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Simulation to Build a Solar Collector upon Fresnel Lens.

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Abstract:
In this work we propose the use of Fresnel lens to build a solar collector. We require to know the dimensions of mirrors to reflect light to the lens. We present the results of a c++-root based program to create a simple simulation of space required on the mirrors to achieve the reflection needed. The results show that dimensions of the mirror should be at least 0.85 x 1.8 m for a 2-lens array and dimensions of a parallelogram of 1.7x 1.5 m for a 3-lens proposal, both arrays show that mirrors should be put a distance of 0 m up to 2m to the lens.

***Background**: In the needs of using renewable energy, it is important do design different methods to collect solar power. This project allows us to design geometrical properties of a solar collector using more than 1 Fresnel lens. Mexico is one country that have an advantage according to the geographical position for use of solar power.*

***Materials and Methods**: This design is based on two mathematical simulations: Geogebra, and C++ on Root to make different lens arrays to determine the geometrical properties for the mirrors needed to align solar rays to the lens.*

***Results**: As result we get the size for the mirrors and the relative position to the lens defining the geometrical properties for two designs of the solar collector.*

Conclusion: The solar collector that we are designing should have dimensions of the mirror to be at least 0.85 x 1.8 m for a 2-lens array and dimensions of a parallelogram of 1.7x 1.5 m for a 3-lens proposal, both arrays show that mirrors should be put a distance of 0 m up to 2m to the lens. With this data the geometrical properties of the collector are at least 3m of radius.

***Key Word**: Solar furnace, Simulation, Solar prototype, Fresnel lens.*

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I. Introduction

Actual civilization requires more energy as time passes, to fulfill different necessities. The modern industry requires nowadays different technologies to make use of energy from different resources, but it is necessary to avoid the production of gases for the well of the atmosphere.

In last 60 years many experiments regarding the use of solar power are made all over the world to concentrate enough energy in a point to melt or study alloys for industrial and scientific purposes. Some of these experiments propose the use of solar energy to accomplish industrial needs as welding steel, melting aluminum alloys or wax.

Mostly of the work is made upon an array of two mirrors to concentrate the electromagnetic wave, the concentrator, a reflecting surface that concentrates the energy in a point, and the heliostat as a mirror that moves freely to align the rays to the concentrator.

Many studies have the problem of measuring the power concentrated after making the prototype, therefore is commonly used ray simulations to analyze the density of rays in the working space, and the behavior of density energy along the working space.

In this article, a solar collector is proposed to solve the problem using Fresnel lens as optic system to collect the energy, as a variation for the typical system use in actual experiments.

To achieve the process, mirrors are use as heliostats to simplify the align process of lens to the sun.

This project is made upon a construction of a house-made solar furnace with one Fresnel lens, which objective is melting silver alloys for jewelry porpoises. This solar furnace has the capacity of melting 12 g of silver-copper alloy and had reached an energy power of 22000 W/m2 according to a simulation and atmospheric data base taken from the university high school weather station program from (PEMBU) at National Autonomous University of Mexico (UNAM).

Knowing the complex process of an optical system to build we search for a a solar collector with more capacities.

II. Material And Methods

The geometrical properties of the lens that are 1.125 m high, 0.85m large and they have a focal distance of 0.85 m, these properties represent theorical properties for the furnace, and are taken from a TV screen which we use for its optic properties. The area made by the high and large is the area that rays must go through to be refracted to join in the focal point, also this area determines the geometrical properties of the mirrors, this feature helps us to compare to many furnaces made by two mirrors with the area of concentration.

For this project, we use a simulation made on c++ Programs and using the CERN Root programing system, to study different optical system to determine the most efficient way of using up to 3 Fresnel lens-mirror systems:

The method used to define all geometrical properties of the collector are Using geometrical calculation, we estimate the position of the Sun to the working place and according to this ray direction.

Using the Sun position, we can define all solar rays' directions to use a program to determine rotation and position of the mirror considering that the lens project its shadows on the floor of the collector. Also, this program gives us the position of the whole collector according to the sun for better alignment. We can appreciate this array in Figure 3. To represent these arrays, we use Geogebra for its simplicity and easy to recognize all properties.

After determining the position and rotation of the lens we use the c++ program to project a high density of rays from the "melting point" to the surface which should be the mirror and take the histogram of rays placed on the mirror, this way we make a histogram to determine the most used points of the mirror.

a. Theory/calculation

This computer program will use the sun position according to a previous calculation employing the movement of one place on Earth around the sun with vectorial calculus. This previous calculus gives the zenith and the azimuthal angle respect to geographic north.

To calculate the position of the sun we determinate the position of Earth to the Sun, then the geographical position of the melting spot to the center of the Earth, and with both results we build the position of the Sun on the celestial vault of the point of the workstation.

The position of Earth to the Sun is given by:

$$\bar{V} = \begin{pmatrix} V_x \\ V_y \\ V_z \end{pmatrix} = \begin{pmatrix} R * \cos\left(\frac{2*\pi*t}{Td*Ta}\right) + R - r \\ r * sin\left(\frac{2*\pi*t}{Td*Ta}\right) \\ 0 \end{pmatrix}$$

Where "R" is the major semi axis of the Earth orbital, "r" the minor semi axis, "Td" is the time in one day in hours, "Ta" the time of one year in days, and finally "t" is certain time in the year.

The position of the melting place to the center of the Earth is given by:

$$\bar{C} = \begin{pmatrix} C_x \\ C_y \\ C_z \end{pmatrix} = E * \begin{pmatrix} -\cos\left(\frac{2*\pi*t}{Td} - \frac{lon*\pi}{360}\right) cos\left(\frac{Th*\pi}{360}\right) cos\left(\frac{lat*\pi}{360}\right) + e * \sin\left(\frac{Th*\pi}{360}\right) * \sin\left(\frac{lat*\pi}{360}\right) \\ \sin\left(\frac{2*\pi*t}{Td} - \frac{lon*\pi}{360}\right) cos\left(\frac{lat*\pi}{360}\right) \\ \cos\left(\frac{2*\pi*t}{Td} - \frac{lon*\pi}{360}\right) sin\left(\frac{Th*\pi}{360}\right) cos\left(\frac{lat*\pi}{360}\right) + e * \cos\left(\frac{Th*\pi}{360}\right) * \sin\left(\frac{lat*\pi}{360}\right) \end{pmatrix}$$

Where "lon" is the longitude of the city, "Th" is the inclination of the rotational axis of the earth in grades, "lat" the latitude of the city, e represents the minor semi axis of the earth and E is the radius of Earth at Equator. Then the position of the melting place to the Sun is given by:

$$\bar{U} = \bar{V} + \bar{C}$$

We consider the tangential surface of the geographical position to the Earth of the furnace in order to calculate the Zenithal and Azimuthal angle, the zenithal will be the angle between the vector normal to this surface ($\bar{C}$) and the vector that represents the solar ray in this case we could use $\bar{V}$, the azimuthal angle is the angle between the projection of the solar ray $\bar{V}$ to the surface and the projection of the vector that point to the geographical north to the same surface. Therefor we use the following equation for the zenithal angle φ:

$$\varphi = \text{acos}\left(\frac{\bar{C} \cdot \bar{V}}{|\bar{C}||\bar{V}|}\right)$$

For azimuthal angle we require the vector that represents the rotation axis of the Earth:

$$\hat{P} = \begin{pmatrix} P_x \\ P_y \\ P_z \end{pmatrix} = \begin{pmatrix} \sin\left(\frac{Th * \pi}{360}\right) \\ 0 \\ \cos\left(\frac{Th * \pi}{360}\right) \end{pmatrix}$$

With $\hat{P}$ we can calculate the vector pointing to the geographical north on the surface ($\bar{C}$), this vector is called $\bar{D}$:

$$\overline{Db} = \begin{pmatrix} C_z C_z P_x + C_y C_y P_x - C_z C_x P_z - C_y C_x P_y \\ C_x C_x P_y + C_z C_z P_y - C_y C_x P_x - C_y C_z P_z \\ C_y C_y P_z + C_x C_x P_z - C_z C_y P_y - C_z C_x P_x \end{pmatrix}$$

$$\hat{D} = \widehat{Db} \cdot \left(\widehat{Db} \cdot \hat{P}\right)$$

To Project the sunray to the surface we use the vector E:

$$\overline{Eb} = \begin{pmatrix} C_z C_z V_x + C_y C_y V_x - C_z C_x V_z - C_y C_x V_y \\ C_x C_x V_y + C_z C_z V_y - C_y C_x V_x - C_y C_z V_z \\ C_y C_y V_z + C_x C_x V_z - C_z C_y V_y - C_z C_x V_x \end{pmatrix}$$

$$\hat{E} = -(\widehat{Eb} \cdot \left(\widehat{Eb} \cdot \hat{V}\right))$$

The azimuthal angle is made of:

$$\alpha = \operatorname{acos}\left(\frac{\hat{D} \cdot \hat{E}}{|\hat{D}||\hat{E}|}\right)\frac{180}{\pi} sign(sial) * sign(coal)$$

Where “sial” and “coal” are factors that define day and night according to the facing of the surface of the city to the Sun:

$$sial = \frac{V_y C_x - V_x C_y}{\bar{C} \cdot \bar{V}}$$
$$coal = \frac{V_x + V_y * sial}{-C_x}$$

For this solar collector we use as working place Mexico City (19°N, 99 W), Fig. 1 shows the results of the position of the Sun on this geographical position according on the celestial vault, it shows the zenith (blue) and the azimuthal angle (red) along the year.

With this result we can describe the position during the day, but still, we should simulate the refraction effect of the ray when it comes in the atmosphere.

The array suggested using Fresnel lens will use one mirror per lens but can move freely in position and inclination. It is supposed that the melting point will be on the origin of the axes and the whole instrument should move around this point to ease lens position building.

In Fig 2 we represent the lens and the mirror in the simulation to determine the effective area of reflection also the distance between these objects according to the direction of the solar ray. To observe the form and array of one mirror (green) and the lens (blue) simulating a solar ray (yellow), we use geogebra program with the same code.

According to the position of the sun, the program will place the optical system to reflect any ray perpendicular to the lens. We will use a vector that represents a solar ray (RSOLR) the normal to the mirror plane (NPE) and the ray reflected to the lens (RSLL)

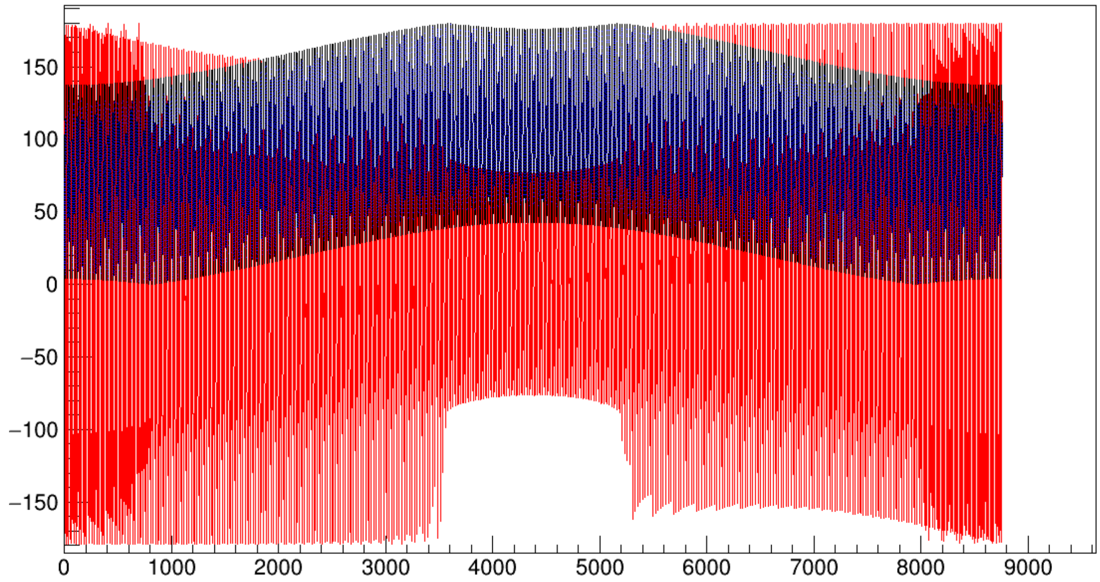

Fig 1: Zenith angle (blue) and azimuthal angle (red) vs time

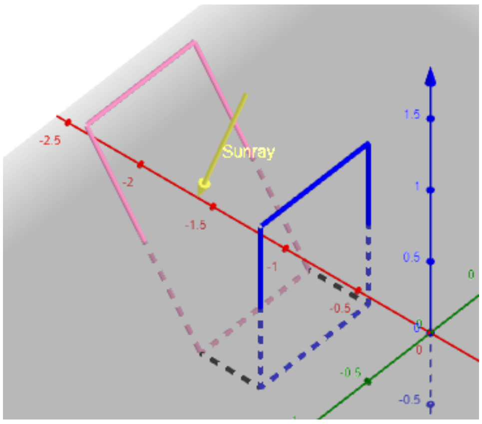

Fig. 2: Lens (blue) and mirror (pink) placement according to the melting point (point at (0,0,0)) and the solar position (yellow)

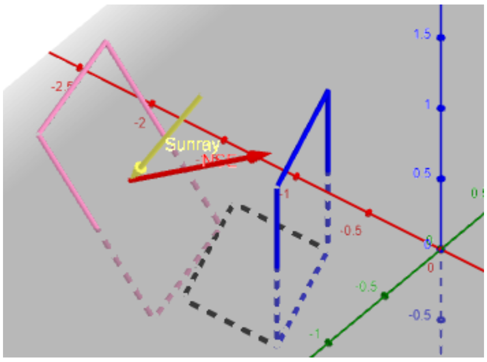

Fig 3: Representation of the solar ray (Sunray yellow), normal to the mirror (NSE red)

b. Simulation of 2 different configures.

With the direction of the sun, and the normal to the mirror, we determine the minimum distance that is required to receive all rays and reflect them.

To know the area required to reflect the sun to the lens we trace 10000 points on the lens and using the distance and the normal of the mirror we project this points on the plane of the mirror and count the number of points on this plane varying the position of the sun with zenith at most 60°, with more angle the solar power will be less effective to use for melting materials. Fig 4 shows the histogram of the rays that were used to calculate the position and inclination of the mirror.

At last, we build the histogram of points on the mirror supposing 2 lens arrays:

a) Constructing a solar collector with 2 lenses in a parallel array.

b) Constructing a solar collector with 3 lenses in a parallel array

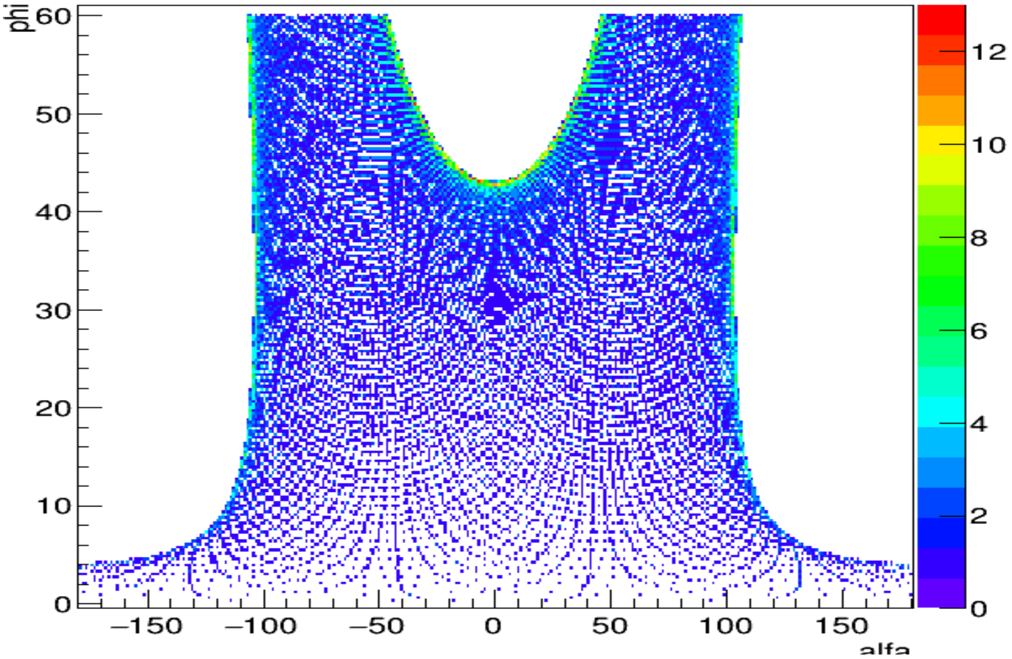

Fig 4: Sun position in zenith angle (phi) and azimuthal angle (“alfa”) to Mexico City

III. Result

For the first array the lenses are placed with its center on the xy-plane, high of lens will be parallel to z axis but optical axis and negative x-axis will have a deviation of 28°.

On the second proposal we use the same program but varying the angle of the 3 lens first lens will have an angle of 58° the second will have 0° and the third will have -56°.

We can determine the effective area of the mirrors using the histograms build by the projection of point on the mirror plane Fig 5 for the first proposal Fig 7 for the second.

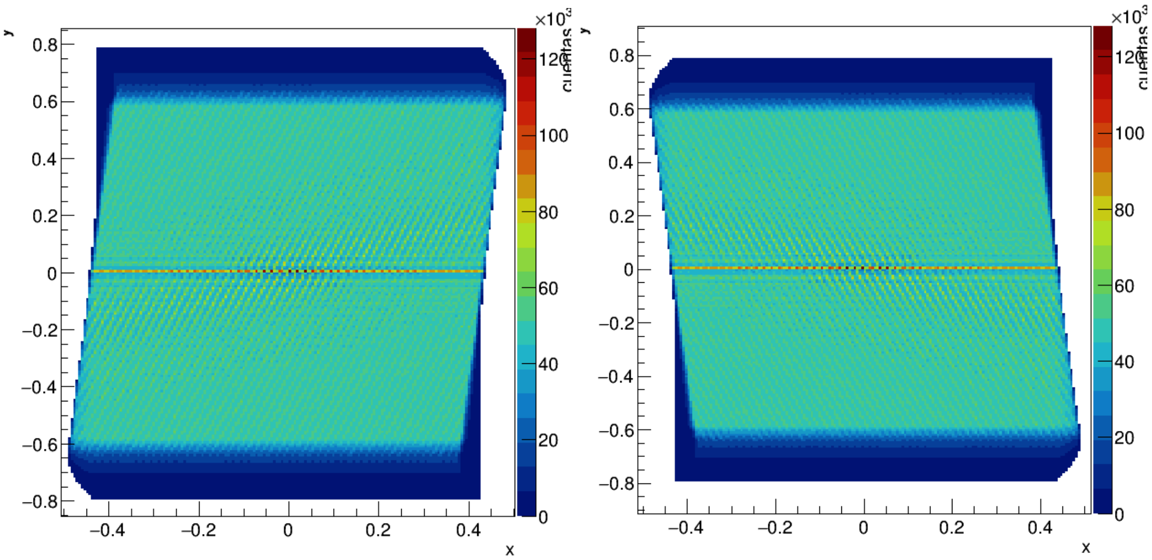

Fig 5: Point projected on the area of both mirrors.

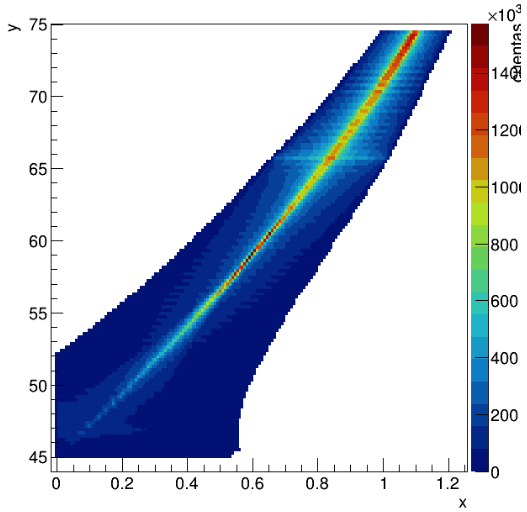

Fig 6: Distance (x) vs rotation angle (y) of first mirror.

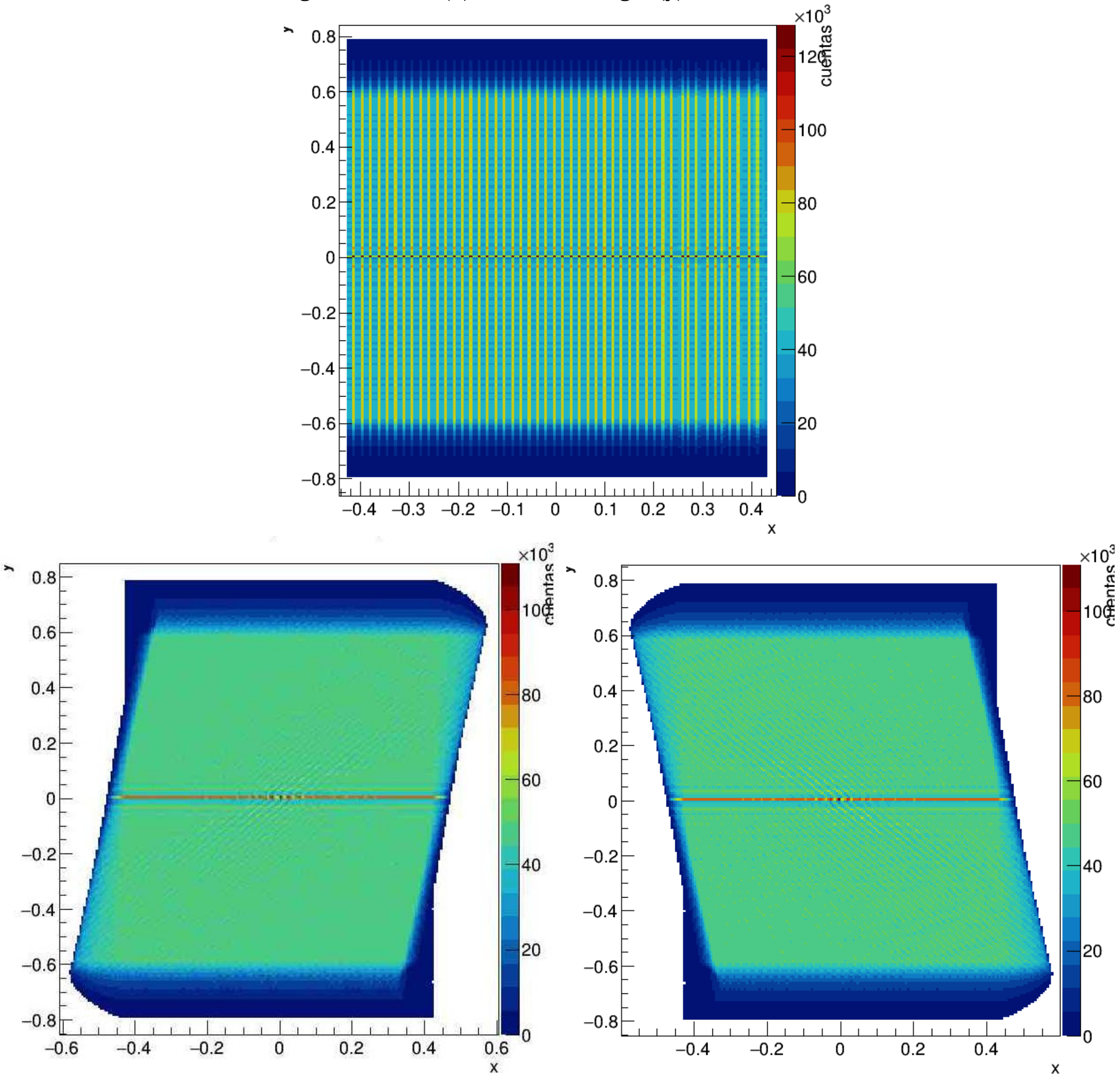

Fig 7: Points of the lens projected on the mirror plane.

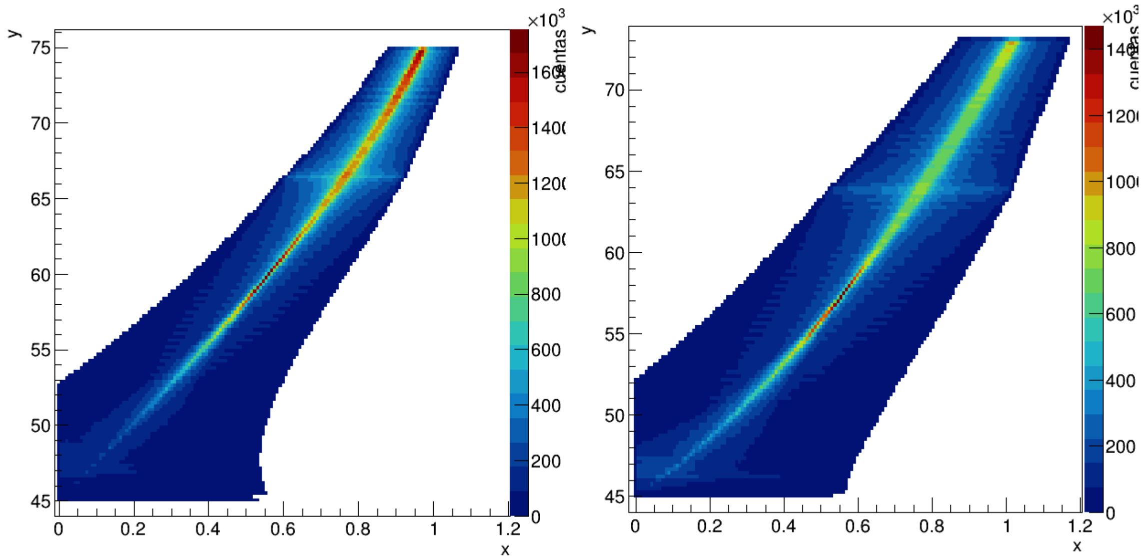

Fig 8: Left: mirror at 0° from negative x axis, right: mirror at 56° from negative x-axis. Distance (x in m) vs rotation angle (y in °) of both cases.

In these prospects of arrays, it shows that considering that the mirrors cannot rotate more than 90° to the vertical axis, mirrors cannot have the shape shown by the histograms, but mirrors can have a parallelogram shape to make the construction easier, also can help this feature while adapting the mirror on the control mechanism.

On the first array the mirrors should have a high of 1.6 m and a length of 1.0 m at least to perform optimal reflection on the lens. These features are seen on Fig 5, but if we want to work most of the year, we see that most of the points fall on a square shaped figure of the mirror, this could propose a smaller figure in case that the budget for constructing the furnace is high, or if we make a proposal of building an array of many mirrors.

Fig 6 represents the position versus the inclination angle of the mirror against the lens. As we study this behavior that for more inclination, we must place the mirror farther to the lens, to have the smaller area for the mirror. This shows ways of constructing the moving and control device for the mirror. Also, we appreciate on this Figure, one area crucial to work, that comes on a position of 0.7 m to the lens up to 1.2 m with inclinations from 45° to 74°. Whit this data we can assure the real space that the whole furnace requires.

On the second array, seeing on Fig 7, it is required two shapes of mirrors:

- Lateral mirrors should have parallelogram shape with dimensions: 1.2x1.6 m.
- A central mirror that should be 1.6 m high and 0.88 m length.

According to Fig 7 these dimensions should be managed to work along the year. But as in the first array there is a smaller version of this mirrors that can change some of the geometrical properties of the mirror.

Finally, according to Fig 8, all three mirrors should be operated at the distance from 0 m up to 1.2 m to each lens with angles from 45° up to 75°. But if we focus on the most probable position to work for all mirrors is at least 0.4 m up to 1.2 m and the lateral mirrors should be able to incline from 58° to 75° and the center mirror from 56 ° to 75°.

Analyzing distance versus angle, we observe an important position in array (a) is 0.85 m and 66° inclined from the mirror, in other hand the array (b) shows an important position of 0.7 m and 75° of inclination. These features show the mostly working positions in one year of working, supposing as every day is clear of clouds.

This gives us the geometrical properties of the solar collector, which gives us details of building properties and represents future decisions according to budget and working place. This process gives us important details of manufacturing like transport capabilities or design settings to make it easier to build.

IV. Conclusion

As first approach for building this type of solar collector, the results shows that mirror sizes are in somehow too big for a first prototype, it is recommended to use different ways of reflecting the light, for example use a system of smaller mirrors that can cover the same area but easier to control.

To reduce space, we could suggest an array that one mirror is located directly to the sun, to improve the solar concentration with a third or fourth lens.

Building a first collector with these aspects demonstrate a high investment only speaking of the reflection system, other alternatives are required to solve this problem.

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