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Solar Tower Power: The Impact of External Receiver on Optimal Performance and Energy Storage

H. Shatnawi, C. W. Lim, F. B. Ismail

***Abstract:** An external receiver was seen as a major component of the Solar Tower Power (STP) plant. This generated stable power from concentrated sunlight. However, the flux distribution on its surface was an issue related to the external receiver that could affect the performance and energy storage in STP. The heat flux increased during long-term use, failure reduction, receiver efficiency and performance. The main advantage of the STP structure was its substantial heat storage capacity which allowed the system to generate stable and continuous electric power. In this study, the researchers reviewed existing literature to investigate the effect of the STP external receiver on the optimum energy storage and performance of the STP; especially regarding the solar flux distribution and efficiency. The researchers aim to improve the external receiver's optimal performance without affecting the incident heat fluxes. The literature review indicates that ideal receiver conditions lead to solar energy flux distribution optimal performance. Therefore, system optimisation was necessary to satisfy all limitations; like loss occurring due to heliostat field, solar flux flow patterns, external tubular receiver designs, and Heat Transfer Fluid (HTF) selection. These limitations, along with factors affecting these limitations, are reviewed in this study.*

***Keywords:** Energy Storage, External Receiver, Heat Transfer Fluid, Solar Tower Power.*

I.INTRODUCTION

The Solar Tower Power (STP) plants, also known as the 'heliostat' power plants, power towers or the 'central tower' power plants are a type of solar heaters that use a tower for receiving the concentrated sunlight. STP plant uses an array of plane-movable mirrors (called heliostats), which focus on the sunrays on the collector in a tower (panel or heliostat) [1]. This concentrated form of sunlight was seen to be a practical energy source that could generate a renewable and pollution-free form of electricity [2]. One of the major advantages of using the STP structure was their high heat-storage capacity, which allowed them to generate stable and continuous electricity. Another characteristic feature was the high amount of power it generates, i.e., up to 100MW [3].

The STPs consist of massive thermal storage structures that stored a huge amount of concentrated solar energy during the daytime, which could be used for generating electricity during cloudy days or in the night-time [4].

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* Correspondence Author
H. Shatnawi, College of Engineering, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia.
C. W. Lim, College of Engineering, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia.
F. B. Ismail, Power Generation Unit, Institute of Power Engineering (IPE), Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia.

The liquid salts (or solutions) used for heat transfer in the power plants were called the molten salts since they are generally solid at normal pressure and temperature [5]. Conventionally, a combination of potassium and sodium nitrate is used as the energy storage solution in the tower or the trough structures [6]. Currently, these nitrates are used as the Heat Transfer Fluid (HTF) for energy storage since they are more effective in the tower plants [7]. Thereafter, molten nitrate salts were developed for storing thermal energy in the parabolic trough or tower-based STP structures [4]. These molten salts were also used in the STPs because they were cost-effective, dense, and could retain a lot of energy per volume compared to the oil-based HTFs [5]. All the stored energy could be retrieved at the near-ambient pressure. Hot fluid is stored or allowed to expand for a short period in the larger tanks, which reduces the use of heat exchangers and helps in an easier integration of this heat storage [8-9]. Use of salts can increase the temperature to 550 °C, which allows an efficient functioning of the steam turbines [10].

Despite these advantages, there are some challenges with regards to the performance of the external receivers. One of the major problems associated with the heat interchange in the external receiver was a high-temperature flux occurring at the receiver's surface (external area) and all transitory thermal processes, which lead to heat spots that can cause a failure or complete collapse of the external receiver. Additionally, the receiver heat or solar flux dissemination must be controlled for improving the performance and energy storage [11-14].

II.MOLTEN-SALTS IN THE SOLAR TOWER POWERS

HTF was an important component used for storing or transferring the thermal energy in the STPs. Amongst the various HTFs like the water/steam, air/gases, thermal oils, liquid metals, and organic compounds, the molten salts were seen to be better due to their efficient energy storage in the external receivers. However, a large HTF amount was needed for operating an STP plant [9]. Some of the general characteristic features of the HTF include a low melting point, low material corrosion, low vapour pressure at high temperatures, lower viscosity, cost-effectiveness, higher boiling points, thermal stability and conductivity, and also a higher heat capacity for the energy storage [15-17].

Molten salts were first used in the 1980s in the Themis demonstration plant [18] that generated 2.5 MW of electricity for 3 years. Then, in 1996, after the unsuccessful implementation of the steam STPs, Sandia National Labs began operating 2 STPs, which displayed 10 MWe of 3 hours thermal storage capacities [19].

In 2005, SENER and CIEMAT developed an efficient receiver compared to the Solar Two receiver, while in 2006; the model was tested in the Plataforma Solar de Almeria [20-21]. One of the last receiver designs was proposed by Torresol Energy, Spain in 2009 and it was used as the first commercial STP plant [22]. This plant was known as the Gemasolar or SOLAR TRES Figure 1A, and it could generate 19.9 MWe with a 15 hours energy storage capacity [20]. This plant helped in establishing the STP technology, and thereafter, many larger projects were initiated globally. For example, in October 2013, the Solar Reserve began the construction of the commercial Crescent Dunes project in Nevada Figure 1B, which could generate 110 MWe of power with a 10hours energy storage capacity 2015 [23]. Currently, several projects are still on-going, where different technologies are being tested in large plant establishments. The molten salt technology is a cost-effective technology, which can be used for generating electricity [24].

Fig. 1 A) GEMASOLAR Thermosolar Plant [29]. (B) Solar-Two plant, Source KJKolb/CC-BY-SA-2.0

The molten salt-based STPs require a field of dispersed mirrors (or heliostats) which independently track the sun, concentrate and absorb the sunlight falling on the STP, more than 600 to 1000-times. The temperatures can reach 650 °C [15]. The total solar energy that is absorbed by the molten fluid is used for generating steam which can power a turbine. The external receiver system acts as the entrance from which the energy is transmitted from a field collector to the electric cycle. This indicated that the performance of a basic STP is directly affected by the amount of thermal energy stored [7]. Additionally, the molten salts can display properties similar to water at higher temperatures, low vapour pressure and a comparable viscosity [17]. On the other hand, the most popular molten salt used in STP was the nitrate, however, its production is strictly regulated (Table 1). This salt consisted of a binary mixture of the eutectic, i.e., 40 wt% KNO3 and 60 wt% NaNO3 (Table 1). This liquid has a higher capillarity. However, it has a higher melting point of 223°C and was more corrosive to the metal alloys at 650 °C [25-26].

Table. 1 Relevant studies on molten-salt solar tower powers (External Receiver)

Authors	Target	Performance/ Findings
[15]	Compares a power tower based on molten salt using direct accumulation of solar salt (60:40 wt% sodium nitrate: potassium nitrate) or single-element nitrate salts at 600°C or instead chloride- or carbonate-based salts at 650°C.	The strong effect of salt and hot-tank costs on general financials led to the assessment of single-tank thermocline alternatives. The thermocline configuration significantly decreases salt inventory (by half or more) and in several cases also decreases the tank size compared to the hot salt tank of the 2-tank system.
[27]	Introduces a receiver model based on molten salt and examines the design selection of cold surge tank in the model.	Cold surge tank can, in effect, enhance the receiver protection at the time of pump failure. On the other hand, hot surge tank can significantly increase functioning duration at the time of downcomer blockage. The temperature of the outlet and level control failure are assessed as well. The findings show the likely outcomes of the failure of a control system.
[28]	To properly aim heliostats at cylinder-shaped molten salt receivers in the Solar Power Tower.	The finding shows that a positive profile of flux density usually has its peak shifted to the entrance of salt at every panel of receiver. As external cylindrical receivers comprise a pattern of down-flow and up-flow panels, the optimum flux profile is difficult for adjoining panels with opposing demands.
[8]	To determine the efficiency of different HTFs (Heat Transfer Fluids) and molten salts when flowing through a section of HCEs (Heat Collecting Elements) in a parabolic trough system.	The fluid that produces the best performance outcomes is the Hitec XL salt because of its functional temperature, which is 100°C higher than the temperature of the oils. Molten salts prove to be a substitute for HTF use as they reduce the total cost of plant operation and also improve its capabilities.
[29]	The ALSTOM central receiver based on molten salts i.e. the solar energy onto the MCSR (molten salt central receiver) optimally positioned on the top of tower in the heliostat field.	The elements making MCSR have been structured to increase the reception of incident solar energy, solar energy transfer to salt, and the volume of hot salt generation.
[30]	To find out heat capacity, melting temperature and molten salt density. To examine their feasibility to be used a fluid for heat transfer.	It has been found that the two molten salts failed to perform similar to the molten salt utilised by Powell and Edgar. A further investigation was carried out to discover the impacts of heat capacity and density on power. As expected, a greater heat capacity raised the power output, while there was no effect of density on the power. Because of the low capacity of heat of KCl and NaCl, they are not practical alternatives for storage of heat.

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III.HELIOSTAT FIELD

The STP structure consists of multiple tracking mirrors (i.e., heliostats) that are situated in a field adjoining the external receivers of the STP [31-32]. These structures allow a high energy concentration compared to the linear (plane) structures [33]. The STP structure is made of a varying, but a large, amount of heliostats, and is based on the size of the single heliostats and preferred thermal energy. They consist of computer-regulated mirrors that can track the sunlight differently in 2 axes for generating electricity [34]. A single heliostat comprises of numerous mirrors, and hence, acts as an alternative to the single mirror with a higher magnitude [35] as shown in Figure 2. The configuration of a single mirror surface is known as the 'heliostat canting' that can significantly affect the optical efficiency of a heliostat field, and thereafter influence the power generated or stored by the STP structures [32]. Several researchers have developed many different canting processes, like the off-axis canting, on-axis canting, stretched parabolic, and the target-aligned processes [36-38]. These researchers have also determined the effect of the various surface alignment processes.

Fig. 2 Heliostat geometry types: (A) Lugo, tested in Solar-Two plant, (B) stretched membrane, tested in, Spain [19]

The heliostats affect the external receivers. This was reinforced by placing a partially-concave mirror, superficially attached to a pivot, which allowed the rotation in the vertical and horizontal axes as illustrated in Figure 3 [31] [34]. The focal length of the heliostats was seen to be equivalent to the distance between the external receiver and the farthest heliostat for every region in the field. Thus, the north end of this receiver was focused on the North field, while the South end focused only on the South field. In this case, the receiver was cylindrical, and the heliostat field should be placed on the tower in a spherical field [39]. This significantly increased the concentration of solar energy on the molten salt, which enhanced the energy generation and the storage.

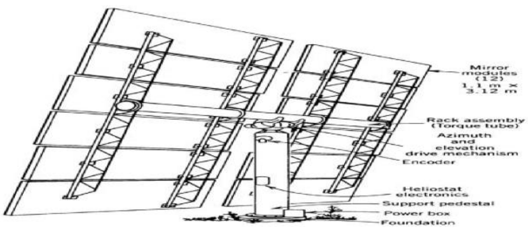

Fig. 3 Heliostat rear side mounted at the Solar-One receiver plant, USA [40]

These patterns were seen to be in conjunction with the interweaving pattern between the heliostat rows and could decrease the obstructive and shading effects of these heliostats, which further increased the optical efficiency and decreased the solar field rate. Though the operations in a heliostat field were easy, they did not highlight the issues related to the heliostat field design. It was stated that the position of the heliostat helped in directing the steam generation field and affected the STP performance [41]. The heliostat field was not investigated on its own since the size of the external receivers and their relative limitations affected the heliostat design and measurements [11] [39]. Hence, the external receiver and the heliostat field should be investigated together for maximising the thermal efficiency and decreasing the heliostat field costs [35]. One needs to understand the mechanisms which affect the heliostat performance for determining the ideal system, as the size and the position of the receiver was an important factor that could affect the heliostat field or vice-versa [31]. The heliostat was affected by the fenestration geometrical factors like external solar shading, despite its flexible weight, height, or shape (spherical/circular). The freer the heliostat geometry, the more the decrease in the radiation reflecting on the receiver surface, associated with the sunlight fallen on the heliostat surface, because of optical losses [12] [42].

Losses from the heliostat field

The effect of a heliostat field was dependent on the individual losses occurring from the field, which comprises of the reflected regions, screening, spillage, reflectivity, field tracking, obstructions, maintenance, atmospheric scattering, and an overseer precision [43]. Such losses were based on the position of every mirror in the heliostat field, with respect to the external receiver, thereby indicating that the aggregated energy incident on the STP peak varied between all heliostats [44].

On the other hand, the effective reflected area was seen to be accountable to a majority of the heliostat field losses, which consisted of the partition between the heliostat and perpendicular areas to the transmission of the reflected radiation [42]. This effect was based on the sun position and placement of every heliostat mirror compared to the receiver [21]. This heliostat position could be determined using a tracking process such that the mirror surface intersected the angle between the sunlight and line of the heliostat and external receiver [42]. This process is described in Figure 4 (I), wherein the reflected area of the heliostat B was lesser than that reflected by the Heliostat A, which indicated that as the angle between the regular surface and radiation incidence (a - incidence angle) increased, the reflected area also decreased. Figure 4 (II) presents the shading and the obstructive losses that are based on the position of every heliostat associated with the enclosing or the bordering heliostats in a field. The shading happens when the radiation did not reach a specific heliostat if it was partially blocked by the adjoining heliostat. The obstruction takes place in a different direction when the reflected radiation does not reach the receiver as it could be intercepted by a different heliostat that acts like an impediment [43].

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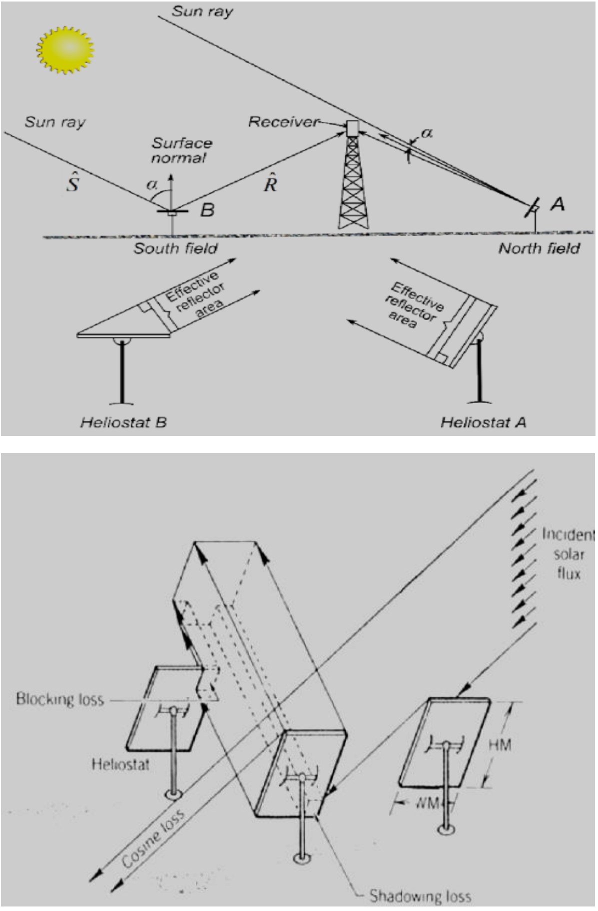

Fig. 4 (I) Real reflection area, (II) Losses by shading and obstruction [40]

IV. EXTERNAL RECEIVER IMPACT AND DESIGN

Many researchers studied the effect of the external receivers on the STP performance (Table 2). Factors like the heliostat field size, HTF used, receiver condition, external features measured, etc., were applied by the earlier studies as an optimal measure for determining the efficiency and performance of the system, as shown in Table 2. Moreover, the external receiver (known as the central receiver) was placed on the peak/top of the tower (a type of pylon), which was aligned as the 360° cylindrical tubular receiver [45]. As shown in these reports, the receiver was designed as a tubular or spherical shaped structure. The perpendicular thin-walled tubes were configured in the panels, which were subjected to the flow path configuration, where the molten salt solution enters from the panels using a down-flow or up-flow panel combination [27].

The external receivers were designed for capturing the solar radiation which emerges from all the directions [10]. The receiver size was based on the amount of solar radiation and heat loss occurring from the external receiver [46]. Thus, a larger receiver absorbs the incident solar radiation, but it suffers from the radiation or convection-related heat losses [47]. The external receiver was seen to be an important component due to its extreme operational conditions. It can receive a higher solar flux incidence in its external tubular surface, while its internal structure consists of a more corrosive environment [48].

Table. 2 Relevant studies about impact of solar tower power external receivers on heat transfer and efficiency

Authors	External Feature Measured (Targeted)	Impact of the Receiver (Findings)
[49]	A computational framework on EES for an external tubular receiver based on molten salt for solar tower plants.	Simulating the energy performance of the receiver through the model as it appropriately projects the working fluid's final temperature.
[45]	Receiver tubes	The finding shows that there is an increase in tower's power capacity by 5.7%. The pressure drop gets incremented by 10 bars. The power produced by variable velocity receiver is 18% greater compared to that produced by conventional receiver. At this time, there is an increase of nearly 20 bars in the pressure drop.
[50]	Receiver functioning modes and tube wall	Both the basic frameworks are able to determine effect of salt, heat fluxes, and the temperature of tube wall with a 6% less variation than CFD simulations. The findings indicate that constant temperature of tube wall leads to less wall temperature, miscalculating film temperature, salt decomposition, and thermal stress.
[51]	Dual-receiver thermal efficiency and cavity absorber	A streamlined tubes layout increases the coefficient of convective heat transfer in the regions with high heat flux. This dual-receiver has a 91% thermal efficiency.
[10]	Perpendicularly incident area, absorption efficiency and the wall temperature.	The efficiency of absorption of the entire pipe with a Pyromark coating is more than 85%, whereas that of the adjoining region is less than 80%.
[52]	Sodium-cooled central receiver system	Efficiency of receiver did not decrease when the receiver was functioning within high peak and power but even increased slightly over the standard 90%. It is capable of increasing the yearly thermal output.

External Tubular Receiver

An external tubular receiver consists of several separable panels that are configured in a perpendicular cylindrical structure at the STP peak [51] [53]. Every panel comprises of a sequence of some thin-walled tubes having a diameter of 20-56 mm [40] that are placed side-by-side. They are generally made using the stainless steel alloy and are filled with an HTF that flows in an analogous manner between the conjoint upper and lower headers [53]. The external receiver used in the Solar-One power plant was positioned 77.1 m above the ground level, and consisted of a 7 m external diameter, with 24 panels that are 13.7 m high. Every panel consists of a maximal of 70 tubes with a 12.7 mm diameter [49].

The number of tubes in every panel was pre-determined for increasing the heat absorption capacity of the HTF while considering the thermal losses and pressure head through a receiver [53]. These tubes were coated using high-absorbance paint (i.e., a black-matte Pyromark paint, which was used in Solar-Two) for optimising the absorption of the incident solar flux [11]. Pacheco [19] stated that this coat could absorb those thermal radiation wavelengths that had an approximate 0.88 emissivity, at an average efficiency of 94-95%.

Flow Patterns

Figure 5 describes 8 types of probable flow paths as noted from the external receiver peaks, presented earlier [53]. The researchers concluded that after the flow paths have acquired a higher pressure drop, they would show high freeloading power consumption. Furthermore, the power plant placed in the North end must be used for a flow pattern moving from the South to North direction (with or without any crossovers), such that the maximal flux occurs in the northern end of the receiver fragment. If the HTF penetrated the northern end of this receiver, the increase in temperature was impulsive and could result in a higher convection or radiation loss. As a result, for improving the thermal efficiency and receiver performance, the panel is configured in 2 different parallel paths, as shown in Parts 1-4 in Figure 5.

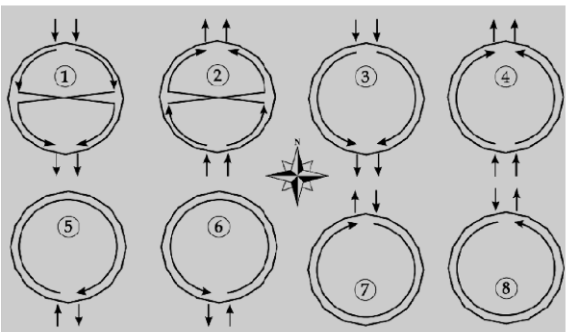

Fig. 5 External receiver possible flow path systems [53]

The Heat Transfer Fluids

HTF was seen to be a medium which helped in collecting thermal energy that was absorbed by a receiver. It acts as a storage medium, and can significantly decrease the investment costs as molten salts like nitrate were more cost-effective than the thermal oil. Additionally, HTF processing required a simpler technological process, which highlighted the advantage of using solar power technologies compared to the wind power or the photovoltaic techniques [25-26]. Furthermore, the loading system that was used in the STP included sensible heat storage as it required lesser materials which did not undergo any alterations in their temperature arrays during the storage [54-55]. Some of the popular HTFs used in the STP include the molten salts (as mentioned in Section 2), thermal oils, air, organic fluids or liquid metals [30]. Molten salt was seen to be an ideal material to be used in the STP system as it remained in a liquid state at the atmospheric pressure (i.e., above a solidification temperature), and was an inexpensive and effective medium for storing the thermal energy. The functional temperatures of this material were similar to the current high-temperature and the high-pressure steam turbines. Furthermore, the molten salts were non-toxic and non-inflammable [55]. Several researchers have focused on the thermal stability limits, melting temperatures and corrosion-related issues of the HTFs [6] [17]. Generally, stainless steel and nickel-based alloys were the vessel and piping materials that were used for HTFs, which ensured a higher STP system durability, since they showed high thermal stability when they interacted with the HTFs [8].

Effect of the Heat Flux on the External Receiver

Heat flux was seen to a significant factor in the STP as it could determine the internal and the external receiver efficiency, long-term usage, performance and failure reduction [56-57]. Many researchers determined the positive and the negative effects of the solar flux on an external receiver (Table 3). The factors like the heliostat field, flux condition receiver size, all measurements and the targeted external features, in addition to the results, have been reviewed (Table 3). Flux density distribution with regards to the solar flux incidents, gradients, and the hot spot on a cylindrical external receiver, were some of the common factors that were measured with regards to a single heliostat field with the help of a small or large receiver. All studies showed that the highest relevant solar flux condition along the heat transfer path was an important first phase that was necessary for the external receiver design. The fluid heat transfer could be enhanced by increasing the turbulence. A perfect control of the solar flux distribution was seen to be a vital parameter while designing a high-temperature solar external receiver and a solar field [46] [56] [58-59]. A flux receiver with higher efficiency could be established using a thin wall tube which allowed a rapid heat transfer without increasing the temperature variation across the tube walls [60].

Furthermore, it could be seen that the higher heat/solar flux and a lower temperature increased the thermodynamic external receiver efficiency [61]. When the fluid aspect of the heat transfer (i.e., percentage of the controlling phase involved in the receiver heat transfer) was very high, the subsequent process temperature was low, so that it did not cause any temperature-based issues, and the cylinder and tube materials could resist the temperature variations if the solar flux increased [6] [55].

For understanding the manner in which a decrease in the emittance could increase the receiver efficiency, several researchers studied the absorber temperatures for the different external receiver systems [62]. A heat-flux related loss was seen to be a function of the absorber temperatures, absorber emittance, and also the collector's optical flux concentration ratio. The external receivers, which did not contain a vacuum attachment, must have an extra insert that represents the convective losses occurring between the absorber and environment [63]. This energy loss could be decreased using directional selectivity where the radiation was repressed at the angles greater than the incident angle of the sun rays that hit the absorber [60]. Furthermore, the directional selectivity helps in determining the efficacies which are comparable to the high solar absorption, without the issues associated with the massive heat flux occurring on an external receiver [4].

The optimisation of the solar fields with the heliostats of differing sizes was investigated earlier, and has been described in Table 3 [31]. However, many researchers have debated the application of a single heliostat size (Table 3), though it was used in numerous studies since the solar flux distribution and density can be easily measured using a single heliostat field (Table 3). At the moment, there are no standard devices that help in designing the fields with a different heliostat size in the market. However, the earlier researchers attempted to solve the issue regarding heliostat field optimization design using 2 heliostat sizes. In their study, Salomé [58] used an open-loop strategy for controlling the flux density distribution on the flat plate of an STP receiver. They considered many distributions of the incident points on the receiver apertures. This strategy offered many suggestions for controlling the heliostats, which can improve the element's lifespan.

Table. 3 Relevant Studies about impact of solar flux on external receivers

Authors	External Feature Targeted	Measurement	Finding
[47]	Gaussian flux density	The distribution of flux density of various rectangular or round focusing heliostats at the plane of receiver is computed through projection.	The elliptical Gaussian function's mean prediction error is 2.24%. It is less than the error of SolTrace, since it uses circular Gaussian distribution for the optical error that causes more errors.
[64]	External solar receiver's transitory behaviour in the tower's power technology	Establishment of 3D transient framework by splitting the tube of receiver into distinct control volumes	The finding suggested that transient thermal performance analysis emphasises certain significant attributes. These attributes include severe issues like thermal stress, corrosion and fatigue in general transitions, possibly requiring the control system to adjust in time accordingly.
[56]	Distribution of flux density on the surface of the central receiver	A multiple-input multiple-output (MIMO) closed control loop.	Results indicate that the basic control loop method distributes successfully the heat flux on the surface of the central receiver.
[28]	Flux density	Permissible flux densities for central molten salt receivers (Gemasolar-like field–receiver system).	The finding shows that a positive profile of flux density usually has its peak shifted to the entrance of salt at every panel of receiver. As external cylindrical receivers comprise a pattern of down-flow and up-flow panels, the optimum flux profile is difficult for adjoining panels with opposing demands.
[65]	Permissible flux density for Solar Two receiver.	A greater permissible flux density is achieved by increasing the fluid velocity and tube material's permissible tension and lowering convective and tube thermal resistance, thickness of wall and tube diameter.	A precise investigation shows that wall diameter, then tube diameter and finally the fluid velocity affects most significantly. Lastly, a receiver with molten salt gives a much greater permissible flux density compared to receivers of steam or water. It is also superior to a supercritical steam receiver.

Variable Velocity Receiver

Recently, a new receiver was developed, known as the Variable Velocity Receiver (VVR) as illustrated in Figure 6. It consisted of the Traditional External Tubular Receiver (TETR), which was made of many valves that allowed the partitioning of every panel in 2 independent panels. This has amplified the HTF velocity in the specific regions of a receiver that bypasses the tube overheating. This novel design helped in developing an optimal aiming process which could enhance the optical efficiency of a solar field and could result in a probable decrease in the heliostat number.

Furthermore, the increase in the solar flux, noted by the receiver, for amplifying the peak flux was also measured.

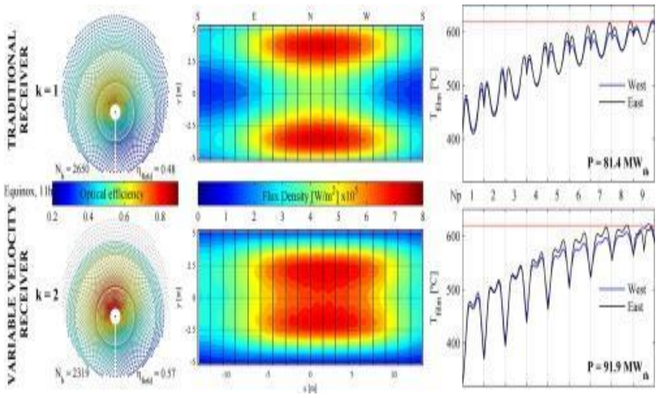

Fig. 6 Traditional external tubular receiver operation (the new VVR) [12]

VVR required only 12.5% of the total solar field, which was lesser than that needed for the conventional TETR. Additionally, VVR offered more operational benefits in winter wherein the panels were divided into 2 parts. This can increase the passage number and HTF velocity. Significant strains and tensions of the receiver walls lead to higher temperatures, thermal shocks, temperature gradient, and a variable and inconsistent flux. Such issues can decrease the external receiver's lifespan.

V.CONCLUSION

In this review, the researchers investigated numerous earlier studies which analysed the effect of the external receiver on the optimal performance and the energy storage of the STP connected to the solar flux and receiver, which used molten salts as the HTF. It was seen that the ideal external receiver conditions generated the optimal performance based on the solar energy flux distribution and optimisation and also fulfilled all the limitation(s), like the losses occurring in the heliostat field, solar flux flow patterns, external tubular receiver designs and the choice of an HTF molten salt. All limitations and factors affecting them were reviewed. The researchers concluded that the heat flux significantly affected the optimal performance and the energy storage capacity of the external receiver. After reviewing the earlier studies, the researchers suggested that an experimental study should be conducted for determining the optimal and allowable material temperatures that affect the external receiver and the optimal allowable strain that could affect the energy storage capacity of the receiver tube materials.

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AUTHORS PROFILE

H. Shatnawi, College of Engineering, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia.

C. W. Lim, College of Engineering, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia.

F. B. Ismail, Power Generation Unit, Institute of Power Engineering (IPE), Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia.