

[34] Yousefi Tooraj, Veysi Farzad, Shojaeizadeh Ehsan, Zinadini Sirus, (2012). 'An experimental investigation on the effect of Al_2O_3-H_2O nanofluid on the efficiency of flat-plate solar collectors', Renewable Energy, Vol. 39, pp. 293-298.

[35] Tijani Alhassan Salami and Roslan Ashraf M.S. Bin, (2014), 'Simulation analysis of thermal losses of parabolic trough solar collector in Malaysia using computational fluid dynamics', Procedia Technology, Vol. 15, pp. 841-848.

[36] Shojaee Seyyed Mohammad Nima, Moradian Mohammad Adel, Mashhoodi Mashhood (2015), 'Numerical Investigation of Wind Flow around a Cylindrical Trough Solar Collector', Journal of Power and Energy Engineering, Vol. 3, pp.1-10.

[37] Sukhatme S. P. and Nayak J. K. (2010), 'Solar Energy: Principles of Thermal Collection and Storage', Tata McGraw Hill Education Private Limited.

 DOI : 10.18231/2454-9150.2019.0169