Receiver for linear Fresnel collector- A review

Abstract

Linear Fresnel collectors (LFC) have, among the four technologies of concentrating solar power (CSP), the simpler technology. They have a one axis sun tracking, plane mirrors and a fix receiver. All these elements make them the most suitable for smalls scales CSP plants adapted to rural area of Sub-Saharan region. The receiver is an important part of the LFC. There is a wide variety of receivers that differ in the shape of the absorber: mono-tube, multi-tube, plane. The shape of the secondary concentrator or its absence allows to categorize the receivers in a butterfly, compound parabolic concentrator, segmented parabolic secondary concentrator or trapezoidal receiver. In this paper a comparative study of the presently existing design of receivers has also been attempted in order to find the most suitable for rural area of Sub-Saharan region which means easy to design by hand and low cost.

Keywords: Concentrating solar power (CSP), linear Fresnel collector (LFC), receiver, trapezoidal receiver, Compound parabolic secondary concentrator (CPC), butterfly secondary concentrator.

I. Introduction

The concentrating solar power (CSP) technology allows to convert solar radiation to in a high heat source and then used that heat for electricity generation, cooling, water desalination and cooking [1]. The most popular CSP are large-scale, more than 500 kW_e, but smalls scales CSP, less than 500 kW_e, are also available [2]. Among the most common CSP technologies including parabolic dish systems (PDS), parabolic trough collector (PTC), solar power tower (SPT) and linear Fresnel collector (LFC), the LFC appears the most suitable for rural area of Sub-Saharan region more precisely for their socio-economic context. The region has a young population, so a high labour forces. By their socio-economic context we mean that they are low income countries. In fact, according to World Bank Group's classification there are twenty-seven (27) low-income countries, fourteen (14) lower-middle-income countries, and seven (7) upper-middle-income countries in Sub-Saharan region. This work has been carried in order to find the most appropriate receiver for an efficient and low cost small scale LFC that may be built using material available in west Africa by local labor. In fact, LFC has a simplified technology, the lowest operating expenses (OPEX) cost among CSP and an important Capital expenditure (CAPEX) reduction potential [1,3,4]. LFC technology proved itself with more than nine large-scale power plants in operation and two power plants under construction in 2022 [5].

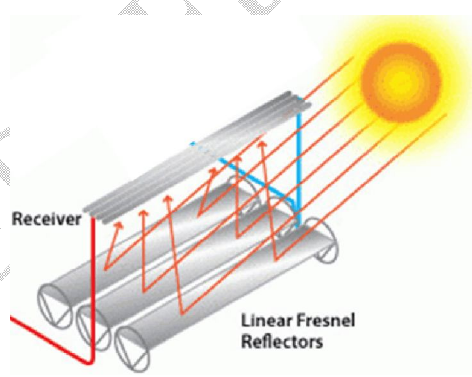

Figure 1: A LFR overview [6].

A LFC, as shown in Figure 1, consists of three parts: the concentrator, the receiver, and the sun tracker. It is the combination of their action that converts solar radiation into heat. There are two families of LFC type: collectors with a single receiver, this is the standard and most widespread technology, and collectors with at least two receivers called Compact Linear Fresnel Reflector (CLFR) [7–10].

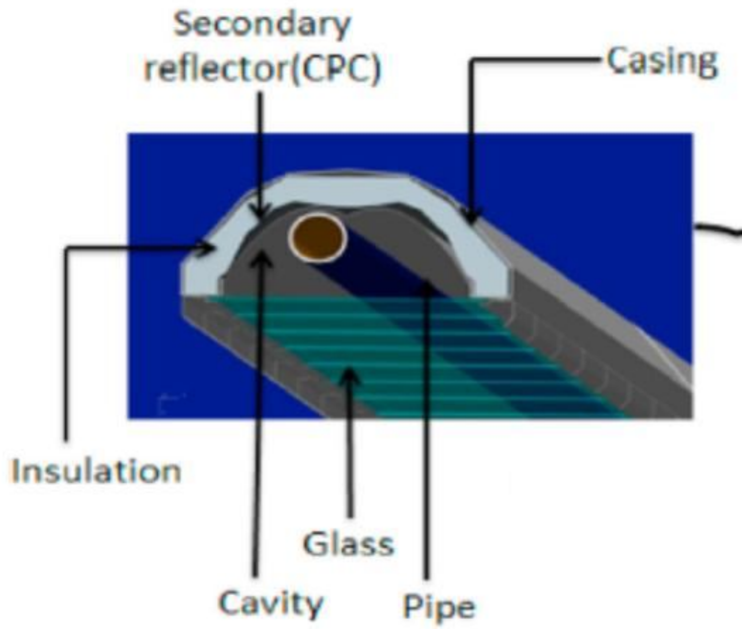

Figure 2. Receiver for LFC with secondary concentrator [11]

The absorber, the secondary concentrator, the thermal insulation and a protective envelope (casing) are the main elements found in a receiver Figure 2. The receiver is a combination of all these elements [12–14]. The operation of a receiver can be summarized as follows. Mirrors of concentrator focus incident sun beam on the receiver precisely on absorber; there the radiation are converted as heat and then transfer by conduction and convection to heat transfer fluid (HTF) that going through absorber. Absorber is the heart of the receiver where heat exchange occurs. There are different shapes of absorber: mono-tube, multi-tube or plane [7,13,15–23]. Each shape has advantages and drawbacks related to both heat transfer from absorber to HTF and thermal losses. Temperature in absorber can reach 400 °C in LFC; due to that high temperature there are significant heat losses. Radiative heat losses are the most important [80-90%] [14,24] followed by convective and conductive heat losses. [25] [21,26] The percentage of radiative losses can be explained by temperature on absorber. A hot body emits radiation in infrared wavelength the amount of energy emit is functioning of body emissivity and it temperature; because of its high temperature absorber emits a lot on the infrared wavelength. Difference between absorber temperature and ambient temperature around absorber are factors of convective losses. Conductive losses are due to contact between absorber and metallic part of receiver. In addition to heat losses, there are optical losses, when some part of reflected sun beam missed absorber. In order to reduce all that losses on absorber some elements are added to absorber. The secondary concentrator is used in order to reduce optical losses. It allows to refocus on absorber reflected sun beam that have already missed it. Secondary concentrator also allows to homogenize reflected sun beam distribution on absorber. It can take different shape, but all of them must be adapted to absorber shape [27]. Selective proprieties of glass are used to reduce radiative heat losses. The use of glass covers or glass envelopes creates a partial vacuum that reduces convection. Insulation is put between secondary concentrator and metallic part of receiver in order to reduce heat losses by conduction [28]. Absorber can be horizontal or vertical [8,29–32] but most of the time absorber has a horizontal position. A vertical absorber receives radiation at both side without secondary concentrator. Left side receives concentrated sun beam from left of concentrator and right side from right of concentrator. Mathur, Negi [29,30] and Mills [7]study a vertical receiver with respectively plane and Dewar tubes absorbers. The effects of absorber orientation is explained in Receivers with plan absorbers. Reflector's mirrors width and position influence the width of absorber. There are two ways as to design a collector. When the shape of the receiver is imposed, the concentrator must be adapted to that particular receiver; mirrors width and position are choosing in order that each incident sun beam must be reflected on absorber. Mirrors have different width and different shift between consecutive mirrors. In the second approach absorber, width is choosing according to mirrors of reflector width they must be more or less equal. Mirror width is the same for all. When mirrors have equal width, absorber width must be approximatively the same. In fact, in good situation reflected image is the same then mirror mirrors [3], [7], [8], [10]. The receiver optimal height and its impact of collector total efficiency are the he subject of considerable scientific research [30,33–35]. Receiver heat is a function of concentrator width; they are joint by an optical ratio: $half\ of\ concentrator\ width\ /receiver\ height$ and excessive height of the receiver gives spread reflected image on receiver so important optical losses [30]. The optical ratio has been investigated by researchers; the ratio must: (= 1) [30], (<1.2) [34], (<1.75) [33]. On this document we will focus on different type of receiver that have been modelled [4]–[12]and experimented [9], [13], [14] according to their absorber shape, material.

II. Design and layout of receivers of linear Fresnel collectors

i. Receivers with mono-tube absorber

Tubular absorber is the most used in LFC system. Absorber tube can be at ambient pressure, under partial vacuum or under vacuum. Stainless steel or aluminium pipe covered with a selective coating are the typical materials used in vacuum absorber. Absorber tube is then surrounded by glass envelope; between absorber tube and glass envelope, there is vacuum. At each extremity a glass to metal seal element and a bellow allow to keep the vacuum. Vacuum absorber tubes are commercialized by Schott Solar CSP, Siemens Solar Power (formerly Solel Solar Systems), Huiyin Group, Gear Solar and Archimede Solar Energy. Vacuum tubes are standardized: pipe diameter ~ 70 mm, glass envelope diameter ~120 mm length 4.06 m. Absorber tubes are place in series to achieve the total length of concentrator. Thermal losses are around 70 - 250 W/m at 250°C - 400 °C [36]. Vacuum absorber tubes are most of the time used for parabolic trough collector where the receiver moves according to sun position. This restriction obliges manufacturers to make light absorber; in LFC receiver do not move so vacuum absorber for Fresnel will be less expensive. In order to reduce heat and optical losses, a secondary concentrator with different shape can be used. Nevertheless, a receiver with vacuum absorber avoid using glass cover. Ambient or partial vacuum absorber tubes aren’t commercialized; they are manufactured with copper, stainless steel, aluminium pipe. They aren’t standardized each constructor made his own absorber. Tube is most of the time cover with a selective coating, the plate glass, insulation and secondary concentrator enable to reduce heat and optical losses respectively. Secondary concentrators also enable to increase the concentration ratio[37]. They are made with reflective material such as silvered-glass mirror or aluminium reflectors [37]. There are alternative of secondary concentrator shape adapted for vacuum or non-vacuum absorber.

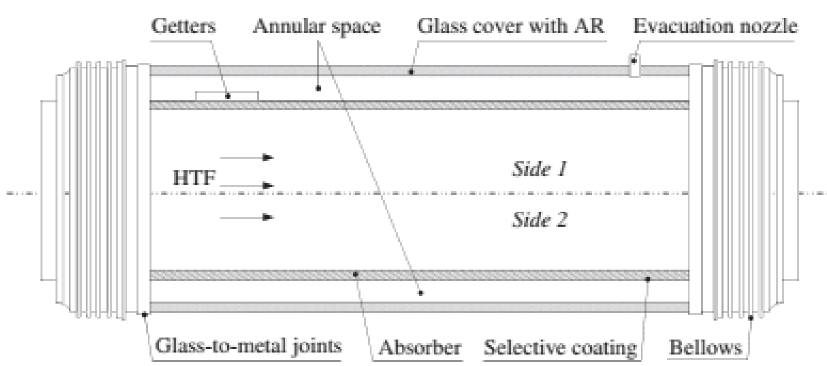

Figure 3: vacuum absorber tube [38].

a. Without secondary concentrator

A tubular absorber under partial vacuum without secondary concentrator was tested by Negi et al.[39]. A partial vacuum was providing by a tubular glass envelope. The thermal losses, in Negi et al.[39] prototype, were [4-12 W/m²/ C] at [0-120 °C]. Both tubular absorber with vacuum and under partial vacuum have been experimented by Choudhury et al. [15]. They achieved a stagnation temperature of 385 °C for vacuum absorber and 360°C for partial vacuum absorber at 600 W/m² with a concentration ratio of 18. Zhu et al. [40] developed a scalable linear Fresnel reflector (SLFR) in order to reduce optical loss dues to shading, blocking and end losses; they are also experimented a vacuum absorber without secondary concentrator [40]. They achieved a global efficiency, useful heat gain divided by incident radiation of the aperture area of the SLFR, of 64 % at an average direct normal insulation of 858 W/m².

Figure 4. Tubular receiver without secondary concentrator [39].

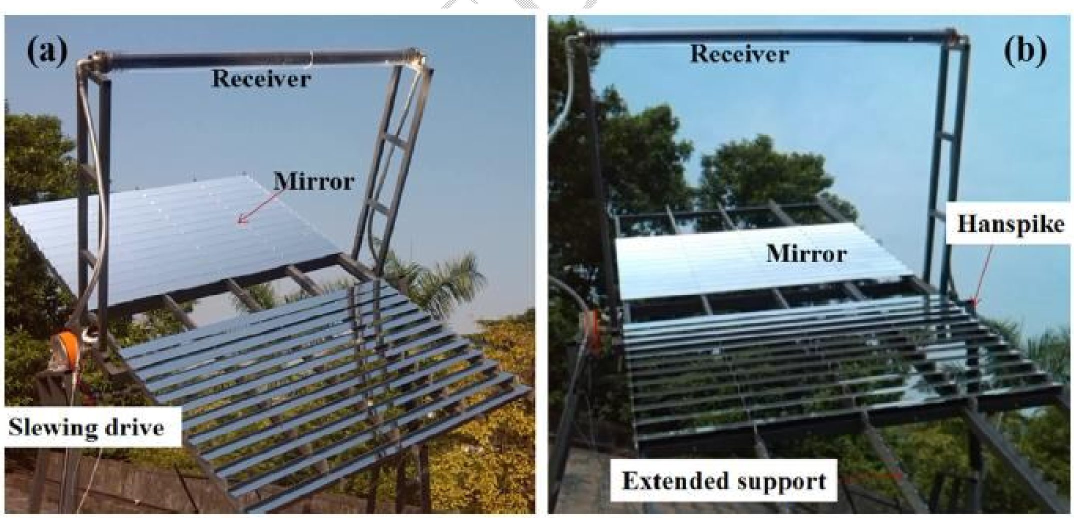

Figure 5. SLFR with a vacuum absorber as receiver [40].

a. Secondary concentrator with two parabolic wings or Butterfly secondary concentrator

This kind of secondary concentrator enables a uniform distribution of concentrated radiation onto each side of absorber; however, two parabolic wings secondary concentrators can be used only with vacuum absorber tube. In fact, secondary concentrator shape does not enable the used of glass cover or insulation. Each wing receives concentrated radiation from opposite side of concentrator and reflects it on corresponding up side of absorber. Absorber low side receives radiation from concentrator. Grena et al. [33] explained the design of that secondary concentrator; it is patterned and under development for commercialization. Concentrator width, receiver height has to be considering when conceiving the secondary concentrator. This secondary concentrator allows to have a wide concentrator for the same height of absorber so most concentration factor.

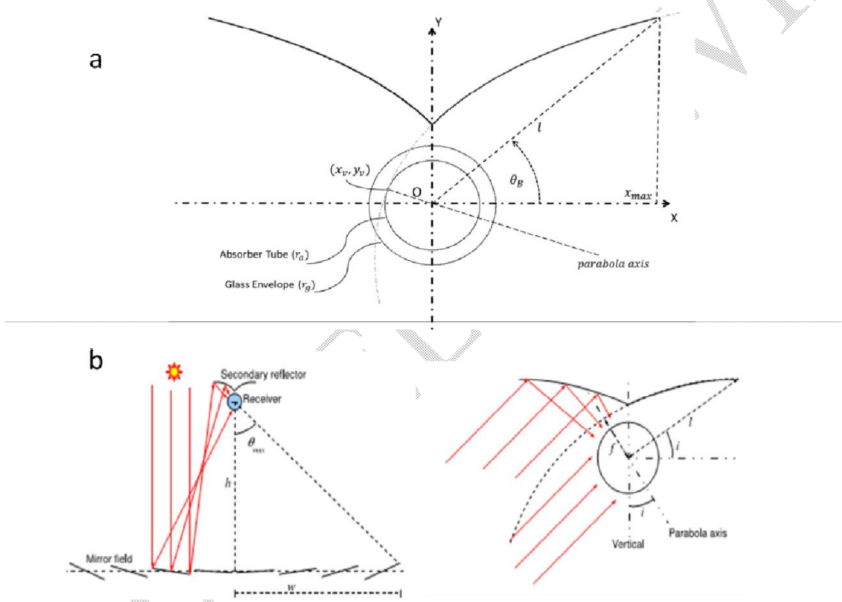

Figure 6: vacuum tubular absorber with butterfly secondary concentrator: a)[41] b) [33].

b. Secondary concentrator with trapezoidal shape.

Trapezoidal secondary concentrator also calls trapezoidal concentrator [42] can be used with either vacuum, partial evacuated or without any vacuum tubular absorber. When tubular absorber without vacuum is used, a glass cover is put at the bottom of trapezoidal cavity helping reduce thermal losses by the vacuum in the annulus [43]. There are a lot of trapezoidal secondary concentrators; some allow a uniformly radiation distribution on absorber [44] [27] Figure 7, Figure 8; others are used to refocus missed sun beam on principal concentrator and protect absorber from convective heat losses [45] Figure 9. Secondary concentrators are designed by taking account absorber and principal concentrator.

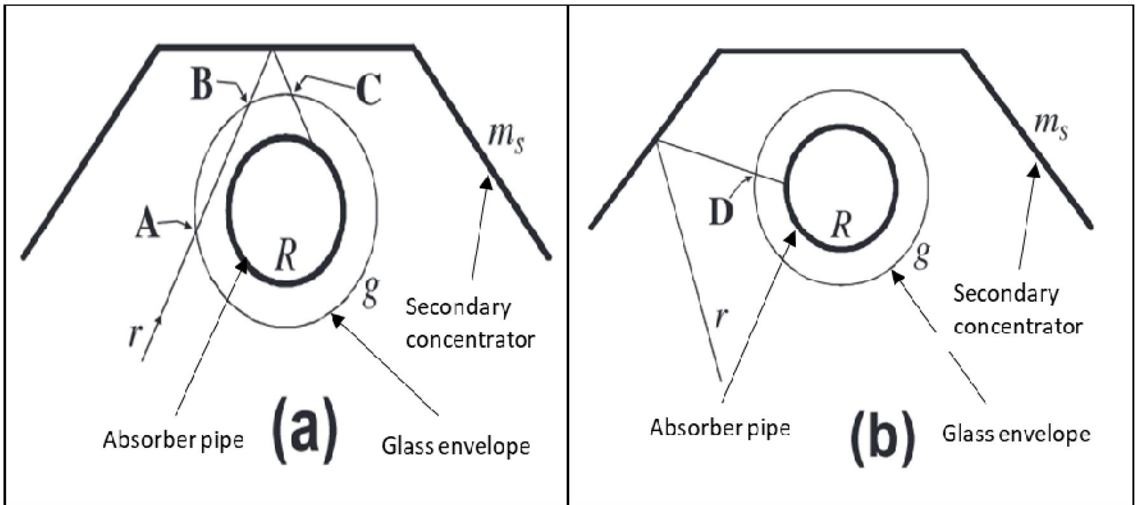

Figure 7. Mono-tube absorber with trapezoidal secondary concentrator used to refocus on absorber sun ray that missed the absorber after a first reflection on principal concentrator [40].

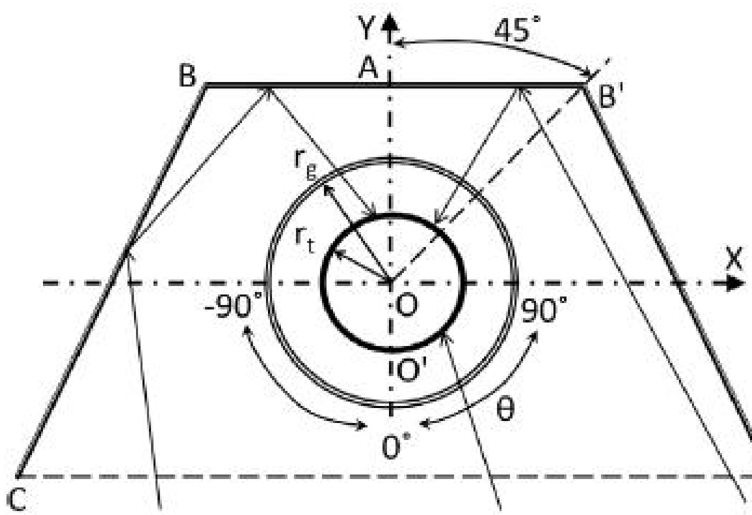

Figure 8. Mono-tube absorber with trapezoidal secondary concentrator used to refocus on absorber sun ray that missed the absorber after a first reflection on principal concentrator [42]

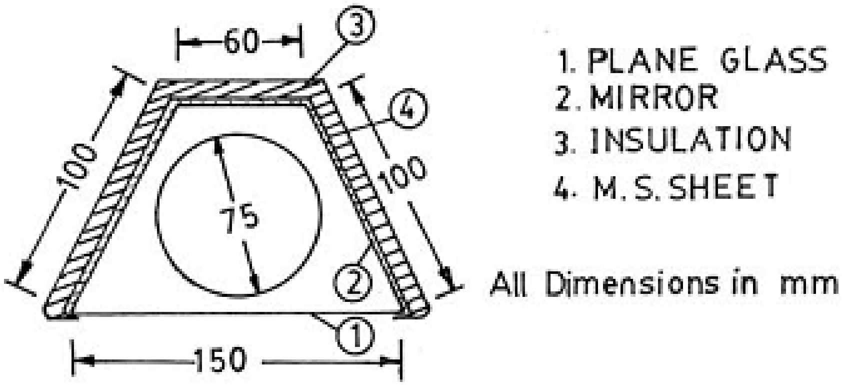

Figure 9: Non-vacuum mono-tube absorber with trapezoidal secondary concentrator and glass cover [45].

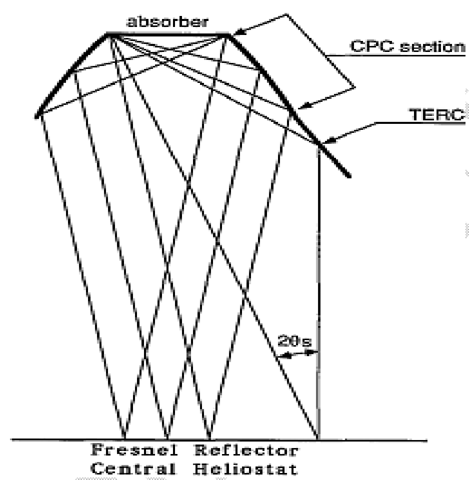

Figure 10. Gordon et al. trapezoidal secondary concentrator [27].

c. Compound parabolic secondary concentrator

Compound parabolic secondary concentrator (CPC) and secondary concentrator with two parabolic wings have several things in common but CPC can be used with any type of absorber vacuum or not Figure 12. Parabola are less flat so we can add a glass cover under in order to reduce convective heat losses Figure 2. However, the receiver must be big, so we have a lot of heat convective heat losses [25]. There are a lot of methods to design a performant CPC the absorber, the principal concentrator, and the acceptance angular must be taking in account for CPC design. The upper of CPC can be open or closed in fact it does not work [25]. This secondary concentrator allows to irradiate the upper of absorber Figure 11. The principal element of CPC is the acceptance angular that depend of receiver height and the half-width of acceptance angular. A small acceptance angular makes a depth secondary concentrator; the recommended acceptance angular must be superior at 30 ° [25]. Nevertheless, there are still some important decisions to take in the design of the receiver, such as the use of one large tube or many thinner tubes (multi-tude receiver). The prototype built in Plataforma Solar de Almeria (PSA) by DLR and Solarmundo – later called Solar Power Group – [48] uses a one tube receiver, with a secondary concentrator above it and a window below. Similarly, Novatec Solar, another Germany company, has used such technology for commercial power plants PE1 and PE2 in Spain [46]. On the other side, Ausra – later bought by Areva Solar – built in 2008 the Kimberlina power plant in California, with open air multi-tube receiver [47]. The eLLO plant built by SUNCNIM in France consists of a mono-tube absorber with a CPC secondary receiver and a glass plate [46,47].

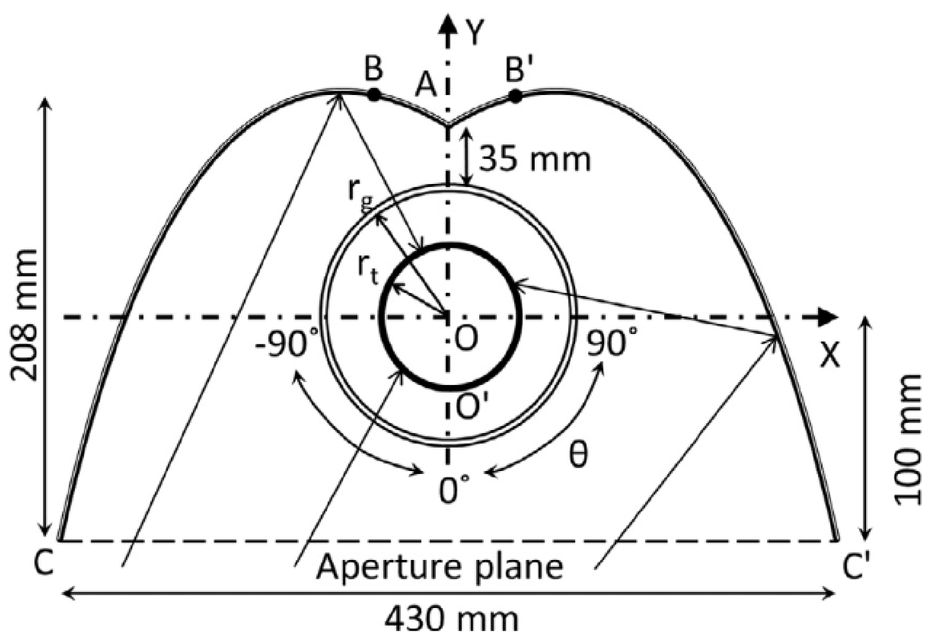

Figure 11. Receiver with CPC secondary concentrator allowing to irradiate the upper of absorber [42]

Figure 12. Mono-tube receiver of Novatec Solar with trapezoidal receiver a) Nova-1 non- vacuum absorber used for Puerto Errado 2 power plant [48], b) Supernova vacuum absorber sous vide

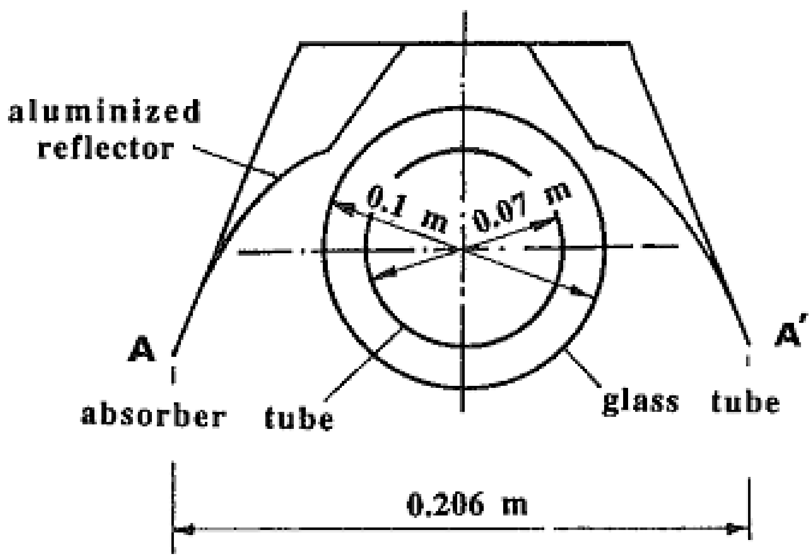

Figure 13. Receiver with under partial vacuum absorber tube and CPC secondary concentrator made of aluminium [49].

Montes et al. [50] developed a hybrid receiver with non-evacuated and evacuated receivers put in series with a CPC secondary concentrator. The non-evacuated receivers are used at the beginning of the collector when the heat transfer fluid is not very hot so radiative losses are low and then evacuated receivers are used at the end when heat transfer fluid is not very hot. They do not use a glass cover at the bottom of the cavity.

A novel Segmented Parabolic secondary Concentrator (SPC) shape has been developed by Chaitanya Prasad et al. [42]. It is a combination of trapezoidal and Compound parabolic concentrator. They conclude that the highest optical efficiency is obtained for the SPC.

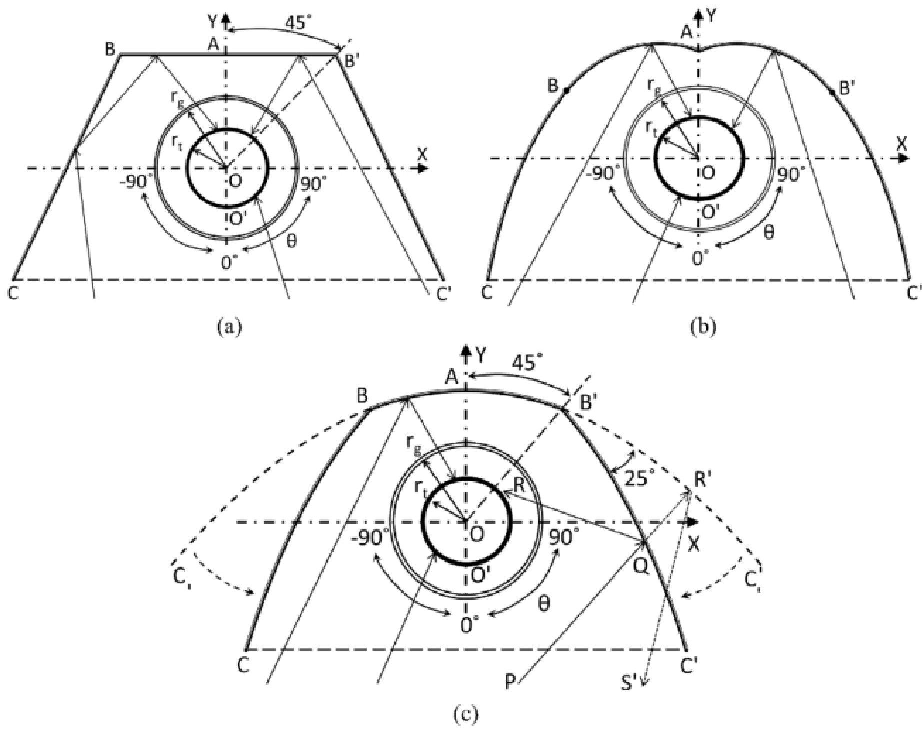

Figure 14. Different profiles of secondary concentrator (a) Trapezoidal Concentrator (b) Compound parabolic concentrator and (c) Segmented Parabolic secondary Concentrator [42]

Hack et al.[41] have studied four different secondary concentrator designs for LFC [41] : an adaptive design which takes care for the collector optical errors to design the secondary receiver; the Compound parabolic concentrator (CPC) design; the trapezoidal design and the butterfly design. They conclude that adaptive design presents the best performance among all four designs. The CPC, the trapezoid and the butterfly, have the second, third and fourth place the respectively.

Beltagy [11] studied the effect of the use of two absorber tubes on optical performance of LFC. He concludes that it is possible to increase the annual gain in optical efficiency estimated from 40.49 to 46.79% using two receiver instead of one Figure 15.

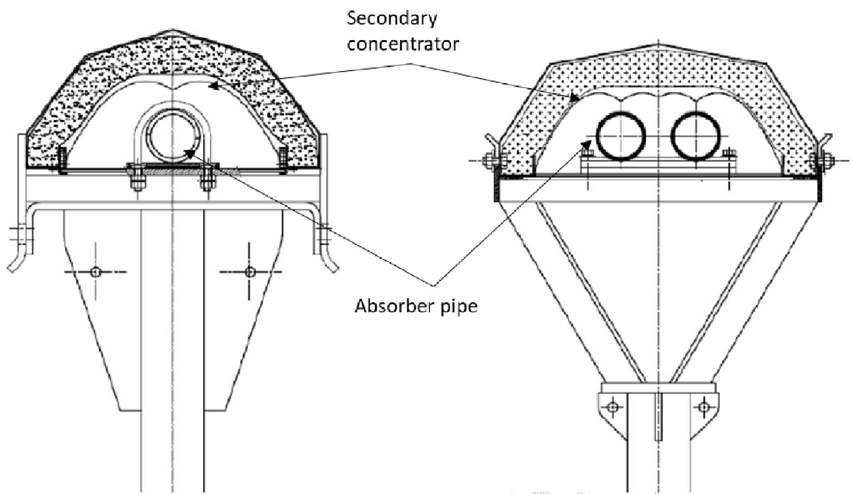

Figure 15. using of two absorbers two instead of one with a CPC secondary concentrator [11].

ii. Receivers with multi-tube absorbers

Absorber is a kind of heat exchanger and it behaves as such. However, the total width of absorber is the same with one or multi-tube absorber it surface isn't the same it is greater. A heat exchanger surface increasing allows to increase efficiency because of better heat transfer coefficient so multi-tube have better efficiency. Absorber pipe can be in copper stainless steel, aluminium at placed under vacuum [7] or without any vacuum [14,24,45,51,52]. Pipes have the length of the concentrator and are put in a parallel direction with space between each one because they can dilate due to high temperature [16,21]. The diameter, number, thickness and position of tube have been studied by Dey [51] the choice taking in account the pressure of the receiver, the materials used to made tubes, and the total width of absorber required. Most of the time heat transfer fluid went in a parallel direction in each pipe but sometimes edge tubes can be used to preheat heat transfer fluid by putting pipes in serial [53]. Pipes are named according to their secondary concentrator shape or their arrangement; there are: trapezoidal receiver, V-shape receiver or triangular receiver. That kind of secondary concentrator does not allow to distribute the flux on the top of absorber [33]; it allows to refocus missed sun beam on concentrator [54].

d. Secondary concentrator with trapezoidal shape

Multi-tube absorbers with trapezoidal secondary concentrator have been the subject of many research [14,16–19,21,24,28,52,55–57]. Receivers have been modelled and some have been experimented [26,52]. The overall heat losses varied from 7.2 W/m² at 150 °C without selective coating to 5 W/m with a selective coating. Experimental and theoretic results allow to give standard for secondary concentrator design. Five elements must be carefully chosen for a trapezoidal secondary concentrator: the large base B, the small base b, the height H, the angle θ and the lodge Figure 16. H, B, θ, lodge can be varied in order to increase efficiency of the receiver; they are related the variation of H involve a variation of θ and lodge, likewise variation of B means variation of θ and lodge. The small base b value is fixed by absorber width.

As to reduce convective heat losses near the absorber air must be at rest so the lodge area must be very small [21,26]. Concerning θ the authors have different about it optimal values. According to Moghimi et al. [58], the value of θ must be < 30 °, 34 ° for Singh et al. [14]. However Natarajan et al. [17] , think that θ value must be 25 °< θ<85 °. Facao et al.[28] give other point of view; they have said that the value of θ must be the complementary to angular between the receiver and the edge mirror. Nevertheless, all that considerations are not false. in fact, as to fluctuate the value of θ Natarajan et al.[17] change the value of B; so for θ= 25 ° B is approximatively twice big then for θ=85 °with augmentation of lodge area as consequences.

According to Moghimi et al.[58] observation's θ fluctuate with variation of B and H values and 30 ° allows to reduce lodge area. The observation of Façao et al. [28] that taking in account the principal concentrator can also be applied.

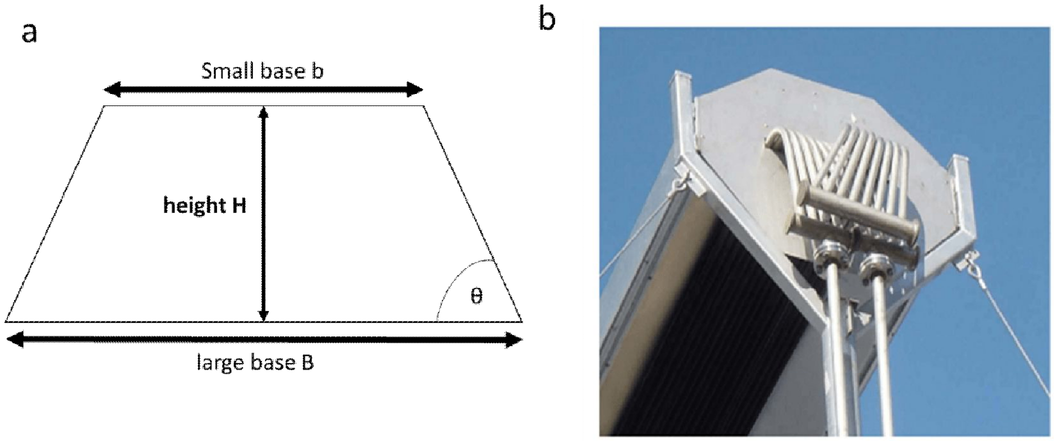

Figure 16: a-cavity overview et b trapezoidal receiver of Areva Solar.

There are two options for trapezoidal receivers with multi-tube absorber: in the first option the absorbers tubes receive directly concentrated sun beam [14,18,21,21,24,45], according to second option absorbers tubes received heat by conduction from metallic plate that receive firstly concentrated sun beam sometimes this plate is the smaller bas b [18,51,52].

The thickness of metallic plate is very important; the contact between pipes and plate is also important. They can be weld together, machine-made or pipes can just be put on plate. The plate must allow a better heat reparation and make easy the use of a selective coating. Manikumar et al. [17] investigate to performance of two trapezoidal multi-tube receivers with plate surface and without plate surface Figure 17 and Figure 18. They concluded that the used of plate allow to reduce thermal losses of the receiver.

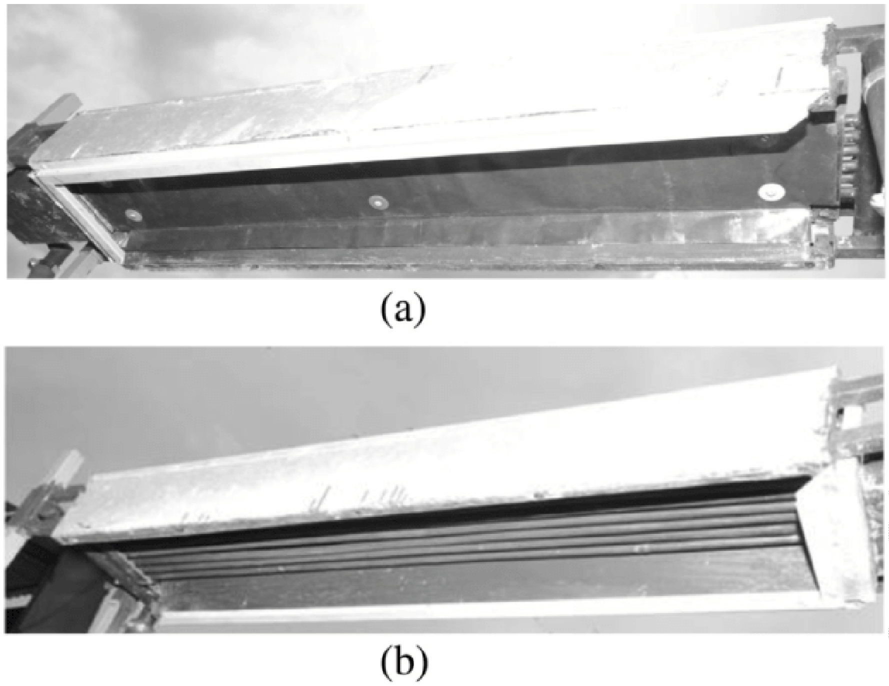

Figure 17. Trapezoidal cavity absorber (a) with plate (b) without plate [18].

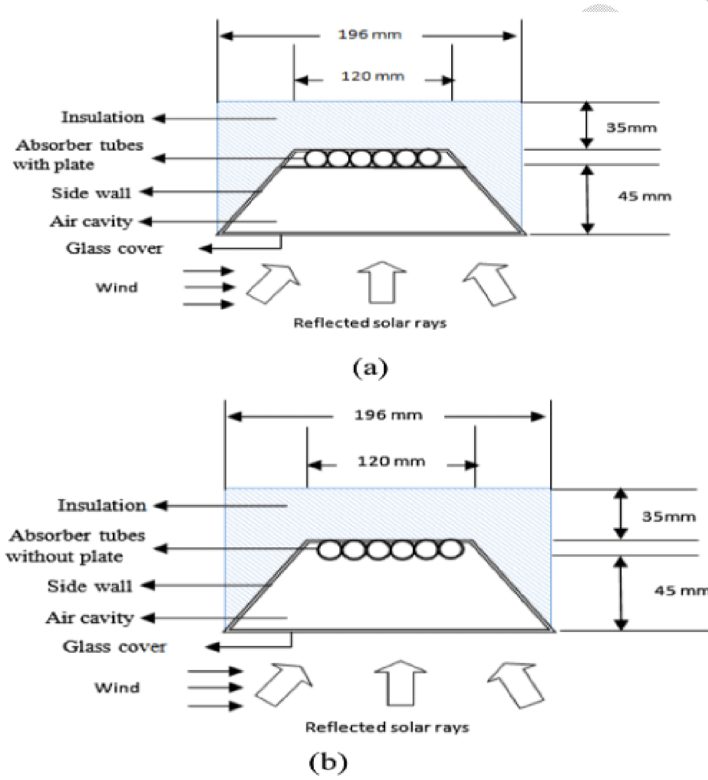

Figure 18. Sketch of trapezoidal cavity absorber (a) with plate (b) without plate [18].

e. Secondary concentrator with V shape

Pipes can be welded to give a V shape or triangular shape [59]. The design of each side of the triangle is like for secondary concentrator with two parabolic wings[33]. That receiver does not have a secondary concentrator.

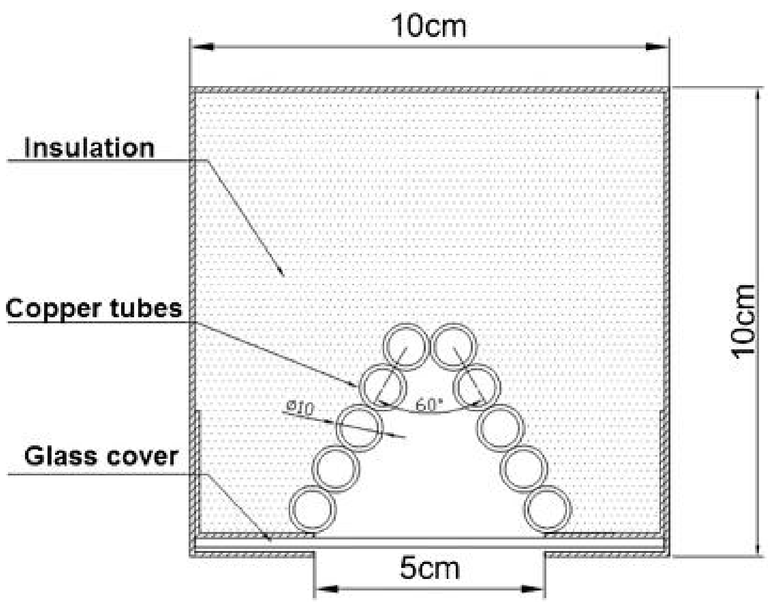

Figure 19: Reverse V-shape or triangular receiver [59]..

f. Vacuum absorber

Dewar tubes are vacuum multi-tube absorber they are design to be used as solar collectors without concentration but they can be used as receiver for CSP Mills and Morrison are they first who decide to used Dewar tubes as Fresnel receiver [7,60]. Dewar tubes are sold with standard dimensions; they can be put together in series or parallel to achieve the desired receiver. Dewar tubes can be horizontal or vertical but for each orientation secondary concentrator have a particular shape that is adapted to orientation.

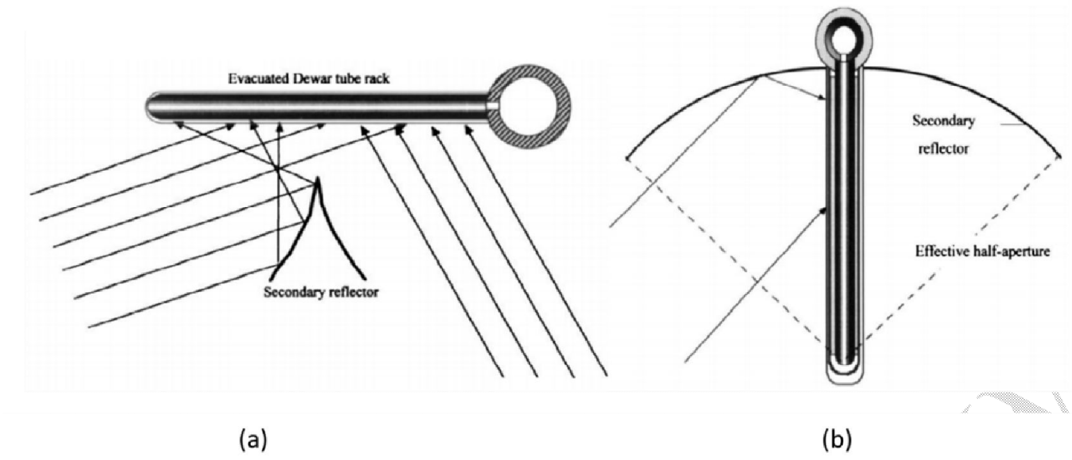

Figure 20: Dewar tubes receiver: a) horizontal orientation; b) vertical orientation [7].

iii. Receivers with plan absorbers

Plan absorber has a rectangular parallelepiped shape [14,24,29,30,61,62]. Most of the time the inside of the parallelepiped is empty, but some researchers design a plane absorber with inside texturing in order to increase thermal exchange between absorber and heat transfer fluid. Texturing can be made with pipe Figure 22. Two identical receivers one with multi-tube absorber the other with plan absorber (Figure 23) have been experienced by Singh et al.[14] They have showed that multi-tube absorber are 8% more efficiency than plan one; in fact, multi-tube absorber have more exchange surface.

Different orientation, vertical and horizontal, of a plan absorber have been designed by Mathur et al. [29,30] using two different methods: one of the methods consisted of using mirrors of varied width because the concentrator is design for the receiver; the second method used mirror of equal width that meaning that receiver must be adapted to concentrator. Vertical orientation allows to reduce shading losses due to the receiver and give a better distribution of concentrated sun beam on two faces of absorber. In horizontal orientation the illuminated face is one that meet mirrors. With a vertical absorber when mirrors must be adapted to the receiver their width increases with the distance to the receiver Figure 21 a). At the contrary for horizontal absorber mirrors width decreases with the distance to the receiver Figure 21 b). Two opposite phenomenon can explain that: in regard to vertical absorber, the more the mirrors are close to the receiver the more reflective image is a spread one. Therefore, the nearest mirrors must be small to avoid losses by spreading. In horizontal position the most distant mirrors from the receiver have a spreading reflected image so they must be narrow to avoid losses by spreading.

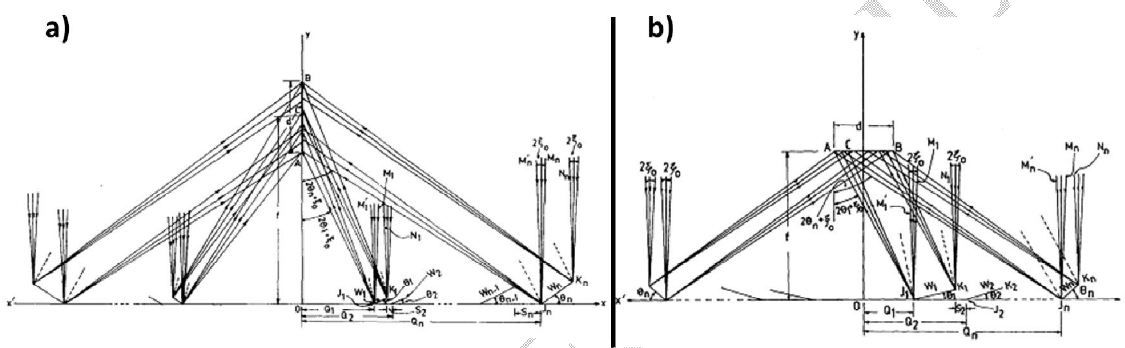

Figure 21: plan absorber a) vertical [30] and b) horizontal [29].

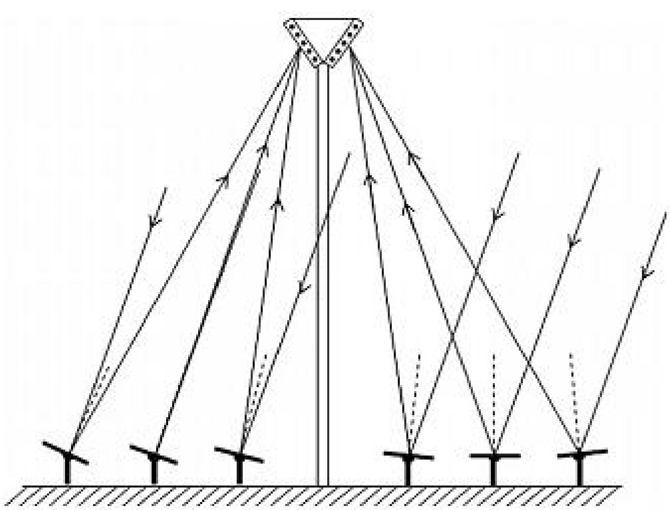

Figure 22: Texturing V-shape absorber [20].

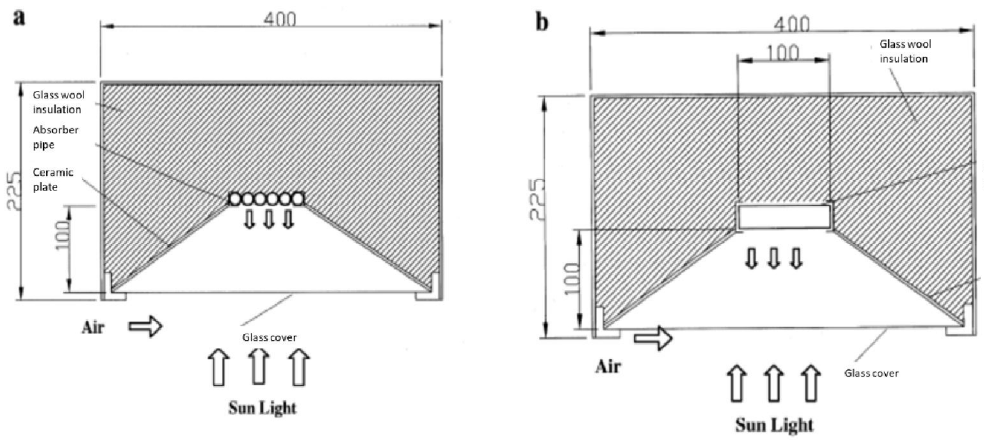

Figure 23: Two identical receivers one with multi-tube absorber the other with plan absorber [14].

Hack et al. [41] have made a comparison study between an adaptive design of secondary concentrator design by Zhu [63] and conventional design of secondary concentrator : CPC, trapezoidal and butterfly. They concluded that, for a mono-tube absorber, the adaptive design of secondary concentrator has better optical performance following by CPC, trapezoidal and the butterfly, respectively. However, for multi-tube absorbers, trapezoidal secondary concentrator has good results.

III. Materials used in the construction of receivers

i. Selective coating for absorbers

One of the important steps in the design of the receiver is the choice of materials to be used for all the elements with particular attention to the absorber. Indeed, to be effective, the absorber must have certain properties which depend on the materials used. The liner material used for the absorber should:

- ✓ ideally absorb all incident radiation. It must tend towards the absorptivity of the black body in the solar spectrum [64] ;

- ✓ have a low emissivity in the infrared;
- ✓ have a very good thermal conductivity;
- ✓ be resistant to chemical attack from the heat transfer fluid used; this fluid can be water, corrosive oil or molten salt;
- ✓ resist attacks from the surrounding environment;
- ✓ be low cost, easy to handle and have a long lifespan.

It is very rare that a single material combines all these properties. Most often, we used to use a combination of different materials, each providing one or more of the required properties. The substrates most often used are copper [65,66], aluminium [67], stainless steel [68], ceramics [65,66] and mild steel [51]. These materials are chosen for their good thermal conductivity, low infrared emissivity, low cost and corrosion resistance. The basic solar receivers are made from the materials mentioned above and then covered with a matte black paint. This matte black paint increases the absorbency of the absorber. The most efficient absorbers are covered with a selective coating.

Selective coatings impart two essential optical properties: high absorptivity (>92%) in the solar spectrum and low emissivity (<15%) in the far infrared. Many researchers have experimentally compared conventional absorbers painted black with the same absorbers coated with a selective coating. They concluded that the selective coating reduced the radiative losses observed at the receiver by 20-30% [24,39,61]. There are several mechanisms for obtaining selective coatings. These mechanisms can be grouped into different large families depending on the materials and the principle used [64–66,69–71,73] : intrinsic or "mass absorbers [61,64–66,69,70,73], Semiconductor-metal tandems [64–66,70], Multilayer absorbers [64–66,70,71], Surface texturing [64,65,70,74,75], Metal-dielectric composite coating or cermets [64,65,68,70,76].

Selective coatings can be directly spread on the substrate, or the top layers of the substrate can be made into a selective coating [71]. Spreading can be done by painting, by Anodization, by a vacuum sputtering, by pyrolytically depositing, by electrolysis, by chemical or Physical vacuum deposition or by sol-gel coating [68]. Metal is transformed into a textured surface by a chemical reaction.

Absorbant black paints are the least expensive and easiest to apply selective coatings. They make it possible to obtain a fairly good selectivity α= 0.83 - 0.96 and ε= 0.13 - 0.3 provided that they are applied to the appropriate substrate: polished copper, polished aluminum, stainless steel [70]. Cermets can be used as a pigment for selective paints. The major drawback is that the cermets cannot be exposed to the ambient environment; they must be protected by a glass envelope or sometimes be under vacuum [33]. The most used materials for the absorbers of LFC receivers are copper and steel coated with a high absorptivity paint. The most marketed products are Solkote [77], MAXORB foil [39], Pyromark [78,79], Cobalt [79].

ii. Glass used for greenhouse effect

Using a suitable material, an absorber can absorb and transfer a maximum heat to HTF, but it is necessary to keep that heat. Glass due to its selective property is also an excellent candidate for reducing radiative losses. In fact, glass is transparent at low wavelengths of solar radiation < 2.5 µm and is almost opaque at high wavelengths such as those of the far infrared; that is calls greenhouse effect. The heated absorber emits far infrared radiation. By enclosing the absorber in a glass-covered enclosure, radiative losses are reduced [11,80–84]. In addition, the use of glass makes it possible to create a closed environment which also makes it possible to limit convective losses. The vacuum is used to insulate the absorber face looking at mirrors; which reduces convection losses. The most used glass cover is borosilicate [11,36,51,55].

IV. Conclusion

A LFC consists of a concentrator, a receiver and the sun tracking system. In this article we are particularly interested in receivers; by carrying out this review, we want to identify the most suitable type of receiver for small scale LFC suitable for rural areas of Sub-Saharan. In the receiver, there are an absorber and a protective envelope. In addition to the above elements, the following can be a found in a receiver for LFC: a secondary concentrator and thermal insulation. There is a wide variety of receivers that differ in the shape of the absorber: mono-tube, multi-tube, plane. The shape of the secondary concentrator or its absence allows to categorize the receivers. The secondary concentrator can be: butterfly, CPC, segmented parabolic secondary concentrator or trapezoidal. Vacuum mono-tube receiver has the best efficiency, but there are very expensive, they can be replaced by mono-tube under partial vacuum. The partial vacuum can be providing by a glass envelope or a glass cover they must have a secondary concentrator. It is possible to make a mixed system with partial vacuum receivers at the start of the line and vacuum receivers at the end of the line. This reduces the cost of installation while minimizing heat loss. The absorber being a receiver, it is possible to improve the heat transfer by increasing the exchange surface and in this case instead of having one tube we can used more than two tubes. The multitude receivers are under partial vacuum with a trapezoidal secondary receiver. Receivers at the partial vacuum are less expensive easy to make by hand because even when there is breakage there is no loss of the vacuum. An efficient receiver must absorb all the incident sun beam and lose as little heat as possible; for this, the absorber must be made of a selective material. A copper or a steel substrate coated with a high absorptivity paint is a good selective material for absorber. Among the secondary concentrators, the trapezoidal one is the simplest to design and the least expensive. Trapezoidal receiver with a multi-tube absorber in copper coated with black paint and glass covers is a king of receivers for LFC that can be used in rural area of Sub-Saharan.

References:

[1] Singh T, Hussien MAA, Al-Ansari T, Saoud K, McKay G. Critical review of solar thermal resources in GCC and application of nanofluids for development of efficient and cost effective CSP technologies. Renew Sustain Energy Rev 2018;91:708–19. https://doi.org/10.1016/j.rser.2018.03.050.

[2] Seshie YM, N'Tsoukpoe KE, Neveu P, Coulibaly Y, Azoumah YK. Small scale concentrating solar plants for rural electrification. Renew Sustain Energy Rev 2018;90:195–209. https://doi.org/10.1016/j.rser.2018.03.036.

[3] European Academies Science Advisory Council. Concentrating solar power: its potential contribution to a sustainable energy future. Halle (Saale): EASAC Secretariat; 2011.

[4] IEA-ETSAP and IRENA. Concentrating Solar Power Technology Brief. 2013.

[5] Concentrating Solar Power Projects by Technology | Concentrating Solar Power Projects | NREL n.d. https://solarpaces.nrel.gov/by-technology (accessed December 3, 2022).

[6] Linear Concentrator System Concentrating Solar-Thermal Power Basics. EnergyGov n.d. https://www.energy.gov/eere/solar/linear-concentrator-system-concentrating-solar-thermal-power-basics (accessed December 14, 2022).

[7] Mills DR, Morrison GL. Compact Linear Fresnel Reflector solar thermal powerplants. Sol Energy 2000;68:263–83. https://doi.org/10.1016/S0038-092X(99)00068-7.

[8] Zhu G, Wendelin T, Wagner MJ, Kutscher C. History, current state, and future of linear Fresnel concentrating solar collectors. Sol Energy 2014;103:639–52. https://doi.org/10.1016/j.solener.2013.05.021.

[9] Chaves J, Collares-Pereira M. Etendue-matched two-stage concentrators with multiple receivers. Sol Energy 2010;84:196–207. https://doi.org/10.1016/j.solener.2009.10.022.

[10] Zhu J, Chen Z. Optical design of compact linear fresnel reflector systems. Sol Energy Mater Sol Cells 2018;176:239–50. https://doi.org/10.1016/j.solmat.2017.12.016.

[11] Beltagy H. The effect of glass on the receiver and the use of two absorber tubes on optical performance of linear fresnel solar concentrators. Energy 2021;224:120111. https://doi.org/10.1016/j.energy.2021.120111.

[12] Duffie JA, Beckman WA. Solar engineering of thermal processes. Hoboken: Wiley; 2013.

[13] Silvi C. The pioneering work on linear Fresnel reflector concentrators (LFCs) in Italy. Proc SolarPACES 2009.

[14] Singh PL, Sarviya RM, Bhagoria JL. Thermal performance of linear Fresnel reflecting solar concentrator with trapezoidal cavity absorbers. Appl Energy 2010;87:541–50. https://doi.org/10.1016/j.apenergy.2009.08.019.

[15] Choudhury C, Sehgal HK. A fresnel strip reflector-concentrator for tubular solar-energy collectors. Appl Energy 1986;23:143–54. https://doi.org/10.1016/0306-2619(86)90036-X.

[16] Facão J, Oliveira AC. Numerical simulation of a trapezoidal cavity receiver for a linear Fresnel solar collector concentrator. Renew Energy 2011;36:90–6. https://doi.org/10.1016/j.renene.2010.06.003.

[17] Natarajan SK, Reddy KS, Mallick TK. Heat loss characteristics of trapezoidal cavity receiver for solar linear concentrating system. Appl Energy 2012;93:523–31. https://doi.org/10.1016/j.apenergy.2011.12.011.

[18] Manikumar R, Valan Arasu A. Heat loss characteristics study of a trapezoidal cavity absorber with and without plate for a linear Fresnel reflector solar concentrator system. Renew Energy 2014;63:98–108. https://doi.org/10.1016/j.renene.2013.09.005.

[19] Flores Larsen S, Altamirano M, Hernández A. Heat loss of a trapezoidal cavity absorber for a linear Fresnel reflecting solar concentrator. Renew Energy 2012;39:198–206. https://doi.org/10.1016/j.renene.2011.08.003.

[20] Abbas R, Montes MJ, Piera M, Martínez-Val JM. Solar radiation concentration features in Linear Fresnel Reflector arrays. Energy Convers Manag 2012;54:133–44. https://doi.org/10.1016/j.enconman.2011.10.010.

[21] Sahoo SS, Singh S, Banerjee R. Analysis of heat losses from a trapezoidal cavity used for Linear Fresnel Reflector system. Sol Energy 2012;86:1313–22. https://doi.org/10.1016/j.solener.2012.01.023.

[22] Pauletta S. A Solar Fresnel Collector Based on an Evacuated Flat Receiver. Energy Procedia 2016;101:480–7. https://doi.org/10.1016/j.egypro.2016.11.061.

[23] Taramona S, González-Gómez PÁ, Briongos JV, Gómez-Hernández J. Designing a flat beam-down linear Fresnel reflector. Renew Energy 2022;187:484–99. https://doi.org/10.1016/j.renene.2022.01.104.

[24] Singh PL, Sarviya RM, Bhagoria JL. Heat loss study of trapezoidal cavity absorbers for linear solar concentrating collector. Energy Convers Manag 2010;51:329–37. https://doi.org/10.1016/j.enconman.2009.09.029.

[25] Rabl A. Comparison of solar concentrators. Sol Energy 1976;18:93–111. https://doi.org/10.1016/0038-092X(76)90043-8.

[26] Sahoo SS, Varghese SM, Suresh Kumar C, Viswanathan SP, Singh S, Banerjee R. Experimental investigation and computational validation of heat losses from the cavity receiver used in linear Fresnel reflector solar thermal system. Renew Energy 2013;55:18–23. https://doi.org/10.1016/j.renene.2012.11.036.

[27] Gordon JM, Ries H. Tailored edge-ray concentrators as ideal second stages for Fresnel reflectors. Appl Opt 1993;32:2243–51.

[28] Facao J, Oliveira AC. Simulation of a linear Fresnel solar collector concentrator. Int J Low-Carbon Technol 2010;5:125–9. https://doi.org/10.1093/ijlct/ctq011.

[29] Mathur SS, Negi BS, Kandpal TC. Geometrical designs and performance analysis of a linear Fresnel reflector solar concentrator with a flat horizontal absorber. Int J Energy Res 1990;14:107–24.

[30] Negi BS, Kandpal TC, Mathur SS. Designs and performance characteristics of a linear fresnel reflector solar concentrator with a flat vertical absorber. Sol Wind Technol 1990;7:379–92. https://doi.org/10.1016/0741-983X(90)90023-U.

[31] Mathur SS, Kandpal TC, Negi BS. Optical design and concentration characteristics of linear Fresnel reflector solar concentrators—II. Mirror elements of equal width. Energy Convers Manag 1991;31:221–32. https://doi.org/10.1016/0196-8904(91)90076-U.

[32] Mathur SS, Kandpal TC, Negi BS. Optical design and concentration characteristics of linear Fresnel reflector solar concentrators—I. Mirror elements of varying width. Energy Convers Manag 1991;31:205–19. https://doi.org/10.1016/0196-8904(91)90075-T.

[33] Grena R, Tarquini P. Solar linear Fresnel collector using molten nitrates as heat transfer fluid. Energy 2011;36:1048–56. https://doi.org/10.1016/j.energy.2010.12.003.

[34] Qiu Z, Li Q, Zhang Y, Jia H. Optical Design of Linear Fresnel Reflector Solar Concentrators. Energy Procedia 2012;14:1960–6. https://doi.org/10.1016/j.egypro.2011.12.1194.

[35] Veynandt F. Cogénération héliothermodynamique avec concentrateur linéaire de Fresnel : modélisation de l'ensemble du procédé 2011. http://ethesis.inp-toulouse.fr/archive/00001786/ (accessed September 30, 2014).

[36] Schott Ptr70 4th Generation Brochure | PDF | Solar Energy | Power Station. Scribd n.d. https://www.scribd.com/document/364034326/Schott-Ptr70-4th-Generation-Brochure (accessed December 5, 2022).

[37] Fernández-García A, Cantos-Soto ME, Röger M, Wieckert C, Hutter C, Martínez-Arcos L. Durability of solar reflector materials for secondary concentrators used in CSP systems. Sol Energy Mater Sol Cells 2014;130:51–63. https://doi.org/10.1016/j.solmat.2014.06.043.

[38] Cheng Z-D, He Y-L, Qiu Y. A detailed nonuniform thermal model of a parabolic trough solar receiver with two halves and two inactive ends. Renew Energy 2014;74:139–47. https://doi.org/10.1016/j.renene.2014.07.060.

[39] Negi BS, Mathur SS, Kandpal TC. Optical and thermal performance evaluation of a linear fresnel reflector solar concentrator. Sol Wind Technol 1989;6:589–93. https://doi.org/10.1016/0741-983X(89)90095-7.

[40] Zhu Y, Shi J, Li Y, Wang L, Huang Q, Xu G. Design and thermal performances of a scalable linear Fresnel reflector solar system. Energy Convers Manag 2017;146:174–81. https://doi.org/10.1016/j.enconman.2017.05.031.

[41] Hack M, Zhu G, Wendelin T. Evaluation and comparison of an adaptive method technique for improved performance of linear Fresnel secondary designs. Appl Energy 2017;208:1441–51. https://doi.org/10.1016/j.apenergy.2017.09.009.

[42] Chaitanya Prasad GS, Reddy KS, Sundararajan T. Optimization of solar linear Fresnel reflector system with secondary concentrator for uniform flux distribution over absorber tube. Sol Energy 2017;150:1–12. https://doi.org/10.1016/j.solener.2017.04.026.

[43] Famiglietti A, Lecuona A. Direct solar air heating inside small-scale linear Fresnel collector assisted by a turbocharger: Experimental characterization. Appl Therm Eng 2021;196:117323. https://doi.org/10.1016/j.applthermaleng.2021.117323.

[44] Canavarro D, Chaves J, Collares-Pereira M. New second-stage concentrators (XX SMS) for parabolic primaries; Comparison with conventional parabolic trough concentrators. Sol Energy 2013;92:98–105. https://doi.org/10.1016/j.solener.2013.02.011.

[45] Singh PL, Ganesan S, Yàdav GC. Technical note: Performance study of a linear Fresnel concentrating solar device. Renew Energy 1999;18:409–16. https://doi.org/10.1016/S0960-1481(98)00805-2.

[46] SUNCNIM et la Banque des Territoires inaugurent la centrale solaire thermodynamique avec stockage d'énergie de Llo | Suncnim n.d. https://www.suncnim.com/en/suncnim-et-la-banque-des-territoires-inaugurent-la-centrale-solaire-thermodynamique-avec-stockage (accessed December 1, 2022).

[47] Montanet E, Rodat S, Falcoz Q, Roget F. Influence de la topographie sur les performances optiques de concentrateurs linéaires de Fresnel : le cas de la centrale solaire eLLO 2022.

[48] Llamas D. Puerto Errado 2: World's largest CSP based on Linear-Fresnel technology. HELIOSCSP n.d. https://helioscsp.com/puerto-errado-2-worlds-largest-csp-based-on-linear-fresnel-technology/ (accessed December 6, 2022).

[49] Feuermann D, Gordon JM. Analysis of a two-stage linear Fresnel reflector solar concentrator. J Sol Energy Eng 1991;113:272–9.

[50] Montes MJ, Abbas R, Muñoz M, Muñoz-Antón J, Martínez-Val JM. Advances in the linear Fresnel single-tube receivers: Hybrid loops with non-evacuated and evacuated receivers. Energy Convers Manag 2017;149:318–33. https://doi.org/10.1016/j.enconman.2017.07.031.

[51] Dey CJ. Heat transfer aspects of an elevated linear absorber. Sol Energy 2004;76:243–9. https://doi.org/10.1016/j.solener.2003.08.030.

[52] Reynolds DJ, Jance MJ, Behnia M, Morrison GL. An experimental and computational study of the heat loss characteristics of a trapezoidal cavity absorber. Sol Energy 2004;76:229–34. https://doi.org/10.1016/j.solener.2003.01.001.

[53] Abbas R, Muñoz J, Martínez-Val JM. Steady-state thermal analysis of an innovative receiver for linear Fresnel reflectors. Appl Energy 2012;92:503–15. https://doi.org/10.1016/j.apenergy.2011.11.070.

[54] Abbas R, Muñoz-Antón J, Valdés M, Martínez-Val JM. High concentration linear Fresnel reflectors. Energy Convers Manag 2013;72:60–8. https://doi.org/10.1016/j.enconman.2013.01.039.

[55] Reddy KS, Kumar KR. Estimation of convective and radiative heat losses from an inverted trapezoidal cavity receiver of solar linear Fresnel reflector system. Int J Therm Sci 2014;80:48–57. https://doi.org/10.1016/j.ijthermalsci.2014.01.022.

[56] Pye JD, Morrison GL, Behnia M, Mills DR. Modelling of Cavity Receiver Heat Transfer for the Compact Linear Fresnel Reflector 2003.

[57] Ordóñez F, Flores E, Soria R. Comprehensive analysis of the variables influencing the techno-economic optimization of medium temperature linear Fresnel collectors. Energy Rep 2021;7:5747–61. https://doi.org/10.1016/j.egyr.2021.08.194.

[58] Moghimi MA, Craig KJ, Meyer JP. Optimization of a trapezoidal cavity absorber for the Linear Fresnel Reflector. Sol Energy 2015;119:343–61. https://doi.org/10.1016/j.solener.2015.07.009.

[59] Lin M, Sumathy K, Dai YJ, Wang RZ, Chen Y. Experimental and theoretical analysis on a linear Fresnel reflector solar collector prototype with V-shaped cavity receiver. Appl Therm Eng 2013;51:963–72. https://doi.org/10.1016/j.applthermaleng.2012.10.050.

[60] Morrison GL, Mills DR, Corporatio S. Solar Thermal Power Systems–Stanwell Power Station Project". Proc. ANZSES Annu. Conf., 1999.

[61] Khan MdKA. Technical note Copper oxide coatings for use in a linear solar Fresnel reflecting concentrating collector. Renew Energy 1999;17:603–8. https://doi.org/10.1016/S0960-1481(98)00023-8.

[62] Capeillère J, Toutant A, Olalde G, Boubault A. Thermomechanical behavior of a plate ceramic solar receiver irradiated by concentrated sunlight. Sol Energy 2014;110:174–87. https://doi.org/10.1016/j.solener.2014.08.039.

[63] Zhu G. New adaptive method to optimize the secondary reflector of linear Fresnel collectors. Sol Energy 2017;144:117–26. https://doi.org/10.1016/j.solener.2017.01.005.

[64] Platzer W, Hildebrandt C. 15 - Absorber materials for solar thermal receivers in concentrating solar power (CSP) systems. In: Lovegrove K, Stein W, editors. Conc. Sol. Power Technol., Woodhead Publishing; 2012, p. 469–94.

[65] Atkinson C, Sansom CL, Almond HJ, Shaw CP. Coatings for concentrating solar systems – A review. Renew Sustain Energy Rev 2015;45:113–22. https://doi.org/10.1016/j.rser.2015.01.015.

[66] Lampert CM. Coatings for enhanced photothermal energy collection I. Selective absorbers. Sol Energy Mater 1979;1:319–41. https://doi.org/10.1016/0165-1633(79)90001-7.

[67] Konttinen P, Lund PD, Kilpi RJ. Mechanically manufactured selective solar absorber surfaces. Sol Energy Mater Sol Cells 2003;79:273–83. https://doi.org/10.1016/S0927-0248(02)00411-7.

[68] Joly M, Antonetti Y, Python M, Lazo MAG, Gascou T, Hessler-Wyser A, 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 2014;57:487–96. https://doi.org/10.1016/j.egypro.2014.10.202.

[69] Hutchins MG. Spectrally selective solar absorber coatings. Appl Energy 1979;5:251–62. https://doi.org/10.1016/0306-2619(79)90016-3.

[70] Kennedy CE. Review of mid-to high-temperature solar selective absorber materials. vol. 1617. National Renewable Energy Laboratory Golden Colorado; 2002.

[71] Petitjean JP, Vander Poorten H. Les revêtements sélectifs et leur rôle dans l'amélioration des performances des collecteurs solaires. Surf Technol 1980;11:229–58.

[72] Zhao S, Uppsala universitet, Teknisk-naturvetenskapliga fakulteten. Spectrally selective solar absorbing coatings prepared by dc magnetron sputtering. Acta Universitatis Upsaliensis, 2007.

[73] Shimizu M, Suzuki M, Iguchi F, Yugami H. High-temperature Solar Selective Absorbers Using Transparent Conductive Oxide Coated Metal. Energy Procedia 2014;57:418–26. https://doi.org/10.1016/j.egypro.2014.10.195.

[74] Harding GL, Lake MR. Sputter etched metal solar selective absorbing surfaces for high temperature thermal collectors. Sol Energy Mater 1981;5:445–64. https://doi.org/10.1016/0165-1633(81)90079-4.

[75] Cuomo JJ, Ziegler JF, Woodall JM. A new concept for solar energy thermal conversion. Appl Phys Lett 1975;26:557–9. https://doi.org/10.1063/1.87990.

[76] Farooq M, Green AA, Hutchins MG. High performance sputtered Ni : SiO2 composite solar absorber surfaces. Sol Energy Mater Sol Cells 1998;54:67–73. https://doi.org/10.1016/S0927-0248(97)00265-1.

[77] Andemeskel A, Suriwong T, Wamae W. Effects of Aluminum Fin Thickness Coated with a Solar Paint on the Thermal Performance of Evacuated Tube Collector. Energy Procedia 2017;138:429–34. https://doi.org/10.1016/j.egypro.2017.10.193.

[78] Ho CK, Pacheco JE. Levelized Cost of Coating (LCOC) for selective absorber materials. Sol Energy 2014;108:315–21. https://doi.org/10.1016/j.solener.2014.05.017.

[79] Boubault A, Ho CK, Hall A, Lambert TN, Ambrosini A. Durability of solar absorber coatings and their cost-effectiveness. Sol Energy Mater Sol Cells 2017;166:176–84. https://doi.org/10.1016/j.solmat.2017.03.010.

[80] Ky TSM, Ouedraogo S, Ousmane M, Dianda B, Ouedraogo E, Bathiebo DJ. Experimental Study of a Stationary Hot Air Solar Collector Built with Hemispherical Concentrators and Enhanced with Fresnel Lenses. Phys Sci Int J 2021:8–22. https://doi.org/10.9734/psij/2021/v25i130233.

[81] Tian Y, Zhao CY. A review of solar collectors and thermal energy storage in solar thermal applications. Appl Energy 2013;104:538–53. https://doi.org/10.1016/j.apenergy.2012.11.051.

[82] Montes MJ, Abbas R, Barbero R, Rovira A. A new design of multi-tube receiver for Fresnel technology to increase the thermal performance. Appl Therm Eng 2022;204:117970. https://doi.org/10.1016/j.applthermaleng.2021.117970.

[83] Montes MJ, Rubbia C, Abbas R, Martínez-Val JM. A comparative analysis of configurations of linear Fresnel collectors for concentrating solar power. Energy 2014;73:192–203. https://doi.org/10.1016/j.energy.2014.06.010.

[84] Rungasamy AE, Craig KJ, Meyer JP. 3-D CFD Modeling of a Slanted Receiver in a Compact Linear Fresnel Plant with Etendue-Matched Mirror Field. Energy Procedia 2015;69:188–97. https://doi.org/10.1016/j.egypro.2015.03.022.