Comparison Between CSP Systems and Effect of Different Heat Transfer Fluids on the Performance

RABAA K. AL-FARAJAT, MOHAMED R. GOMAA *, Mai Z. ALZGHOUL
Mechanical Engineering Department
Faculty of Engineering, Al-Hussein Bin Talal University
Maan, 71110 Maan
JORDAN

Abstract: - While fossil fuel sources have declined and energy demand has increased, in addition to the climate change crisis, the world turned to using renewable energies to get its energy. Concentrated solar power (CSP) is one of the main technologies used for this purpose. This study aims to compare the different concentrated solar power technologies in terms of their efficiency, cost, concentration ratio, and receiver temperature. Results showed that technologies were arranged according to temperatures from high to low as follows; the parabolic dish reflector, central receiver collector, linear Fresnel reflector, and parabolic trough collector. According to cost, the parabolic dish reflector has the highest price, while the linear Fresnel reflector has the lowest price. Also, the parabolic dish reflector has the highest efficiency among the others, followed by the central receiver collector, then the linear Fresnel reflector, and the parabolic trough collector respectively. Additionally; the study represented that point-focus devices have a high percentage of concentration ratio than line-focus devices. Finally, in order to exploit these sources throughout the day, it is recommended to use phase change materials to store the excess thermal energy as a positive and effective approach to solving the energy problems.

Key-Words: - Solar energy; Concentrated Solar Power; Parabolic trough collector; Linear Fresnel reflector; solar tower; central receiver; solar dish, Heat transfer fluid.

Received: May 19, 2022. Revised: October 22, 2022. Accepted: November 28, 2022. Published: December 31, 2022.

1 Introduction

Due to the problems of near depletion of conventional energy sources and issues of climate change, the world is currently moving towards using clean energy to obtain energy sources. One of the most widely used sources of this energy is the use of solar energy; the use of which in recent years has increased by 35%. One of the most critical technologies used in this field is CSP technologies [1,2]. It is an active solar system meaning that it requires mechanical equipment such as fans and pumps to convert solar energy into electricity or heat [3-6]. CSPs techniques can provide high and medium heat for many uses such as industrial processes, electricity generation, solar heating, and cooling as well as desalination of brine [7]. CSPs are characterized by dealing with direct radiation from the sun, as it uses solar energy tracking systems to obtain the largest possible amount of solar radiation to use in generating energy and supplying energy to operate the tracking system. Despite its efficiency and high productivity, it is expensive construction and maintenance cost [8]. The world's installed capacity of solar energy is expanding rapidly to accommodate energy demand. Indeed, the installed capacity increased for CSPs from 1266 MW in 2010 to 6479 MW in 2020 [9].

1.1 system components

Concentrated Solar Power systems usually contain multiple ingredients like a receiver, electrical generator, solar concentrators, and steam turbine. Fig. 1 illustrates the most important parts of this system [10].

Fig. 1. Components of CSP plant [10].

In a solar field, there is a mirror or concentrator used to redirect direct normal irradiance to the absorber named receiver, in addition to a heat transfer system, also thermal energy storage system which improves the efficiency and stores energy to make it possible to use at night, but storage capabilities might not be present in all CSPs plants [11-14].

1.2 Working principle of CSP

In CSPs plants, direct solar energy is focused on solar collectors in order to heat a working fluid that generates hot steam in order to spin turbines to generate electrical power. Fig. 2 describes the process in parabolic trough [15]. Firstly, the direct solar rays fall on the reflecting mirrors, which act as a concentrator for solar rays. Then these mirrors reflect the solar rays to the receiver, which can be a tower or tube depending on the type of station. The receiver receives the solar radiation coming from the mirrors and then stores the energy of this radiation to Form heat through a working fluid, which retains heat for a later steam generation [16].

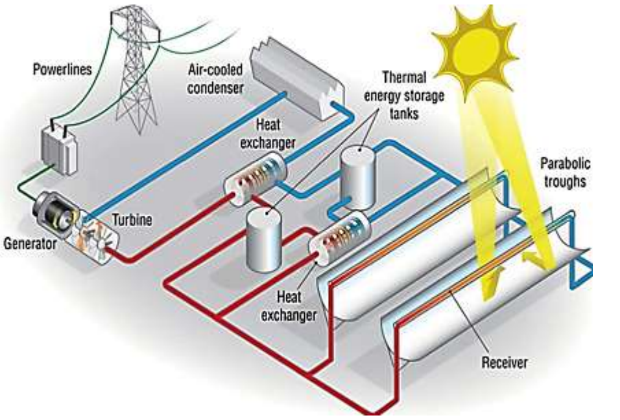

Fig. 2. Power generation in parabolic trough [15].

1.3 Thermal energy storage in CSP

Renewable energies such as; wind and solar suffer from the issue of that are available for a limited period of time. So, to solve this problem storage of energy are a critical solution for these issues, storing thermal energy is cheapest than storage of electrical energy Fig. 3 Shows a parabolic trough station integrated with thermal energy storage unit [17].

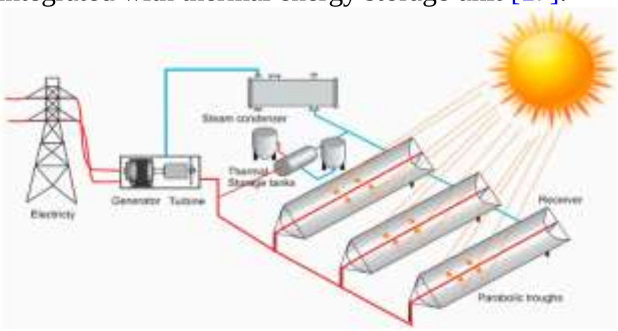

Fig .3. A parabolic trough station integrated with thermal energy storage unit [17].

The combination of (CSPs) and energy storage is seen by the energy sector as a positive and effective approach to solving the energy problem [18]. CSPs are considered a vital source of power generation, as they can provide deployable electricity in addition to the capability to store thermal energy. the largest widely used technique in thermal energy storage (TES) in commercial CSPs is Molten salt TES, but the industry is searching for cheaper and more efficient TES systems; and phase change materials (PCM) are marked as low-cost, high-energy TES systems [19]. Because PCMs offer high-density energy storage, isothermal in nature, and operation in a variety of temperature conditions is available [17]. The use of the PCM has several advantages including;

1-Improved exergy efficiency [19].
2- Faster charging and discharging rate [19].
3- Raised heat transfer rate at the time of charging and discharging, specifically during phase change [19].

PCM energy storage involves phase change processes (like; evaporation, and crystallization, in addition to melting,), in these processes, the transition of the phases occurs when the temperature of the material reaches the transition temperature, then the material is transferred from one state to another, for instance: from liquid to gas, from solid to liquid, and from solid to gas, among them Solid to liquid PCMs are the most used due to high density in addition to low volume change during the phase transition process [20].

2 Types of CSP

A concentrating solar collector consists of a tracking reflector that tracks the sun and concentrates radiation onto a line or point receiver. A thermal fluid circulates in the receiver and its temperature can rise to about 400 °C (for linear focus) or up to 800 °C (for point focus) [21]. There are four different types of CSPs techniques, which differ from each other in economic and technical criteria, these types are parabolic trough concentrator (PTC) [6], linear Fresnel reflectors (LFR) [14, 21,22], central receiver \ solar tower (ST), and Solar dish [23]. Now CSPs technologies are in tremendous progress all over the world, where the total installed of it at the end of 2015 was 4.8 GW, and it is predicted that by the end of 2030 it will reach 261 GW [24].

2.1 Parabolic trough collector (PTC)

The parabolic trough collector is one of the advanced and mature technologies used to produce steam in electrical power plants or to produce useful process heat by absorbing direct solar radiation through either mechanical or hydraulic tracking systems that are associated with sensors [6,25]. PTC consists of [26];

a) Collector: polished aluminium, steel, or glass.

b) Receiver: made up of a glass covering and metal pipe.

c) Reflector: reflector sheet or glass mirrors.

d) Tracking system.

Fig. 4 Clarify this component [26]. Many types of working fluid can be used as heat carriers inside the receiver, like; pressurized water, thermal oil, and Nanofluids which can increase the efficiency of the process; when using it the temperature of the PTC receiver tube can reach 350–400 °C [27], the installation cost of it about 4500–5800 $/kW [26]. Also, the efficiency is about 13-14 %, while the concentration ratio ranges between 15 and 70, Fig. 5 Shows the actual parabolic trough field [28].

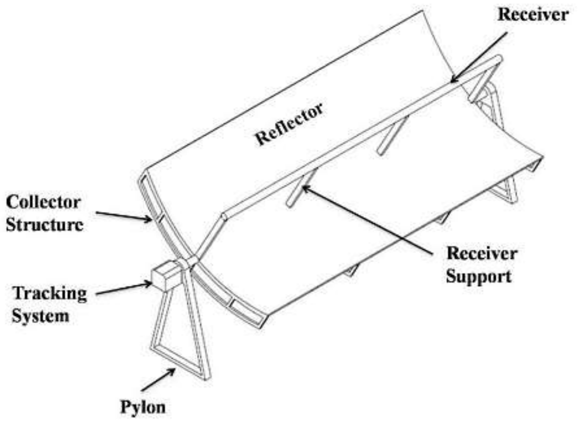

Fig. 4. Parabolic trough component [26].

Fig. 5 Parabolic trough field [28].

2.2 Linear Fresnel reflector (LFR)

Linear Fresnel reflector (LFR) is an evolving technology that has improved over the years and has the ability for cost-effective heat generation. But, LFR undergoes high optical losses, resulting in lower thermal efficiency which is estimated between 11%-19 %. LFR consists of separate linear primary mirrors placed near the ground at a height of about 3-5m above the ground, this construction is a prosperous future option due to its low cost and few mechanical issues due to wind loads compared to PTC. On the other hand, the optical efficiency of LFRs is limited due to the space between the main mirrors in addition to the shadowing and blocking effects of the main mirrors [29]. It's a linear focusing technique that requires a single-axis tracking mechanism to accurately track the position of the sun Fig. 6 shows an LFR station. Also, it's one of the most important concentrating solar systems for producing usable heat in the medium and high-temperature range (< 500°C). The concentration ratio ranges from 10 to 50 and the cost of it is very low. LFR receivers typically have an evacuated tube collector coupled to a secondary concentrator which is commonly a compound parabolic concentrator (CPC). Water/steam is frequently chosen to produce a high-pressure Super heater saturated steam, which can be used in Rankine cycle turbines or industrial processes, thermal oil too Therminol VP-1, and others are used for various thermal applications up to 400°C.

Fig. 6. LFR station [30].

In addition to that, molten salts can be further utilized in power generation and also used for storage goals. It is also emphasized that molten salt application is found to be more thermally efficient compared to hot oil operation and that molten salt offers the possibility of operation at higher temperatures up to 600°C [30]. Its advantages are summed by: firstly, the support structure is simple and has an acceptable price, A little bit of wind load on the concentrator because of its planar structure, also, the danger of heat transfer fluid (HTF) leakage is reduced due to the fixed receiver, in addition to that, automatic cleaning appliance can be comfortably extended, finally, its production and spare parts are readily available on the market [23].

2.3 Parabolic dish reflector

The solar dish is a point-focus device, which uses a parabolic concentrator that receives direct solar radiation and focuses it into a cavity receiver. It has the ability to generate a large amount of clean energy with higher efficiency and quietness compared to conventional engines, but the cost of maintenance and installation will be higher. The system consists of a parabolic concentrator connected to a power conversion unit which consists of a Stirling engine, an alternator, and a spiral cavity receiver. Incident solar radiation is collected by a parabolic concentrator and focused on a focal point on a receiver that is stable, Fig .7 shows the system.

The temperature of the receiver will be very high because it receives a large supply of concentrated solar energy, this heat which is absorbed by the receiver will work on heating the working fluids, which can be hydrogen gas or helium gas. As the temperature of these gases will reach 650 °C – 750 °C. Also, for a 25MW plant the cost of investment is about 2000 $/kW and 8000 $/kW and the efficiency maybe reach 35% when a concentration ratio equals 1300, and the temperature of the receiver 850 K [31].

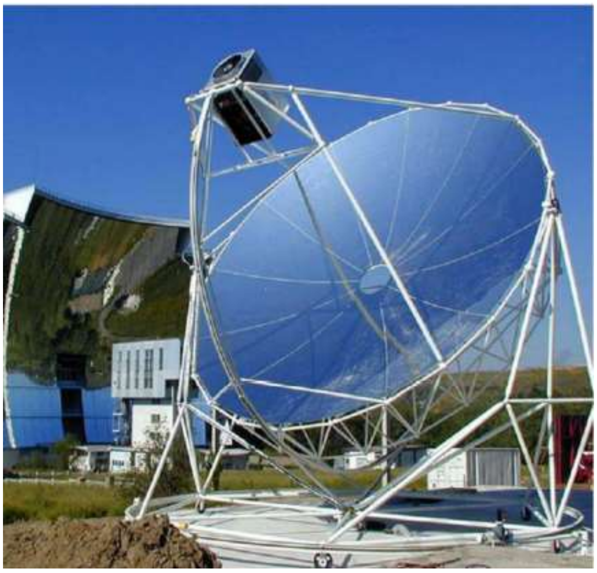

Fig .7. Photo of parabolic dish collector [31].

Due to its high thermal efficiency, it can be generally used to supply prime movers such as the Bryton cycle, Rankine cycle, organic Rankine cycle, and micro gas turbines which require high operating temperatures [32]. also, one of its properties is that it doesn't require water for its cooling or operating processes, making it more suitable for power plant construction in where water-shortage areas [33]. The Solar Dish Stirling System has several uses, the most important of which is shown in Fig. 8 [34].

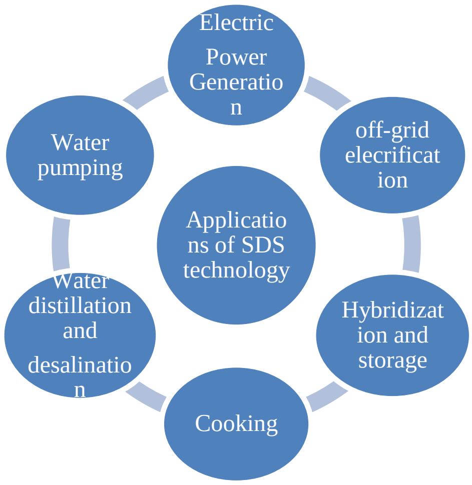

Fig. 8. Solar dish Stirling application [35].

2.4 Central receiver collector/Heliostat field collector

In this system, mirrored collectors which are named heliostats reflect incident solar radiation through a two-axis tracking mechanism to the absorber surface which is located at the top of the tower to concentrate the sunlight at the focal point, then this heat can heat the HTF by convection and radiation. This technique helps in rising the temperature of HTF and increases the efficiency in addition to reducing thermal losses [36]. It’s distinguished by its ability to produce a hundred megawatts or a thousand gigawatts universally in 2050 in inexpensive ways [37]. Moreover, it doesn't need large spaces to create the solar tower station. Also, the temperature of HTF can reach 1000°C or above, Fig. 9 Illustrates the Operation of a solar power plant with a central receiver [38]. Its efficiency ranges from 17% - 21%, and its concentration ratio = 1000 [39].

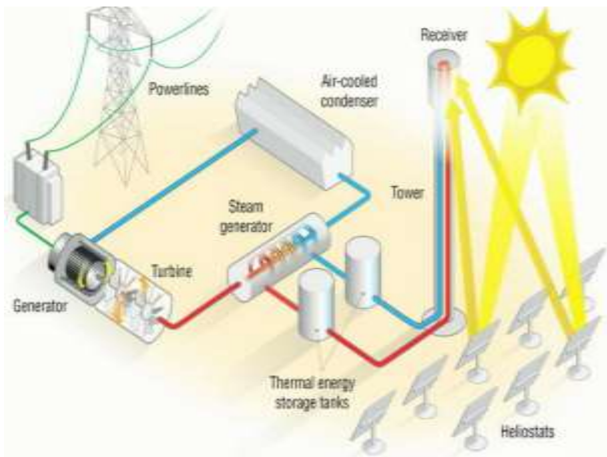

Fig. 9. Working principle of the solar tower [30].

3 Results and discussion

3.1 Comparison between CSP systems

The presented work summarizes the main difference between CSP systems in the next table and charts. Table 1 explains the most important differences between CSPs, including efficiency, cost, and concentration ratio, in addition to the receiver temperature for each type. In terms of efficiency, the Parabolic dish reflector occupies the highest rank, as it can reach up to 35 %, followed by the central receiver collector with an efficiency of about 21%, then the Linear Fresnel reflector and the Parabolic trough collector with an efficiency of about 19% and 14% respectively. On the other hand, in the field of price, the Linear Fresnel reflector is the most cost-effective with a very low price, followed by the parabolic trough collector, central receiver collector, and Parabolic dish reflector respectively. the concentration ratio is categorized in ascending order as follows; firstly, the Linear Fresnel reflector with a ratio of 50, secondly, the Parabolic trough collector with a ratio of 70, thirdly, the central receiver collector with a ratio of 1000, finally the Parabolic dish reflector with the highest ratio of concentration up to 1300. according to the Receiver temperature for each concentrator, the Parabolic trough collector Receiver temperature can reach 400 °C, the Linear Fresnel reflector with a Receiver temperature of about 500°C, then the central receiver collector Receiver temperature can estimate at 1000°C, And the highest Receiver temperature among each concentrator is for a Parabolic dish reflector which can be reached to 1500 °C.

Fig. 10 refers to the difference between the efficiencies of each technique of CSPs, indeed, the parabolic dish reflector has the highest efficiency among the others, and it can reach 35%, also, it indicates that the efficiency of the central receiver collectors is around 21%, while the efficiency of the Linear Fresnel reflector is 19%, finally, the Parabolic trough collector has the lowest efficiency which estimated approx. 14%.

Also, it's clear from Fig. 11 which is titled Cost differences for CSPs that the parabolic dish reflector is the most expensive of the other CSPs type which can be equal to 8000 $/kW. The central receiver collector price is around 6500 $/kW. While the Parabolic trough collector price is estimated at approx. 4000 $/kW, finally the most economical concentrator is the Linear Fresnel reflector with a price of nearly 3000 $/kW. The concentration ratio differences for CSPs that are shown in Fig. 12 clarify that the point focuses concentrators (Parabolic dish reflector and Central receiver collector) own the highest concentration ratio as it can reach 1300 for the parabolic dish reflector and 1000 for the Central receiver collector. Compared with linear focus concentrators (Parabolic trough and linear Fresnel reflector) which are estimated to the parabolic trough as 70 and the linear Fresnel reflector as 50.

Finally, Fig. 13 Illustrates the differences in receiver temperature for all CSPs, the highest temperature can be obtained from parabolic dish reflectors as it can reach Up to 1500 °C, then the central receiver collector with 1000°C, followed by the Linear Fresnel reflector with 500 °C, and last is the parabolic through with around 400 °C.

According to the previous comparisons, we can access that the receiver of parabolic dish reflectors has a higher temperature than the other CSPs, in addition to the highest efficiency and concentration ratio than the others. But, the cost of construction is more expensive than the others. So, it's used to supply prime movers such as the Bryton cycle, Rankine cycle, organic Rankine cycle, and micro gas turbines which require high operating temperatures. On the other hand, the Linear Fresnel reflector is the cheapest price among the CSPs. So, it's used for producing usable heat in the medium and high-temperature range.

Table 1: CSPs technologies analysis [26-39].

Parameter/concentrator	Parabolic trough collector	Linear Fresnel reflector	Parabolic dish reflector	Central receiver collector
Efficiency	13-14 %	15%-19 %	35%	17% - 21%
Price	low	Very low	Very high	High
Concentration ratio	15-70	10-50	1300	1000
Receiver temperature	350–400 °C	<500°C	Up to 1500 °C	1000°C

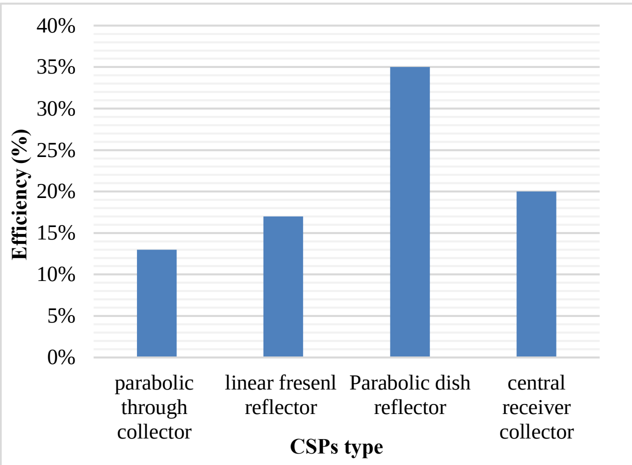

Fig. 10. Efficiencies difference for CSPs

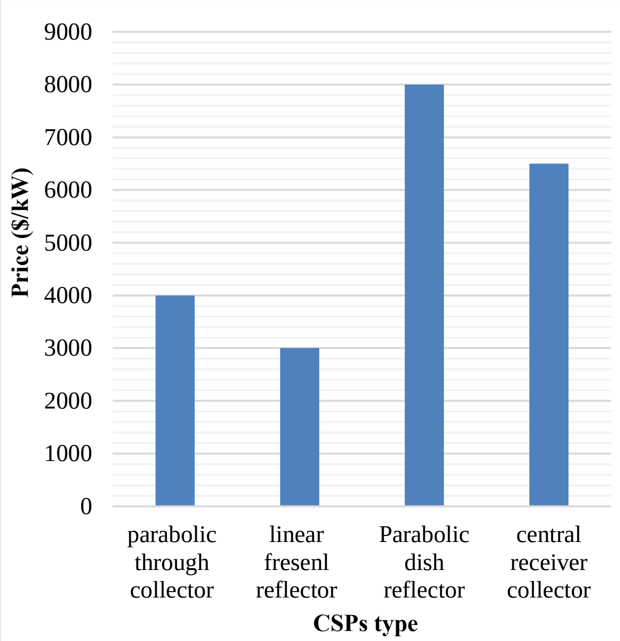

Fig. 11. Cost differences for CSPs.

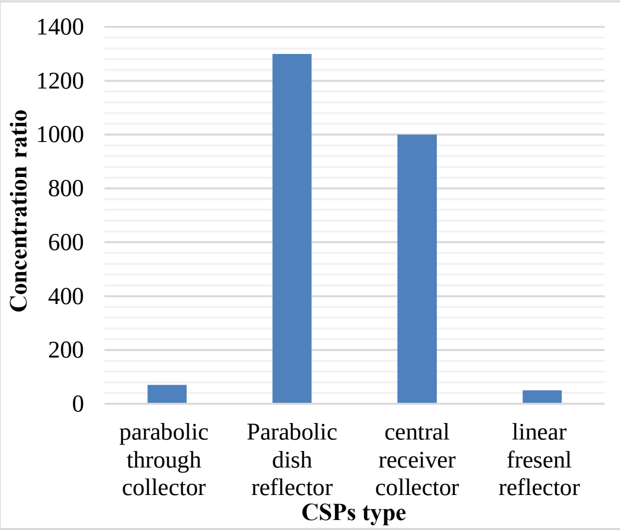

Fig. 12. Concentration ratio differences for CSPs.

3.2. Heat transfer fluid (HTF)

Detailed accounting of exergy is represented in Fig. 14, the liquid Sodium has the best performance within the selected HTFs, especially in the higher range of temperature. In contrast to the molten salt, liquid sodium is able to supply heat to the high-temperature sCO_2 Brayton cycle, that has the higher efficiency of thermal-to-electrical and will cost less than that of a steam Rankine cycle. The receiver performance of the liquid sodium at lower temperature range is only marginally better than the molten salt due to the lower external wall temperature, before considering the exergy losses in the heat exchanger. Molten salt *is* still a competitive as a working fluid in the receiver, and both with its dual role as HTF and TES, and its low price, it is the most used HTF in central tower CSP systems today [40]. Water/steam can connect with the steam turbine directly, that saves cost of equipment such as the heat exchanger, but it has a difficult in integrating with storage system [41-43].

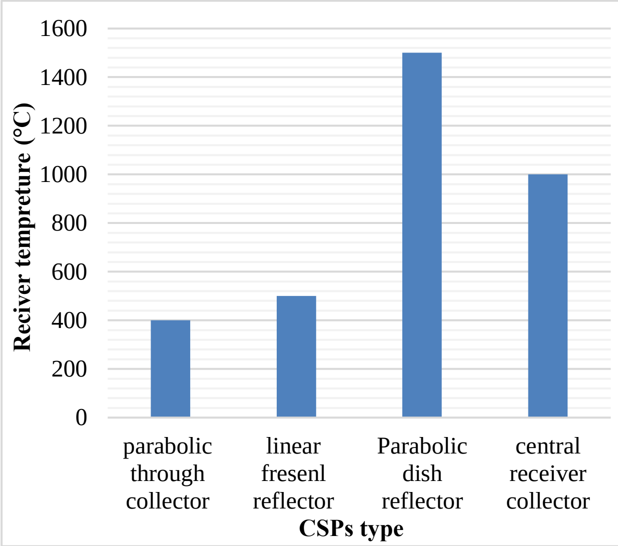

Fig. 13. Receiver temperature differences for CSPs.

Exergy destruction in absorption was large during the boiling process because of the low external wall temperature, while exergy losses in external radiation are low [44-47]. SCO_2 seems that it is not a promising HTF selection for the receiver. Dealing with a high working temperatures and pressure in the tubes of receiver causes higher exergy losses than that *of* anticipating saving resulting from the direct connection to a sCO_2 Brayton cycle. Air seems that it is not a strong HTF due to its poor thermophysical properties that cause extremely high external wall temperatures. It has the largest exergy destruction in internal convection and in pumping work, across all the fluids. It has to operate at the lower temperature with low flux to avoid high external wall temperature, even though it has the ability to work at a high temperature range (e.g., 800–1000 °C). Air receivers, if it feasible, will require to make use of channels with enhanced heat transfer [48].

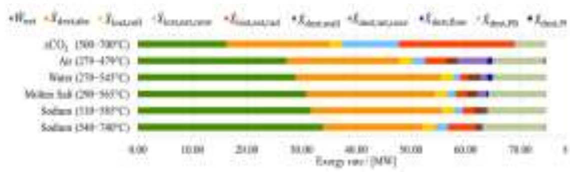

Fig. 14 Detailed exergy of the best-case configurations found for each working fluid [41].

The Overall results are shown in Table 2, which summaries the optimal configurations of the flow for each fluid and shows a comparison between receiver efficiency and T_{max} for the selected (HTFs), which shows that the liquid sodium has the highest performance, then molten salt followed it.

Table 2: Summary of the best-case receiver configurations identified for each HTF [41].

Case	Molten Salt (290–565 °C)	Sodium (310–585 °C)	Sodium (540–740 °C)	sCO_2 (500–700 °C)	Air (279–479 °C)	Water (270–545 °C)
CR	800	800	800	160	640	800
$p_{i,rec}$ (bar)	17.93	5.76	8.72	204.20	101.85	144
$p_{o,rec}$ (bar)	1	1	1	200	100	119.60
d_o (mm)/DN	10.3	10.3	10.3	13.7	48.3	10.3
$\eta_{I,rec}$ (%)	89.65	90	83.81	41.79	85.03	91.40
$\eta II_{,rec}$ (%)	55.45	56.72	60.92	29.52	49.43	51.73
$\eta II_{,PU}$(%)	47.73	49.24	63.52	91.20	78.45	89.03

4 Conclusion

The Different types of CSPs produce different receiver temperatures and varying efficiencies, due to differences in the way that they track the sun and focus light. parabolic trough and linear Fresnel reflectors focus the sun rays into a linear receiver, so it's single-axis tracking, while Parabolic dish reflectors and central receiver collectors are tracking the sun by more than one axis, and then concentrate the sun rays into a point receiver.

On the other side, the Parabolic dish reflector has the highest receiver temperature which can reach Up to 1500 °C and the highest efficiency value of about 35%, and the highest concentration ratio in a range of 1300. Despite this, it's the most expensive technique among CSPs it can reach 8000 $/kW. while the central receiver collector can record the temperature of 1000°C with an efficiency of 21% and a concentration ratio of approx 1000 with a high cost of investment, in contrast with the Linear Fresnel reflector Which is the most economically effective as it is the very low-cost investment, but limited concentration ratio estimated by 50 and its receiver temperature can reach 500 °C with efficiency 19%. Finally, the parabolic trough collector receiver temperature can reach 400 °C with an efficiency of 14% and a concentration ratio of about 70 with a low cost of investment.

Also, it recommended using phase change materials to solve the problem of the availability of thermal energy throughout the day, where it is low-cost and its ability to thermal energy storage is high, as it Improved the exergy efficiency of the process and increases charging and discharging rate in addition to Raised heat transfer rate, especially during phase change.

References:

[1] A. Peinado Gonzalo, A. Pliego Marugán, F. P. García Márquez, A review of the application performances of concentrated solar power systems. *Applied Energy*. 255 (2019),, https://doi.org/10.1016/j.apenergy.2019.113893

[2] Mohamed R. Gomaa, Talib K. Murtadha, Ahmad Abu-jrai, Hegazy Rezk, Moath A. Altarawneh, and Abdullah Marashli. Experimental Investigation on Waste Heat Recovery from a Cement Factory to Enhance Thermoelectric Generation. Sustainability 2022, 14, 10146. https://doi.org/10.3390/su141610146

[3] M. Shahabuddin *et al.*, A critical review on the development and challenges of concentrated solar power technologies. *Sustainable Energy Technologies and Assessments*. 47 (2021), https://doi.org/10.1016/j.seta.2021.101434

[4] Abdullah Marashli, Enas Alfanatseh, Mohammad Shalby, Mohamed R. Gomaa. Modelling single-effect of Lithium Bromide-Water (LiBr–H2O) driven by an evacuated solar tube collector in Ma'an city (Jordan) case study. Case Studies in Thermal Engineering 37, (2022), 102239. https://doi.org/10.1016/j.csite.2022.102239

[5] Mohamed R. Gomaa, Mohsen Ahmed, Hegazy Rezk. Temperature distribution modelling of PV and cooling water PV/T collectors through thin and thick cooling cross-fined channel box. Energy Reports 8 (2022), 1144-1153.

[6] Mohamed R. Gomaa, Ramadan J. Mustafa, Mujahed Al-Dhaifallah, Hegazy Rezk. A Low-Grade Heat Organic Rankine Cycle Driven by Hybrid Solar Collectors and a Waste Heat Recovery System. Energy Reports 6 (2020) 3425–3445. https://doi.org/10.1016/j.egyr.2020.12.011

[7] D. R. Rajendran *et al.*, Review on influencing parameters in the performance of concentrated solar power collector based on materials, heat transfer fluids and design. *Journal of Thermal Analysis and Calorimetry*. 140 (2020), pp. 33–51. https://doi.org/10.1007/s10973-019-08759-8

[8] S. K. Verma, N. K. Gupta, D. Rakshit, A comprehensive analysis on advances in application of solar collectors considering design, process and working fluid parameters for solar to thermal conversion. *Solar Energy*. 208 (2020), pp. 1114–1150. https://doi.org/10.1016/j.solener.2020.08.042

[9] Maka, A. O. M., and Alabid, J. M. (2022). Solar energy technology and its roles in sustainable development. *Clean. Energy* 6 (3), 476–483. https://doi.org/10.1093/ce/zkac023

[10] M. T. Islam, N. Huda, A. B. Abdullah, R. Saidur, A comprehensive review of state-of-the-art concentrating solar power (CSP) technologies: Current status and research trends. *Renewable and Sustainable Energy Reviews*. 91 (2018), pp. 987–1018. https://doi.org/10.1016/j.rser.2018.04.097

[11] M. Walczak, F. Pineda, Á. G. Fernández, C. Mata-Torres, R. A. Escobar, Materials corrosion for thermal energy storage systems in concentrated solar power plants. *Renewable and Sustainable Energy Reviews*. 86 (2018), pp. 22–44. https://doi.org/10.1016/j.rser.2018.01.010

[12] Mohamed R. Gomaa, Waleed Hammad, Mujahed Al-Dhaifallah, Hegazy Rezk. Performance enhancement of grid-tied PV system through proposed design cooling techniques: An experimental study and comparative analysis. Solar Energy 2020, 211, 1110–1127. https://doi.org/10.1016/j.solener.2020.10.062.

[13] Mohamed R. Gomaa, Ghayda' A. Matarneh, Mohammad Shalby, Hani A. AL-Rawashdeh. A State-¬of-¬the-¬art Review on a Thermochemical Conversion of Carbonaceous Materials: Production of Synthesis Gas by Co-gasification Process- Part I. Current Alternative Energy 2020, 4, 1. https://doi.org/10.2174/2405463104999200904115100.

[14] Mohamed R. Gomaa, Mujahed Al-Dhaifallah, Ali Alahmer, Hegazy Rezk. Design, Modeling and Experimental Investigation of Active Water Cooling Concentrating Photovoltaic System. Sustainability 2020, 12(13), 5392. https://doi.org/10.3390/su12135392.

[15] P. Jenkins, G. Ramamoorthy, Design, Thermodynamic Performance Comparison and Cost Analysis of Photovoltaic (PV), Concentrated Solar Power (CSP), Wind Turbine, Natural Gas Combined Cycle (NGCC), and Integrated Solar Combined Cycle (ISCC) Power Plants. *Energy and Power Engineering*. 12, 288–313 (2020). https://doi.org/10.4236/epe.2020.126018

[16] M. Liu *et al.*, Review on concentrating solar power plants and new developments in high temperature thermal energy storage technologies. *Renewable and Sustainable Energy Reviews*. 53 (2016), pp. 1411–1432. http://dx.doi.org/10.1016/j.rser.2015.09.026.

[17] Mofijur, M., Mahlia, T. M. I., Silitonga, A. S., Ong, H. C., Silakhori, M., Hasan, M. H., … Ashrafur Rahman, S. M. (2019, August 17). Phase change materials (PCM) for solar energy usages and storage: An overview. *Energies*. MDPI AG. https://doi.org/10.3390/en12163167.

[18] Mao, Q., Chen, H., Zhao, Y., & Wu, H. (2018). A novel heat transfer model of a phase change material using in solar power plant. *Applied Thermal Engineering*, *129*, 557–563. https://doi.org/10.1016/j.applthermaleng.2017.10.038

[19] Prieto, C., & Cabeza, L. F. (2019). Thermal energy storage (TES) with phase change materials (PCM) in solar power plants (CSP). Concept and plant performance. *Applied Energy*, *254*. https://doi.org/10.1016/j.apenergy.2019.113646

[20] Liu, D., Xin-Feng, L., Bo, L., Si-quan, Z., & Yan, X. (2018, December 1). Progress in thermochemical energy storage for concentrated solar power: A review. *International Journal of Energy Research*. John Wiley and Sons Ltd. https://doi.org/10.1002/er.4183

[21] Mohamed R. Gomaa, Ramadan J. Mustafa, Hegazy Rezk. An Experimental Implementation and Testing of a Concentrated Hybrid Photovoltaic/Thermal System with Monocrystalline Solar Cells Using Linear Fresnel Reflected Mirrors. International Journal of Energy Research 2019; 43: 8660–8673. https://doi.org/10.1002/er.4862

[22] Mohamed R. Gomaa, Ramadan J. Mustafa, Hegazy Rezk, Mujahed Al-Dhaifallah, A. Al-Salaymeh. Sizing Methodology of a Multi-Mirror Solar Concentrated Hybrid PV/thermal System. Energies 11(12), 2018, 3276. https://doi.org/10.3390/en11123276.

[23] Tsekouras, P., Tzivanidis, C., & Antonopoulos, K. (2018). Optical and thermal investigation of a linear Fresnel collector with trapezoidal cavity receiver. *Applied Thermal Engineering*, *135*, 379–388. https://doi.org/10.1016/j.applthermaleng.2018.02.082

[24] O. Ogunmodimu, E. C. Okoroigwe, Concentrating solar power technologies for solar thermal grid electricity in Nigeria: A review. *Renewable and Sustainable Energy Reviews*. 90 (2018), pp. 104–119. https://doi.org/10.1016/j.rser.2018.03.029

[25] R. Mena, R. Escobar, Lorca, M. Negrete-Pincetic, D. Olivares, The impact of concentrated solar power in electric power systems: A Chilean case study. *Applied Energy*. 235, 258–283 (2019).. https://doi.org/10.1016/j.apenergy.2018.10.088

[26] G. K. Manikandan, S. Iniyan, R. Goic, Enhancing the optical and thermal efficiency of a parabolic trough collector–Areview. *Applied Energy*. 235 (2019), pp. 1524–1540. https://doi.org/10.1016/j.apenergy.2018.11.048

[27] P. V. Gharat *et al.*, Chronological development of innovations in reflector systems of parabolic trough solar collector (PTC) - A review. *Renewable and Sustainable Energy Reviews*. 145 (2021), https://doi.org/10.1016/j.rser.2021.111002.

[28] A. J. Abdulhamed, N. M. Adam, M. Z. A. Ab-Kadir, A. A. Hairuddin, Review of solar parabolic-trough collector geometrical and thermal analyses, performance, and applications. *Renewable and Sustainable Energy Reviews*. 91 (2018), pp. 822–831. https://doi.org/10.1016/j.rser.2018.04.085

[29] E. Bellos, C. Tzivanidis, Alternative designs of parabolic trough solar collectors. *Progress in Energy and Combustion Science*. 71 (2019), pp. 81–117. https://doi.org/10.1016/j.pecs.2018.11.001

[30] Bellos, E., Tzivanidis, C., & Moghimi, M. A. (2019). Reducing the optical end losses of a linear Fresnel reflector using novel techniques. *Solar Energy*, *186*, 247–256. https://doi.org/10.1016/j.solener.2019.05.020

[31] Bellos, E. Progress in the design and the applications of linear Fresnel reflectors – A critical review. *Thermal Science and Engineering Progress*. Elsevier Ltd. https://doi.org/10.1016/j.tsep.2019.01.014

[32] Zayed, M. E., Zhao, J., Elsheikh, A. H., Li, W., Sadek, S., & Aboelmaaref, M. M. (2021, February 10). A comprehensive review on Dish/Stirling concentrated solar power systems: Design, optical and geometrical analyses, thermal performance assessment, and applications. *Journal of Cleaner Production*. Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2020.124664

[33] Kasaeian, A., Kouravand, A., Vaziri Rad, M. A., Maniee, S., & Pourfayaz, F. (2021). Cavity receivers in solar dish collectors: A geometric overview. *Renewable Energy*, *169*, 53–79. https://doi.org/10.1016/j.renene.2020.12.106

[34] Abdelhady, S. (2021). Performance and cost evaluation of solar dish power plant: sensitivity analysis of levelized cost of electricity (LCOE) and net present value (NPV). *Renewable Energy*, *168*, 332–342. https://doi.org/10.1016/j.renene.2020.12.074

[35] Malik, M. Z., Shaikh, P. H., Zhang, S., Lashari, A. A., Leghari, Z. H., Baloch, M. H., … Caiming, C. (2022, November 1). A review on design parameters and specifications of parabolic solar dish Stirling systems and their applications. *Energy Reports*. Elsevier Ltd. https://doi.org/10.1016/j.egyr.2022.03.031

[36] Avila-Marin, A. L., Fernandez-Reche, J., & Martinez-Tarifa, A. (2019, September 1). Modelling strategies for porous structures as solar receivers in central receiver systems: A review. *Renewable and Sustainable Energy Reviews*. Elsevier Ltd. https://doi.org/10.1016/j.rser.2019.03.059

[37] Mahmoud, M. S., Khudheyer, A. F., & Abdul Ghafoor, Q. J. (2020). A Novel design of the solar central receiver to improve the performance of the central solar power tower plant. In *IOP Conference Series: Materials Science and Engineering* (Vol. 928). IOP Publishing Ltd. https://doi.org/10.1088/1757-899X/928/2/022003

[38] Praveen, R. P. (2020). Performance analysis and optimization of central receiver solar thermal power plants for utility scale power generation. *Sustainability (Switzerland)*, *12*(1). https://doi.org/10.3390/SU12010127

[39] Crespo, L., & Ramos, F. (2020). Making central receiver plants modular, more efficient and scalable. In *AIP Conference Proceedings* (Vol. 2303). American Institute of Physics Inc. https://doi.org/10.1063/5.0028916.

[40] Craig S. Turchia, Judith Vidalb, Matthew Bauer. Molten salt power towers operating at 600–650 °C: Salt selection and cost benefits. Solar Energy (2018) 164:38-46. http://dx.doi.org/10.1016/j.solener.2018.01.063

[41] Meige Zheng, Jos´e Zapata, Charles-Alexis Asselineau, Joe Coventry, John Pye. Analysis of tubular receivers for concentrating solar tower systems with a range of working fluids, in exergy-optimised flow-path configurations. Solar Energy, 211, (2020), 999-1016. https://doi.org/10.1016/j.solener.2020.09.037.

[42] Monther Alsboul, Mohd Sabri Mohd Ghazali, Mohamed R. Gomaa and Aliashim Albani. Experimental and theoretical investigations of temperature and solid volume fraction-dependent thermal conductivity of Erbium oxide/Ethylene Glycol (Er2O3/EG) nanofluid for thermal energy applications. Chemical Engineering & Technology 2022. 45(12), 2139-2149. https://doi.org/10.1002/ceat.202200159.

[43] Monther Alsboul, Mohd Sabri Mohd Ghazali, Mohamed R. Gomaa and Aliashim Albani. Experimental and Theoretical Investigation of the Thermophysical Properties of Cobalt Oxide (Co3O4) in DistilledWater (DW), Ethylene Glycol (EG), and DW–EG Mixture Nanofluids. Nanomaterials 2022, 12, 2779. https://doi.org/10.3390/nano12162779.

[44] Farah M. Falahat, Mohamed R. Gomaa. A Review Study on Solar Tower Using Different Heat Transfer Fluid. Technology Audit and Production Reserves 2022, 5 (1 (67)), 00–00. doi: http://doi.org/10.15587/2706-5448.2022.267560

[45] Eric C. Okonkwo1, Chinedu F. Okwose, Muhammad Abid, and Tahir A. H. Ratlamwala. Second-Law Analysis and Exergoeconomics Optimization of a Solar Tower–Driven Combined-Cycle Power Plant Using Supercritical CO2. Journal of Energy Engineering 2018, 144 (03).

[46] Maiyada A. Alamr, Mohamed R. Gomaa. Comparison between the Evacuated and Flat Plate Collectors. International Journal for Innovative Engineering Research 2022, 1 (3): PP. 01-09.

[47] Suhib a. Abu taha, Mohamed R. Gomaa, Sohaib Al-Ma'asfeh. Hydro Pump Storage System Driven by PV System for Peak Demand. WSEAS Transactions on Systems 2022, 21: 49-54. http://doi.org/10.37394/23202.2022.21.5.

[48] Sara el Hassani, Hanane Ait Lahoussine Ouali, Benyounes Raillani and Mohammed Amine Moussaou. Thermal Performance of Solar Tower Using Air as Heat Transfer Fluid under MENA Region Climate. (2020) 5th International Conference on Renewable Energies for Developing Countries (REDEC). http://dx.doi.org/10.1109/REDEC49234.2020.9163893

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

Author Contributions: The authors are equal in all work.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself
No funding