# SOLAR OVENS AND HOT PLATES FOR COOKING AND AVOID FIREWOOD CONSUMPTION

ANES
Asociación Nacional de Energía Solar, A. C.

**Eduardo A. Rincón Mejía**

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In Mexico and in other developing countries, the use of firewood as combustible for cooking has contributed to deforestation of large zones. This was caused due to the lack of alternative combustibles for the poor inhabitants of the countryside and remote areas.

In this contribution, a new solar ovens and hot plates, intended to contributing to solve this problem, are presented. They can be used for cooking not only a great variety of pre-Hispanic and traditional meals, like tortillas, fried meat and vegetables, but also hot cakes, bacon, eggs, steaks and fries.

The solar hot plates and ovens, called "Tolocatzin", have multi-compounded solar concentrators; the hot plate consists of a horizontal metallic plate, which is heated from both of its top and bottom surfaces by concentrated sun light from a multi-compounded concentrator based on non-imaging optics, and built with nine ordinary plane glass-silvered, and two curved aluminum mirrors, so it can be manufactured easily in a small factory or at home.

For an acceptance angle of 15°, which allows the concentration of sun light without sun-tracking for about one hour, it can reach temperatures up to 240°C in a few minutes. This temperature is high enough for cooking almost all fried or grilled meals.

A solar hot plate is a device which collects and concentrates solar beams on a metallic or ceramic horizontal plate in order to heating it for cooking meals.

In Mexico, conventional hot plates are indispensable to heating tortillas and to fry several typical meals.

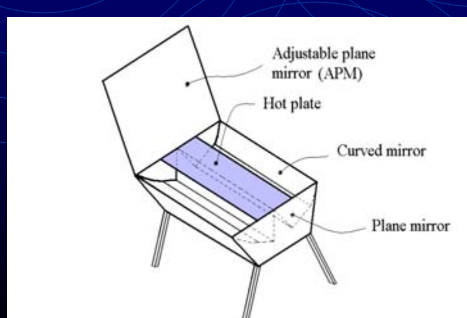
Nowadays there are lots of designs for solar cookers, and several organizations intended to promote their use have been created, but it is not common to find practical hot plates.

Solar cooker *Tolocatzin* developed in Mexico

Internal recipient of the solar cooker *Tolocatzin*

Solar cookers *Tolocatzin* are easily manufactured at low cost

The solar hot plate presented here, called "Tolocatzin", uses a multi-compounded concentrator (MCC) based on non-imaging optics conformed by eleven mirrors: four pairs of plane mirrors, a pair of curved and a big and articulate plane mirror.



Hot plate prototype

Side view of prototype

With this construction, light entering on the aperture of the concentrator within an acceptance transversal angle $2\theta_o$ is collected and reflected concentrated towards the both sides of the horizontal plate without sun tracking for many minutes (most of beams impinge on the bottom side)

# Design criteria (1)

The following requirements are to be satisfied by the hot plates:

- They could be heated very quickly to temperatures over 200º C, high enough to fry, keeping the plate horizontal in order to avoid grease wringing.
- They do not need to follow the sun while the meals are prepared.

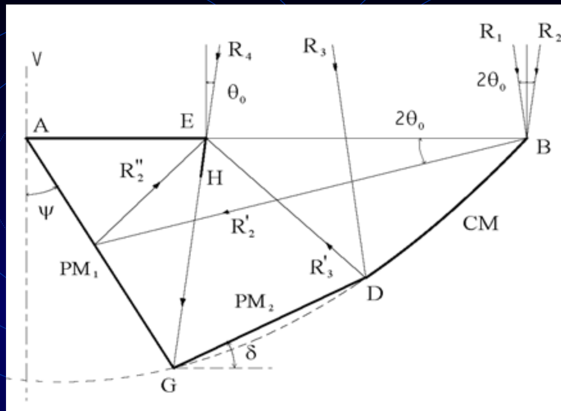
# Design criteria (2)

- They must be safe and easy to use.
- They could be manufactured with easy at home.
- They should have an attractive design and be light and portable.

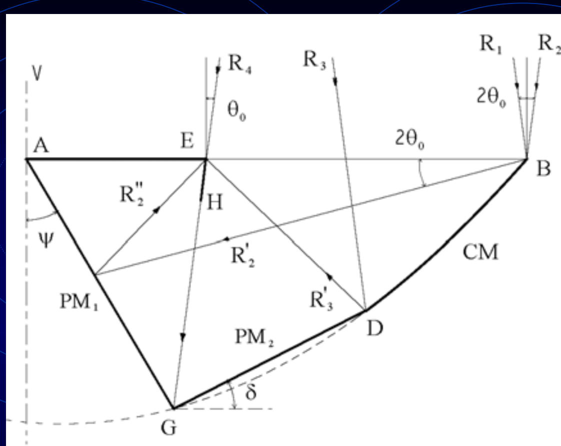
After exploring several options, the foregoing eleven mirrors design was selected.

Some design parameters such as the geometric solar concentration, which influences the maximum temperature, the time required to reach it and the solar non-tracking period, or the size of the plate, depends on the customer needs and the climate conditions in the site where the hotplate will be employed.

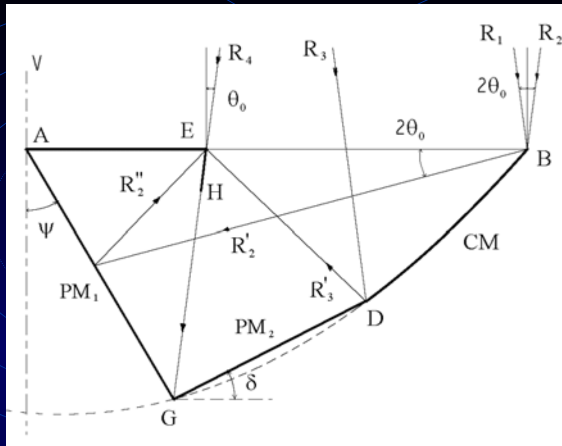
# Principle of operation




A ray of light $R_1$ impinging at the extreme collecting angle - $\theta_o$ on the point B, which is the rim of the curved mirror CM, shall be reflected horizontally towards the plate. A ray $R_2$, impinging on the same point B, but at an extreme angle + $\theta_o$, shall be reflected toward the plane mirror $PM_1$ ( ray $R_2$' ), and then reflected again to the plate's rim E ( ray $R_2$" ) .



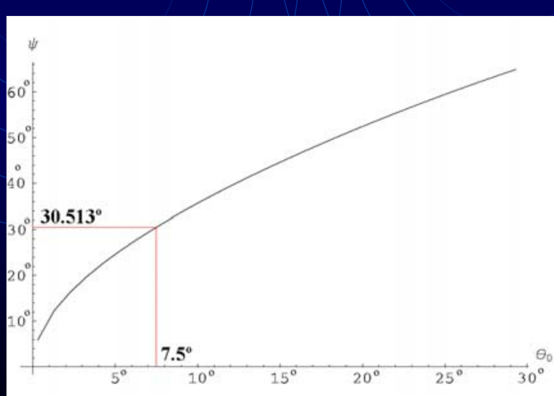

This way, all rays impinging on point B within the total acceptance angle $2\theta_o$ shall be reflected towards the bottom face of the horizontal plate AE. The plane mirror $PM_2$ and the curved one CM are joined at point D; $PM_2$ has an inclination $\delta$ respect to the horizontal in such a way that a ray $R_3$ which impinges on point D at an angle - $\theta_o$, shall be reflected towards point E.



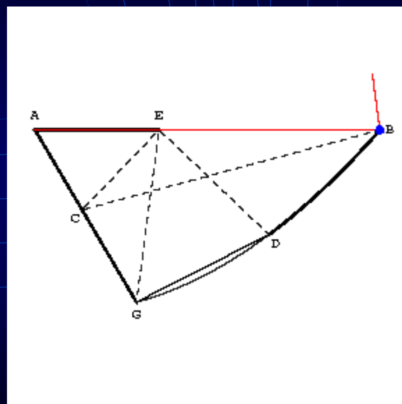

The position of point G, which is the junction between the plane mirrors $PM_1$ and $PM_2$ , is determined by the interception between ray $R_4$ , which enters at an angle $+\theta_o$ , and the plane mirror $PM_1$ . This way, all rays entering the concentration's half aperture AB within the $\pm\ \theta_o$ acceptance window, shall impinge on a face of the plate.

If the curved mirror has a simple profile, for instance, a parabola, the angle $\psi$ , which is formed between the plane mirror $PM_1$ and the vertical, shall be a function of the acceptance half angle $\theta_o$ given by:

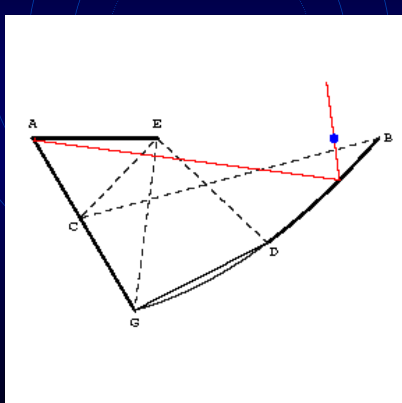
$$\cos^2\psi = 0.25\,(3 + \cos 2\theta_0 - \sin\theta_0 - \sin 3\,\theta_0 - 2^{1/2}\sin\theta_0\,(5 + 3\cos 2\theta_0 - 2\sin\theta_0 - 2\sin 3\,\theta_0)^{1/2})$$

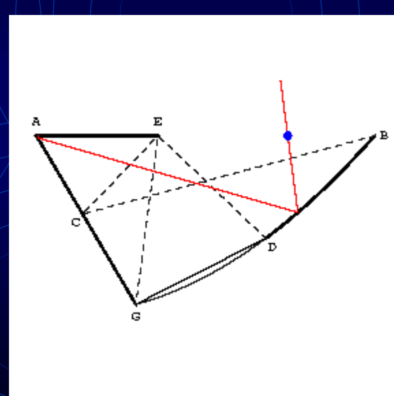


# Tracing of a ray impinging on extreme point B

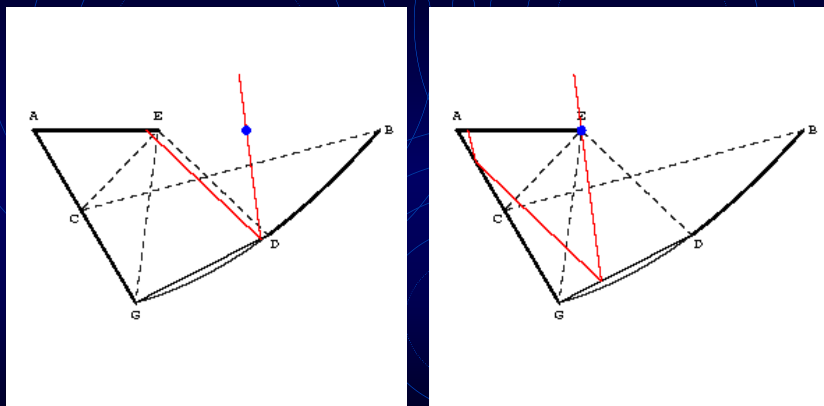



# Tracing of rays impinging on curved mirrors



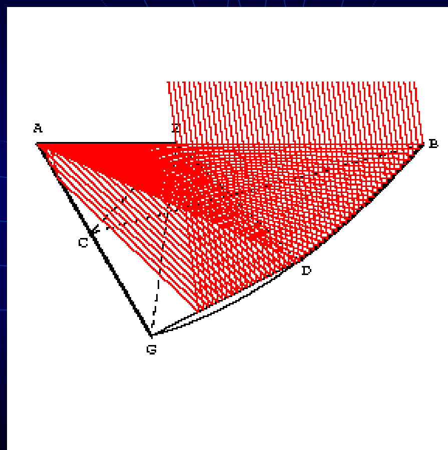
## Tracing of rays impinging on flat mirrors

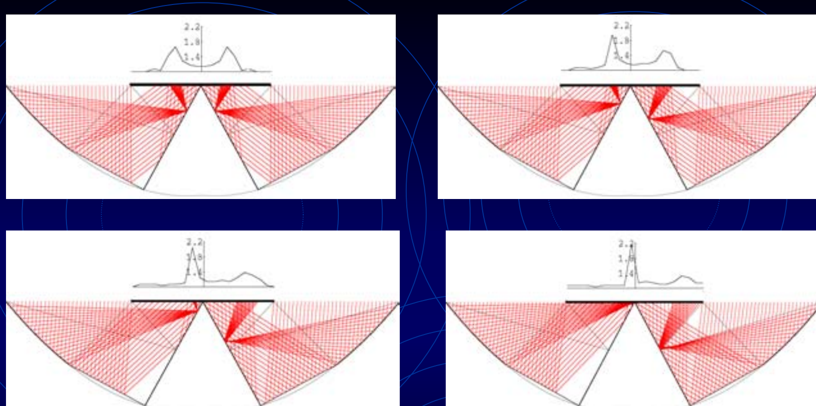



This way, if $\theta_o = 7.5°$, then $\psi$ would be 30.513°; these values were chosen for the first prototype of the solar hot plate Tolocatzin with excellent results.

For smaller values of the acceptance angle, the solar concentration and the maximum temperature reached is higher, but the time of acceptance of beam radiation without sun-tracking is reduced.

## Rays entering by the aperture and reflected toward plate's bottom.



Ray – tracing results for beams entering to the concentrator's aperture at transversal angles $\theta_T$ of 0°, 2.5°, 5.0° and 7.5°, along the corresponding optical concentration on the hot plate.

In this figure, the effect of the four end mirrors and the hinged plane mirror is not considered, so the concentration in this case is two-dimensional.

As a matter of fact, the optical concentration on the hot plate and its temperature are three - dimensionally distributed when the longitudinal component $\theta_L$ is different to zero and the contribution of the hinged mirror is included, but in order to simplify the description of the basic operational principle of the solar hot plate, these important factors were disregarded.

This way, all beams entering to the concentrator aperture within a transversal angle $\pm \theta_T \leq \theta_o$, and a longitudinal angle $\theta_L$ between $\pm 60°$, impinge on the plate.

Furthermore, the big articulated plane mirror APM can collect and reflect to the aperture an extra radiation increasing the geometric concentration and the general performance of the hot plate.

# Operational experience and conclusion

- Several prototypes of these solar hot plates and ovens have been made employing inexpensive materials with very good results.
- A broad variety of meals has been prepared using it.
- These devices have been demonstrated in several technical and educational Fora.

- The use of multi-compounded solar concentrators in hot plates and ovens has been very successful. Due to its excellent performance they could effectively contribute to avoid deforestation in sunny areas where there is not optional combustibles to firewood or lack of it, as many rural areas of Mexico and other developing countries.