International Journal of Latest Engineering and Management Research (IJLEMR)
ISSN: 2455-4847
www.ijlemr.com || Volume 06 - Issue 02 || February 2021 || PP. 34-40

Concentrated solar central receiver thermal power plants: A-review

Mahmoud Sh. Mahmoud[1], Qusay J. Abdul-Ghafoor[2], Ahmed F. Khudheyer[3]
[1,3]*(Mechanical, Engineering College/ Al-Nahrain University, Iraq)*
[2]*(Mechanical, Engineering College/university of Technology, Iraq)*

Abstract: Using concentrated central receiver system to produce thermal power which could be converted to electricity, is a promising technique and one of the most feasible options to use clean energy instead of the fossil fuel power plants. The most important studies on the main solar central receiver thermal power plants components are represented in this review paper, the plant component includes the solar receiver, the heliostat field and the tracking system. A detailed literature survey for the mentioned components have been arranged. The paper contains recent improvements for solar receiver, heliostat, and tracking systems contributions during the past 10 years.

Keywords: Central receiver system, Heliostat field, solar receivers, tracking system, concentrating solar power.

I. INTRODUCTION

This paper provides a review of previous researchers and studies that investigated the main effecting parameters on the central tower solar power system performance. Solar receivers are the main part of a solar power tower plant (SPTP) and they are classified according to geometrical configuration, absorber tube material, and working fluid type. The results of several researchers regarding design, development, experimentations, and enhancement of the receiver in addition to tracking system, and heliostat filed.

II. SOLAR RECEIVER DESIGN

The design for SPTP depends on the application used by the plant and it was investigated by several researchers, in this section a brief description is shown. A molten salt tube receivers was simulated using CFD to solve a complex heat transfer case for the temperature and heat flux distributions where various heat flux is subjected on the front half of the tube's circumference and other half is considered isolated. The results showed that the molten salt temperature distribution on tube wall is variable, whether in radial or an axial direction, the inner tube wall temperature is an important parameter to prevent the molten salt from decomposing. They also founded that local Nusselt number was almost steady verses the change in cosine angle over the tube circumference, heat flux density varies with working fluid velocity and thus heating surface temperature gradient is large with a (34 K) temperature difference. [1] while [2]had developed and tested several shapes and arrangement of pipes (flat plate, 0o, 30 o and 45 o offset tubes, diamond and offset rectangular tube) with 5cm length to increase the receiver's thermal efficiencies by increasing the effective solar absorptance. Linear and radial patterns structures and geometries works as a sunlight trapping systems that works to reduce the amount of radiative losses and reflected solar radiation and. Several meso-scale receiver prototype parts were manufactured. The solar receivers were evaluated under same conditions. They had showed that both tests and simulations of the irradiance distribution on corrugated samples produced greater irradiances in the valleys of the corrugations that promoted higher solar absorptance relative to the flat samples the most efficient was diamond shape tube arrangement with 91.5%, then offset rectangular tube with 90.7%, while the 45 o, 30 o, 0o offset tubes gave 90.3%, 90.2%, 89.7% respectively compared with flat plate of 86%. Relative to a flat plate, the new geometries could increase the effective solar absorptance 13.2% for 0.6 essential material absorptance. ANSYS FLUENT for modeling and to calculate the losses due to convective heat at wind speeds ranging from (2 to 10) m/sec in both cavity and external STR (solar tower receiver). For the cavity receiver, a fixed tilt angle ($\theta t = 90°$) is implemented. The outcomes indicated that convective heat loss from cavity receiver convective heat loss is slightly smaller and was around half the loss associated with using external receivers. [3]. An innovative technique for comprehensive simulation of the phenomenon of fluid movement and heat transfer in the solar tower receiver. Four secondary models (heat conduction, radiation caused by solar and thermal, two phase flow, and free convection) were considered. A detailed data gained from computational fluid dynamic free convection simulation around the tubes, the simulation of two-phase fluid in the tubes uses the measured heat transfer convective coefficient, the convective heat transfer equation and the measurement of losses caused by the radiant using the average temperature within the tubes were founded. The complex unstable heat transfer and fluid-dynamic phenomena were simulated using present-day technology [4]. The development and construction of solar power tower system (SPTS) prototype had been conducted. Ten heliostats were fixed to reflect the solar energy to the central receiver located at 7m height tower. The heliostat rotational and elevation movements were operated with two motors. In the heat exchanger, 11.26kW of thermal power transferred to the water as it is heated by the molten salt. While in the heat exchanger the thermal power provided by the molten salt was also calculated and found to be 12.31 kW. Thermal power for the system was 13kW. The percentage error in the obtained thermal power was around 5.3% [5]. A detailed three-dimensional numerical simulation model of solar serial receivers for power tower plant was presented. The proposed model aims to consider all the major phenomena influencing the performance of a serial receiver, including transfer medium, the heat flux imposed on the wall and the velocity of heat transfer fluid. The software used for this study was ANSYS CFX, with an unstructured grid with 825300 cells. It helps to choose the best fluid, the fluid velocity in inlet according to turbine that was used for make solar tower, and heat flow imposed on the receiver according to the selection and orientation of heliostat field [6]. Analyzing the energy output from a solar tower for southern Jordan's Ma'an area, by using 3D-Energy simulation software. The reliance of the power output on the tower height was discussed showing that greater power output can be enabled by optimizing the tower height. The relation between the solar tower's height and its ability to generate energy has been studied. Two solar towers, (16 and 32) meters tall, were used. The assumption was that the energy output is proportional to the height of the tower. The nearest mirrors to the tower are the most capable of producing energy, as it works very well to concentrate the solar radiation compared to the mirrors far from the tower. Maximum annual power output from the first (16) m high solar tower field was 1.3 MWh while total annual power production from the second field with a (32) m tower height was 2 MWh[7].A theoretical model for the receiver's new design using an evacuated tube as shown in Fig. 1 was introduced, to eliminate heat losses caused by radiation and convection heat transfer modes this is done by using a zigzag configuration. The results of the simulation illustrated that the input energy varies proportionally to solar irradiation; increases range from (3429 to 5584) W for preheating and from (1879 to 3875) W for the overheating at 9:00 AM and 1:00 PM. Thermal efficiency of the receiver's was about 0.72. A detailed description of the proposed novel receiver design had been presented. The zigzag configuration was used to reduce the spillage from the receiver and maximize the number of pipes and absorb as much solar energy as possible, cosine and spillage are the greatest losses impact on optical performance [8].

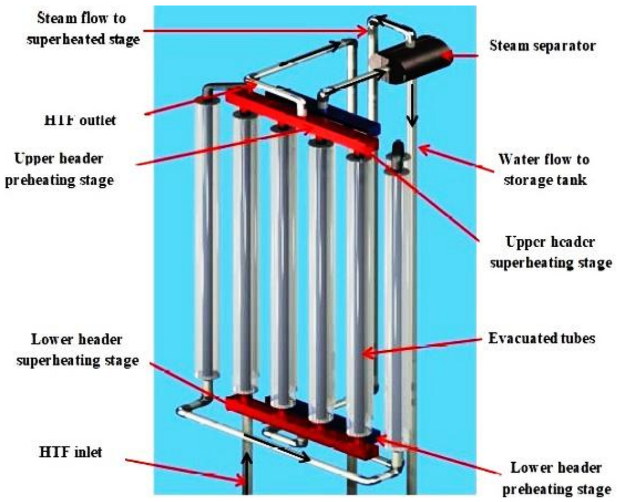

Fig. 1 Evacuated tube receiver [8]

III. HEAT TRANSFER OPTIMIZATION

Numerical and experimental methods to analyze various velocities at entrance and its effect on the flow output and the tube receiver thermal efficiency. A lamp light (Xe-arc) of five kW power was used to simulate the solar rays. The results show that the water and tube wall temperatures distribution are unequal in both axial and radial directions. They observed that with the change in entrance velocity, a slight increase in the thermal capacity of the tube receiver. The tube receiver thermal efficiency decreases with reduction in volume flow rate. Convection losses is about twice radiation losses. Bulk working fluid temperature is lower than tube sides [9]. Analyzing heat transfer and optical performance of a central tower plant, optimizing heliostat field configuration and receiver geometry for a 1MW cavity receiver was applied. A polar heliostat area of 413 heliostats combined with an aperture oriented 60o below the horizon of 55 cm radius was found to provide an average annual thermal efficiency of 50.35% for the facility. The thermal efficiency at the design point of the optimized receiver configuration was found to be 91.6% and maximum radius of the cavities was 82.5 cm [10]. While [11] proposed a new hybrid receiver design for a compound parabolic concentrator, the receiver consist of a U-shaped tubular receiver and a bifacially irradiated flat receiver. A modelling for the transmission and absorption of solar energy, optical losses, heat transfer within the receiver, and the thermal losses was performed. The oil flow rate was considered constant, the thermal resistance of the thermal oil flow within the receiver reduces when the flow passage is narrowed leading to increase the thermal efficiency. Thermal oils have low thermal conductivity and high viscosity, which increase the thermal resistance, hence reduced collector thermal efficiency. One way to minimize the thermal resistance is by having turbulent flow of the thermal oil within the receiver. Typically, this hybrid receiver has similar or better thermal efficiency than that for the tubular receiver. Thermal efficiency and eff ective thermal efficiency, which accounts for the pumping power consequence. It is also had been shown that the performance improvement for using thermal oil due to receiver shape optimization depends on the receiver area, concentration ratio, absorptivity and emissivity for the selective surface of the receiver, the mass flow rate through the receiver and fluid temperature. For temperatures less than 150 oC, water has been found to give better performance than that for thermal oil at all mass flow rates with no significant improvement in collector performance achieved by reducing the tube diameter. A thermal receiver was designed to estimate the thermal power with minimal heliostats number, and to measure thermal power. The receiver is a flat plate with parallel pipes for inlet and outlet flow that has 1.20 m height, 1.23 m width and 0.1 m depth with 1.476 m2 reception area and 0.95 heliostats reflectivity as shown in Fig. 2. It also had 1228 uniformly spaced cylindrical fins, each fine has a diameter of 0.0095 m and 0.09 m length, which increases the reception area by up to 329%. At Re number of 29000, the experiments were performed; the system's thermal efficiency was found to decrease as the radiative flux rises. Fins temperature gradients has a proportional behavior with the radiative flux and the fluid temperature as it moves through the receiver, the higher temperatures are located at the middle of the plate. The receiver wall mean temperature increases with increase of the heat flux. The plate's mean temperature is at central portion and appears to diminish radially. System's thermal efficiency decreases as the radiative flux increases. Increase in radiative flux causes diminishing of the thermal boundary layer thickness [12].

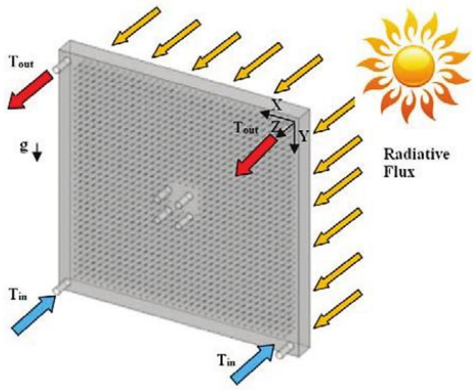

Fig. 2 Flat plate receiver [12].

IV. RECEIVER COATING

A black selective coating made by sol-gel dip-coating was developed. The characteristic matrices method was used to simulate the designed thin multilayered films. The profile depth of the multilayered three areas coating was confirmed by means of Time of Flight Secondary Ion Mass Spectroscopy (ToF-SIMS) and X-Ray Photoelectron Spectroscopy (XPS). Nanocrystalline particles of (5 to 20) nm in diameter were observed using Transmission Electron Microscopy (TEM). The achieved enhancement in solar absorption had reach more than 0.95 while the thermal emittance was about 0.12. A comparison of corrosion resistance and thermal stability of the presented novel coatings was done with black chrome coatings giving enhanced properties [13]. The improvement of central solar power (CSP) systems efficiency by using selective coatings for the solar receiver that withstand higher temperatures leading to high absorptivity and low emissivity coatings. A thermal coating spray (Pyromark) compositions (Ni-25 graphite, Ni-5Al and WC-20Co) were compared according to the solar emittance and absorptance with other oxidation materials used in coating like NiCo2O4, CuCo2O4, and (NiFe) Co2O5, the results showed that there was an optical improvement using both type of coatings [14]. Studied experimentally the improvement of thermal performance for a flat plate solar collector. The surface radiative properties were modified by testing three types of coating, copper oxidization by using ammonia, graphene, and black matt paint. Results showed that the radiative properties and thermal efficiencies of the absorbers were evaluated, the best performance was observed to be the oxide with a maximum efficiency of 39.5% compared with the black matt paint [15]. An experimental comparison for a flat-plate collector coated using three different materials, black matt paint, black chrome, and carbon-coating was conducted. Results showed that the carbon-coated absorber plate had the highest thermal efficiency due to its higher optical absorptivity. Comparing the thermal efficiency of the black-painted absorber collector with other two collectors had showed an increase by approximately 13% for the carbon-coated absorber while a 11.3% increase for the black chrome-coated absorber. Although it is noticed that the coating cost is proportional to the enhancement. The lowest coating cost was for the black matt paint with a thermal efficiency of 56.4% and in second level the black chrome had a thermal efficiency of 67.7% and the carbon coated which is the most highly expensive coating among the mentioned materials but with a thermal efficiency of 69.4%. It is obvious that using selective coatings leads to an enhancement in the thermal efficiency and decreases the heat loss due to higher optical absorptivity and lower emissivity [16].

V. TRACKING SYSTEM

Several researchers have tried to develop creative, cost-effective double-axis tracking techniques to optimize the collected amount of solar energy from the sun, thus the total gain of the produced power is maximized. The expense and complexity of the device compared to single axis tracking is the challenge key facing the researchers in selecting the suitable tracking system. Planning, developing and confirmation for the accuracy of sun tracking system based on a photo-sensor device to monitor the heliostat by using an equatorial support in addition to two aided- sensors to maintain stable tracking in cloudy weather. They reached sun-tracking at clear weather with (0.6 mrad) error. However, during rainy times the error is larger, and thus the greater the loss of energy [17]. An experimental investigation for a tracking system performed by using a commercial webcam which had been used as a sensor for the sunlight, which was connected by USB port to a PC, a DC motors driver were used to receive the signal from the PC to adjust the location by a stepper motor, they had found that the accuracy of the system was about (0.1o), by using the webcam instead of the common used sensors had led to cost reduction and showed compatibility with the weather changes [18]. Tested a microcontroller universal multi-function tracking system for a PV panels, a comparison between stationery and training equipped panels had been done, they had founded an increase of (30-60)% increase in gained energy, the detected sunlight that gives maximum power is stored in a memory card that could be used as a reference point and by using a digital system which connects the photo-resistors with a stepper motor to control the panel movement according the signal feedback. This type of system is self-powered, and all its components are connected to get power from the sunlight only by converting the solar radiation into electrical power, the efficiency of the proposed system was calculated on a summer clear sky day and found to be 63.92% [19]. A comparison between two types of sun tracking techniques of dual axis used in the application of heliostat, the Spinning-Elevation (SE) and Azimuth-Elevation (AE), for a single heliostat or a heliostat field. A simulation for the two types was conducted using a special algorithm for the annual accumulated facing and target angles in addition to the latitude, they had founded that the sun altitude angle for (αAE) was about double that for (αSE) as shown in Fig. 3 (a) and (b). Also the total consumed power of (SE) was (4.8-9.3) % lesser than that for (AE) tracking type [20].

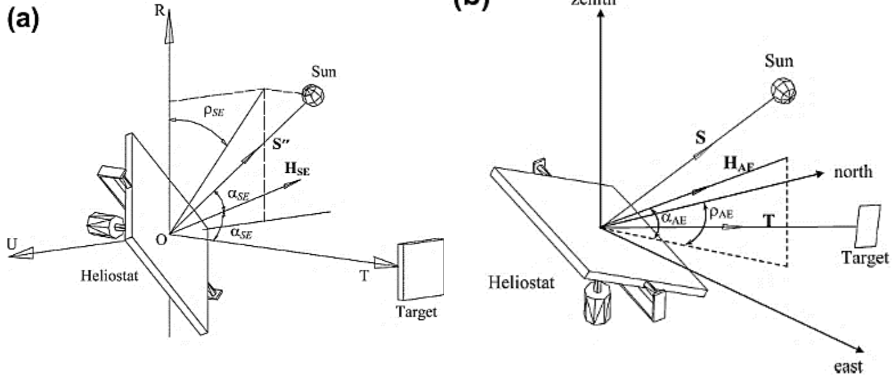

Fig. 3 Local heliostat reference coordinate system for the (a) (SE) and (b) (AE) [20].

Investigating the effect of azimuth and tilt angles on power output of a PV panel located at Tunisia, Monastir city (36o latitude). A comparison between single and dual axes tracking systems was conducted, also the optimum tilt angle for a fixed panel was compared with the two moving systems. Comparing the fixed type with the single axis system for summer and winter had given a 10.34% and 15% gain while the gain for comparing the traditional fixed PV panel with the dual axes for summer and winter had reached 30% and 44%

respectively [21]. Designing, construction and testing a dual axes solar tracking system for PV panel, the used components for the tracking system was sunlight sensing unit, light comparison unit, microcontroller, and movement adjustment unit. The working duration was from 8:00 am till 5:00 pm and a comparison with the fixed system was conducted at each working hours with the same environmental conditions, the maximum reached enhancement with 215.14% was recorded to be at 4:00 pm, while the minimum enhancement with 6.67% was found to be at 1:00 pm. The energy gained form the system was found to be 52.78% compared to stationary panels [22]. Investigation for the importance of monitoring the location of the sun with high accuracy in order to ensure maximum permissible output power generated by concentration of solar and photovoltaic systems, the amount of energy produced was proportional to the amount of solar energy obtained by the solar system using solar tracking systems. Solar tracking device was the most common method of growing solar radiation from the sun to either flat plate or focused collectors in the solar collectors. Solar energy gained ground rapidly as an important means of expanding the use of renewables. Solar monitoring was operated by a photovoltaic screen to optimize captured solar radiation. Setting it apart from other clean energy technology is the ability to concentrate solar power (CSP) to effectively store vast quantities of electricity. Nonetheless, it requires cost savings and increased productivity to come to be more economically feasible. There are considerable opportunities for budget saving, especially for central receiver system (CRS) technology, where the heliostat field accounts for 40 to 50 % of total capital expenditure. Heliostats are used by CRS plants to reflect sunlight on a central receiver. The realization of high solar concentration ratios requires heliostats with good tracking precision, It allows for efficient energy recovery at high working temperatures. Tracking errors mainly take place owing to tolerances in the manufacture, ordination and placement of heliostats, but high tolerance standards typically raise costs. Therefore, a way to develop tracking accuracy is required with no growing demands for tolerance[23]. A design and built a solar tracking system using Arduino microcontroller. This system was designed to respond to its environment in a short time. Any errors at hardware and software was removed or controlled. System responsiveness was verified for its real-time, stability, reliability, and safety. It was designed to be withstand mechanical stresses, climates changes. LDR sensors were used to sense the solar light intensity reaching the solar panels. They concluded that the new design is sensitive to a small torch light, in a dark room. The cost and reliability of this solar tracker makes it appropriate for the usage even in the rural areas [24]. While [25] had studied numerically and experimentally a dual-axes heliostat solar tracking system, as a case study in Dhahran province in Saudi Arabia. A mathematical algorithm of solar position was used for the tracking system. This algorithm had been realized numerically in MATLAB Simulink and experimentally using microcontroller (Arduino-Mega). Results gave accurate tracking elevation and azimuth angles.

VI. HELIOSTAT FIELD

CRS performance depends strongly on the efficiency of the solar field which is in turn related to the heliostat type, field configuration, tracking and control system. Researchers focused on the heliostat field as mentioned in this section, and their outcomes are reported briefly. Proposed techniques and used methods to improve the heliostats field performance are also outlined. The solar field contains a huge number of tracking heliostats. Every single heliostat requires one or several mirrors, frame, base structure, monitoring device, and control system.

Simulating a new model for heliostat field layout, a detailed calculation of the annual average optical efficiency for the model was considered including cosine losses, shading and blocking, spillage, and atmospheric attenuation. Discretization of the heliostat's layout was viewed as ray tracing with a carefully selected distribution of rays. Radially staggered layout was optimized with the objective of maximizing the annual insolation weighted heliostat field efficiency. Land area was reduced by 15.8% while field efficiency was improved by 0.36%, and relationship between land area and efficiency was achieved. Also, it was found that for a fixed energy collected, it was possible to control the number of heliostats and also to reduce the working site area that leads to reduction in the plant capital cost, which leads to a reduction in levelized cost of energy (LCOE) [26]. Investigation for the output of heliostat fields as a function of the optical quality. Optical heliostat performance was influenced by key factors; shadowing, blocking and cosine effects, also receiver spillage, atmospheric attenuation, and mirror reflectivity. Single heliostat basic architecture is shown in Fig. 4. The heliostat area is associated to 40% of total energy losses and about half the cost of the overall investment. Optimizing the architecture had been performed to reduce the capital cost and increase the overall performance of the power plant is then crucial [27].

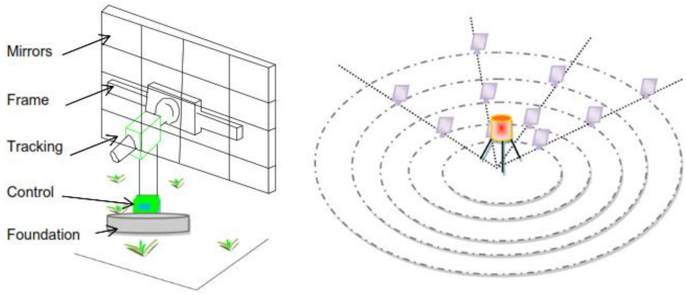

Fig. 4 Heliostat basic concept; radial staggered layout [27].

Suggestions for the applicability of central receiver system (CRS) at high latitude with appropriate site selection and layout optimization. Also, site selection implies to select a location with advantageous geographical features for optical efficiency improvement. Therefore, analysis on the site slope effect and guideline to select the most optically efficient site type are the main concerns of this study. Alternate modeling and genetic algorithm are utilized for efficient and accurate optimization of the heliostat field layout. The optimal site type varies according to the latitude, and utilization of the most efficient heliostat field site improves the optical efficiency by up to 1.65% point that can hardly be achieved by field layout optimization only [28].

VII. CONCLUSION

From the above mentioned studies, it is obvious that there are many studies that deals with solar central tower. Aresearch aims to fabricate new staggered configuration for the solar absorber heat exchanger equipped with a new individual dual axes tracking system. This can be achieved by experimental and numerical investigations.

REFERENCES

[1]. X. Yang, X. Yang, J. Ding, Y. Shao, and H. Fan, Numerical simulation study on the heat transfer characteristics of the tube receiver of the solar thermal power tower, *Appl. Energy*, vol. 90, no. 1, pp. 142–147, 2012, doi: 10.1016/j.apenergy.2011.07.006.

[2]. J. Yellowhair, C. K. Ho, J. D. Ortega, J. M. Christian, and C. E. Andraka, Testing and optical modeling of novel concentrating solar receiver geometries to increase light trapping and effective solar absorptance, *High Low Conc. Syst. Sol. Energy Appl. X*, vol. 9559, p. 95590A, 2015, doi: 10.1117/12.2186647.

[3]. R. Abdiwe and M. Haider, Investigations on Heat Loss in Solar Tower Receivers with Wind Speed Variation, vol. 4, no. 4, pp. 159–165, 2015, doi: 10.11648/j.ijrse.20150404.15.

[4]. G. Colomer, J. Chiva, O. Lehmkuhl, and A. Oliva, Advanced Multiphysics Modeling of Solar Tower Receivers Using Object-oriented Software and High Performance Computing Platforms, *Energy Procedia*, vol. 69, no. January 2017, pp. 1231–1240, 2015, doi: 10.1016/j.egypro.2015.03.165.

[5]. N. H. Abu-Hamdeh and K. A. Alnefaie, Design considerations and construction of an experimental prototype of concentrating solar power tower system in Saudi Arabia, *Energy Convers. Manag.*, vol. 117, pp. 63–73, 2016, doi: 10.1016/j.enconman.2016.02.077.

[6]. M. Hazmoune, B. Aour, A. Bouhallassa, and S. Lecheheb, 3D Simulation Study of a Receiver on a Solar Power Tower, vol. 9, no. 38, pp. 141–148, 2016.

[7]. S. S. Alrwashdeh, The effect of solar tower height on its energy output at Ma'an-Jordan, *AIMS Energy*, vol. 6, no. 6, pp. 959–966, 2018, doi: 10.3934/ENERGY.2018.6.959.

[8]. A. K. Khlief, S. I. U. Gilani, H. H. Al-Kayiem, and S. T. Mohammad, Design a New Receiver for the Central Tower of Solar Energy, in *MATEC Web of Conferences*, 2018, vol. 225, p. 2009.

[9]. P. Xu, J. Liu, Y. Xiang, Q. Lei, J. Zhou, and K. Cen, Numerical simulation and experimental study of the tube receiver's performance of solar thermal power tower, *Energy Procedia*, vol. 61, pp. 1618–1621, 2014, doi: 10.1016/j.egypro.2014.12.307.

[10]. D. Potter, A. Burton, and J. Kim, Optimised Design of a 1 MWt Liquid Sodium Central Receiver System, *Proc. Asia Pacific Sol. Res. Conf.*, p. 10, 2015.

[11]. N. Karwa, L. Jiang, R. Winston, and G. Rosengarten, Receiver shape optimization for maximizing medium temperature CPC collector efficiency, *Sol. Energy*, vol. 122, pp. 529–546, 2015, doi: 10.1016/j.solener.2015.08.039.

[12]. A. Piña-Ortiz *et al.*, Experimental analysis of a flat plate receiver for measurement of low thermal

power of a central tower solar system, *AIP Conf. Proc.*, vol. 2033, no. 1, p. 40031, Nov. 2018, doi: 10.1063/1.5067067.

[13]. M. Joly *et al.*, Selective solar absorber coatings on receiver tubes for CSP - Energy-efficient production process by sol-gel dip-coating and subsequent induction heating, *Energy Procedia*, vol. 57, pp. 487–496, 2014, doi: 10.1016/j.egypro.2014.10.202.

[14]. A. Hall, A. Ambrosini, and C. Ho, Solar selective coatings for concentrating, *Adv. Mater. Process.*, vol. 170, no. 1, pp. 28–32, 2012.

[15]. A. H. Alami and K. Aokal, Enhancement of spectral absorption of solar thermal collectors by bulk graphene addition via high-pressure graphite blasting,*Energy Convers. Manag.*, vol. 156, no. May 2017, pp. 757–764, 2018, doi: 10.1016/j.enconman.2017.11.040.

[16]. S. A. Sakhaei and M. S. Valipour, Investigation on the effect of different coated absorber plates on the thermal efficiency of the flat-plate solar collector, *J. Therm. Anal. Calorim.*, vol. 140, no. 3, pp. 1597–1610, 2020, doi: 10.1007/s10973-019-09148-x.

[17]. K. Aiuchi, K. Yoshida, M. Onozaki, Y. Katayama, M. Nakamura, and K. Nakamura, Sensor-controlled heliostat with an equatorial mount, *Sol. Energy*, vol. 80, no. 9, pp. 1089–1097, 2006.

[18]. M. M. Arturo and G. P. Alejandro, High – Precision Solar Tracking System, no. May, pp. 1–4, 2014.

[19]. A. Kassem and M. Hamad, A microcontroller-based multi-function solar tracking system, *2011 IEEE Int. Syst. Conf. SysCon 2011 - Proc.*, no. May, pp. 13–16, 2011, doi: 10.1109/SYSCON.2011.5929048.

[20]. K. K. Chong and M. H. Tan, Comparison study of two different sun-tracking methods in optical efficiency of heliostat field, *Int. J. Photoenergy*, vol. 2012, 2012, doi: 10.1155/2012/908364.

[21]. T. Maatallah, S. El Alimi, and S. Ben Nassrallah, Performance modeling and investigation of fixed, single and dual-axis tracking photovoltaic panel in Monastir city, Tunisia, *Renew. Sustain. Energy Rev.*, vol. 15, no. 8, pp. 4053–4066, 2011, doi: 10.1016/j.rser.2011.07.037.

[22]. S. Rahman, R. A. Ferdaus, M. Abdul Mannan, and M. A. Mohammed, Design & implementation of a dual axis solar tracking system, *Am. Acad. Sch. Res. J.*, vol. 5, no. 1, pp. 47–54, 2013.

[23]. K. Malan, A heliostat field control system,*Sol. Energy*, vol. 71, no. 3, pp. 155–164, 2014, doi: 10.1016/S0038-092X(01)00041-X.

[24]. S. patil Pratik Pawar, Ashish Yadav, Pritam Makwana, Solar Tracking System Using Arduino, *Int. J. Res. Sci. Innov.*, vol. 5, no. 2, pp. 186–188, 2018.

[25]. W. M. Hamanah, A. Salem, and M. A. Abido, Heliostat dual-axis sun tracking system: A case study in KSA, *Renew. Energy Power Qual. J.*, vol. 18, no. 18, pp. 488–493, 2020, doi: 10.24084/repqj18.406.

[26]. C. J. Noone, M. Torrilhon, and A. Mitsos, Heliostat field optimization: A new computationally efficient model and biomimetic layout, *Sol. Energy*, vol. 86, no. 2, pp. 792–803, 2012.

[27]. D. Y. G. and F. Kreith, *Energy Conversion*, 2nd ed., vol. 53, no. 9. Taylor & Francis Group, LLC., 2017.

[28]. K. Lee and I. Lee, Optimization of a heliostat field site in central receiver systems based on analysis of site slope effect, *Sol. Energy*, vol. 193, no. September, pp. 175–183, 2019, doi: 10.1016/j.solener.2019.09.027.