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Advances in Solar Thermal Food Processing

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INSTITUTE OF ENGINEERING; UNIVERSITY OF ALGARVE; CAMPUS DA PENHA; FARO-PORTUGAL

Experimental evaluation of the Tolokatsin V Solar Oven

Eduardo A. Rincón Mejía
Marco Aurelio Díaz Leal González
Eduardo Vázquez Valdez

Programa de Energía – Universidad Autónoma de la Ciudad de México Ciudad de México; México

Wonders can be done with concentration solar power plants, photovoltaic panels, solar heaters and biofuels, but first:

THE PAUNCH IS FIRST!

Eduardo del Río (Rius), 1973

Around 28 million Mexicans eat food stewed with firewood (worldwide there are about 2 billion people who eat food cooked with firewood) ...

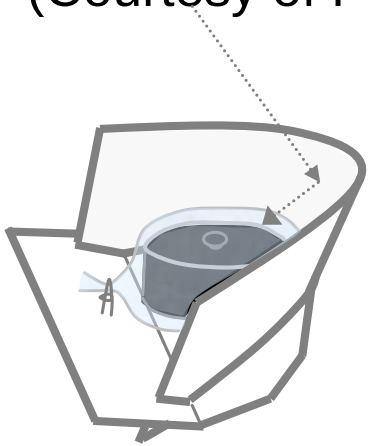
And the rest we eat food cooked with electricity, LP gas, or natural gas…

And hundreds of people when cooking are injured every year by burns, poisoning, gas explosions ...

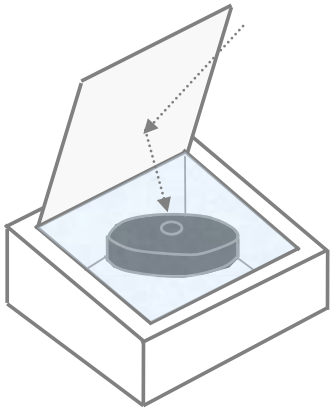
Solar Cooking is an excellent option to solve all these problems;

as a matter of fact, Solar Cooking is their solution!

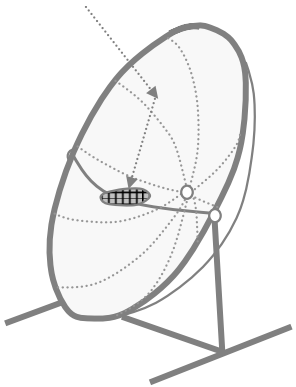
Four types of solar cookers
(Courtesy of Prof. Celestino R. Ruivo)



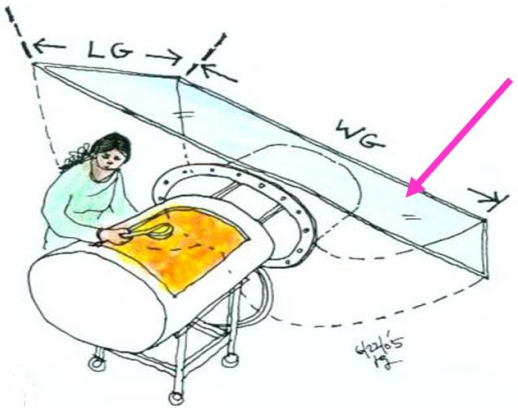
Panel
(slow cooker)



Box
(slow cooker)



Parabolic
(fast cooker)

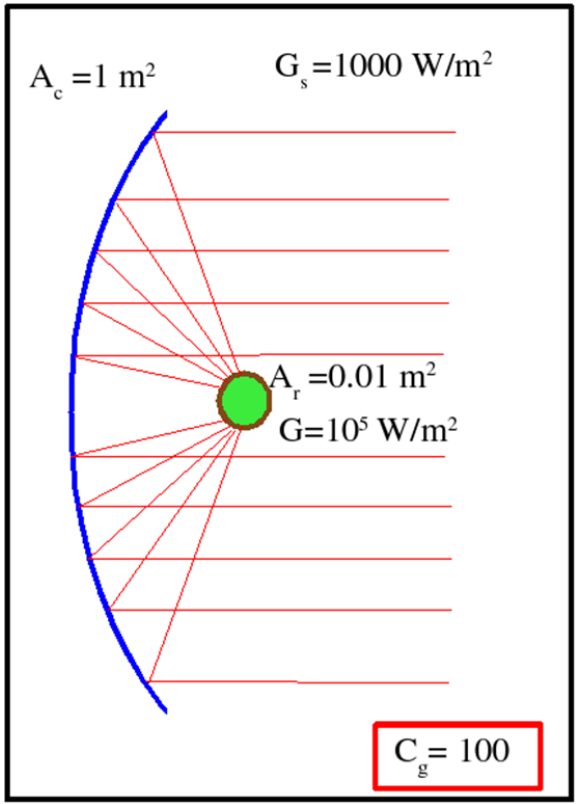


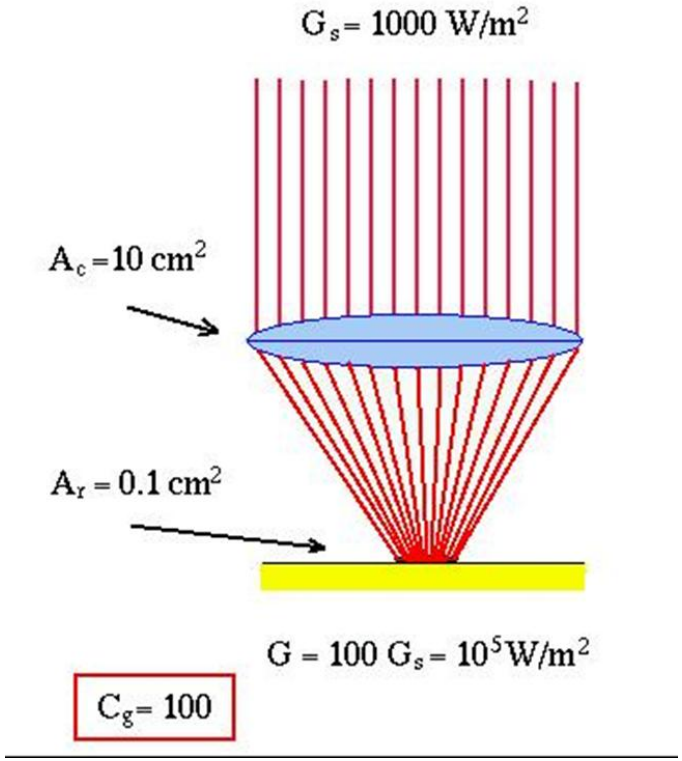
Non-Imaging
(neither slow nor fast cooker)

In order to get high-enough temperatures for frying and fast cooking, solar concentration is often used… but too high temperatures can create toxic substances, burn the meals, and they ALWAYS reduces the **thermal efficiency**!

Solar (Geometric) Concentration Cg = Ac / Ar

Ac: Acceptation area ; Ar: Absorber area





Temperature as a function of the Geometric Solar Concentration

After a simple energy balance on a solar concentrator, it is found for the useful thermal power $\dot{Q}_u$:

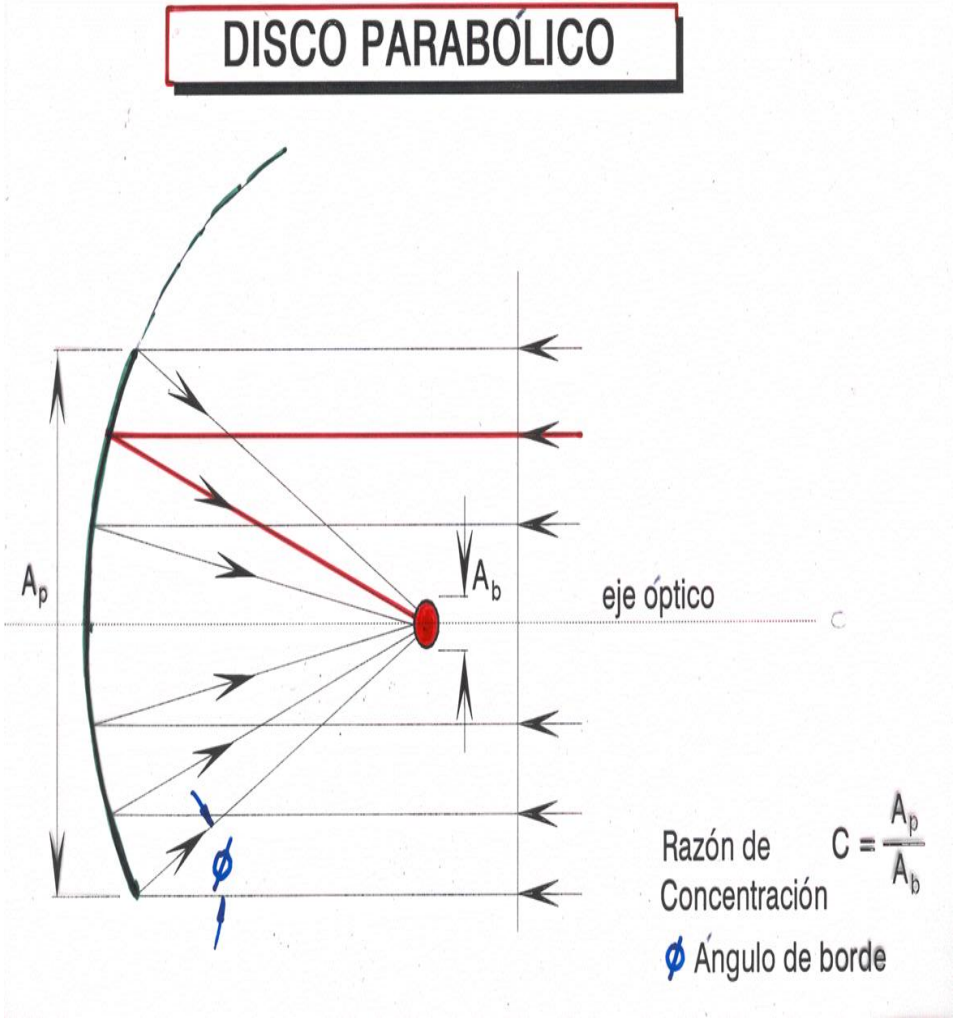
$$\dot{Q}_u \approx A_c\, G_s\, \eta_o - A_r\left[\varepsilon\, \sigma\, T_r^{\,4} + (h\,\Delta T + \kappa\,\nabla T)\right]$$

So, thermal efficiency is given by:

$$\eta_t = \frac{\dot{Q}_u}{A_c\, G_s} \approx \eta_o - \frac{1}{C_g G_s}\left[\varepsilon\, \sigma\, T_r^{\,4} + (h\,\Delta T + \kappa\,\nabla T)\right]$$

Proposing f as: $f = \dfrac{(h\,\Delta T + \kappa\,\nabla T)}{\epsilon\, \sigma\, T_r^{\,4}}$

It is obtained that : $T_r \approx \left[\dfrac{C_g\,(\eta_o - \eta_t)\,G_s}{(1+f)\,\varepsilon\,\sigma}\right]^{\frac{1}{4}}$

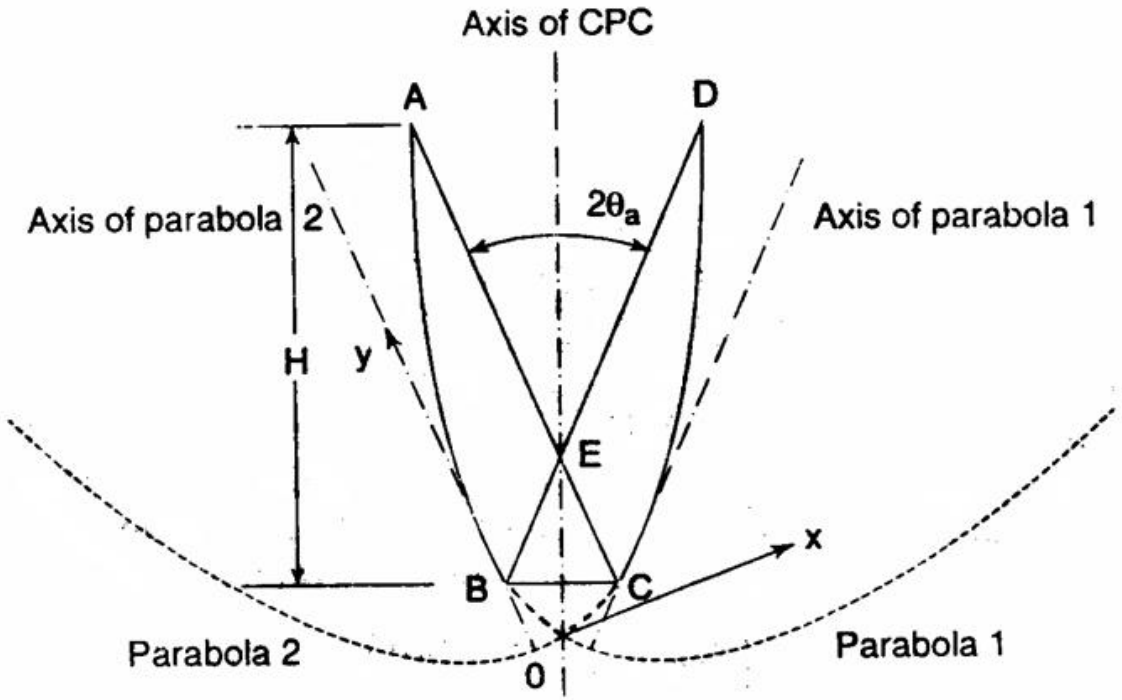


DISADVANTAGES OF USING PARABOLIC MIRRORS:

1. Solar tracking
2. Only beam radiation
3. Expensive mirrors
4. Maximal concentration falls far from the Thermodynamic Limit

THE PARABOLIC CONCENTRATING COLLECTOR (CPC)

Baranov, Melnikov, Winston, Ploke ... (1966)



Geometry of a Compound Parabolic Concentrating Collector

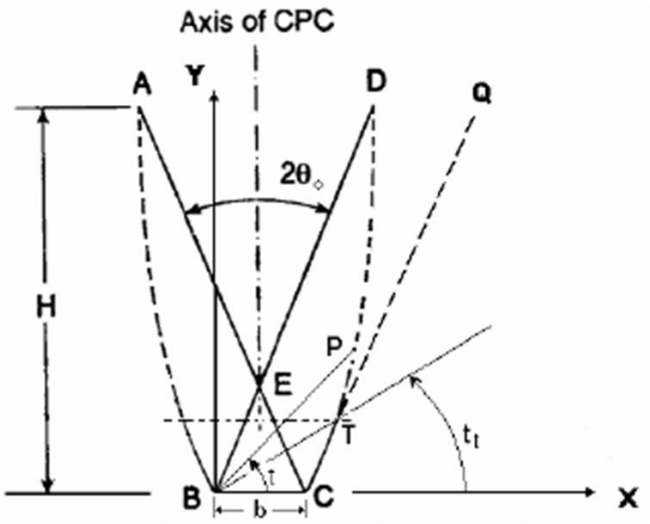


Figure Truncation of a CPC according to Rincón's Criterion.

Rincón's criterion states simply that: "the CPC must be truncated in such a way that rays parallel to the extreme rays (AC and BD in figure A1), are not blocked by the mirrors of the CPC". Observing figure A2, this implies that line QT, which is a tangent to the parabolic mirror CD at point T, must be parallel to the extreme ray BD. That occurs, independently of the shape of the absorber, assuming that its surface is uniformly convex or plane, when the truncation angle t_t is:

$$t_t = \pi / 2 - 3\,\theta_0.$$

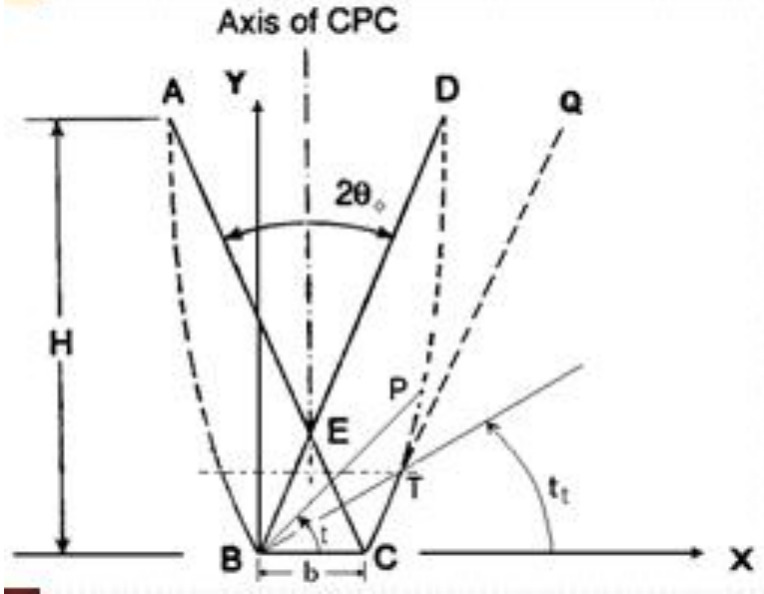
Truncation of a CPC according to Rincón's Criterion

Solar Concentration: $C_g = [2 \times (t) - b] / b = 2 \times (t) / b - 1$

$C_{g\,max} = 1 / \sin \theta_0$ when $t = \pi / 2 - \theta_0$

When $t_t = \pi / 2 - 3\theta_0$ (for Rincón's Criterion)

Thus: $C_g = 2 (1 + \sin \theta_0) \sin (3\theta_0) / [1 - \cos (4\theta_0)] - 1$



The solution of the equation :

For $C_g = 2$

$\theta_0 = 18{,}48°$

DESIGN AND FABRICATION OF THE CCPC CONCENTRATOR

CCPC was designed by sweeping four symmetrical parabola profiles to a square cross-section to form a 3D CCPC that has a square entry and square exit to efficiently collect and concentrate the light. The acceptance angle and the height are calculated by using Equations 1 and 2, respectively [9]. The CCPC geometry was designed on SolidWorks CAD software using Rincon et al. [10] equations as shown in FIGURE 1. The CCPC profile reflects all the light which hits at any point of the curve (or internal surface) to its focal point, where will be absorbed by a square solar cell placed there. The CAD file was sent to PreForm Formlabs software and printed by 3D Laser Printer.

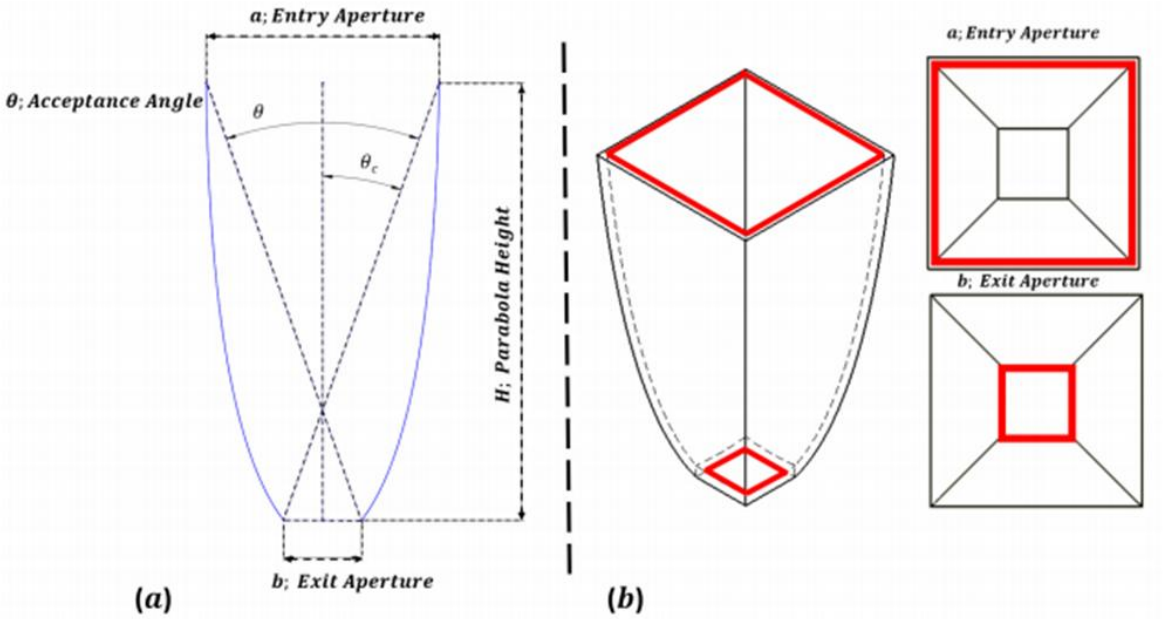
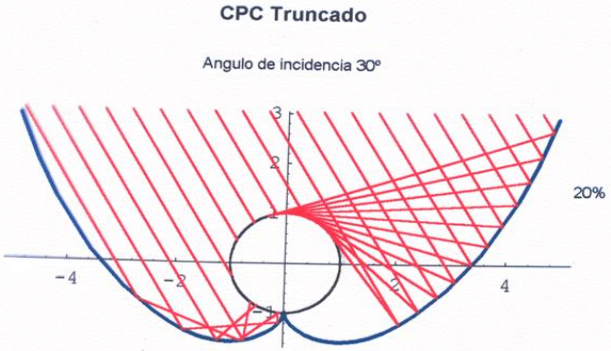
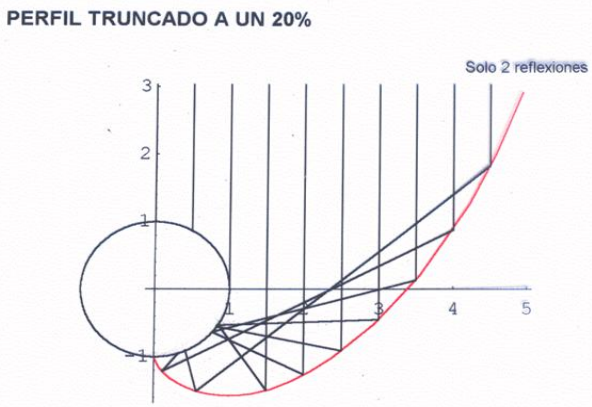


FIGURE 1. CCPC CAD Drawing, (a) 2D CCPC Profile, (b) 3D CCPC Profile.

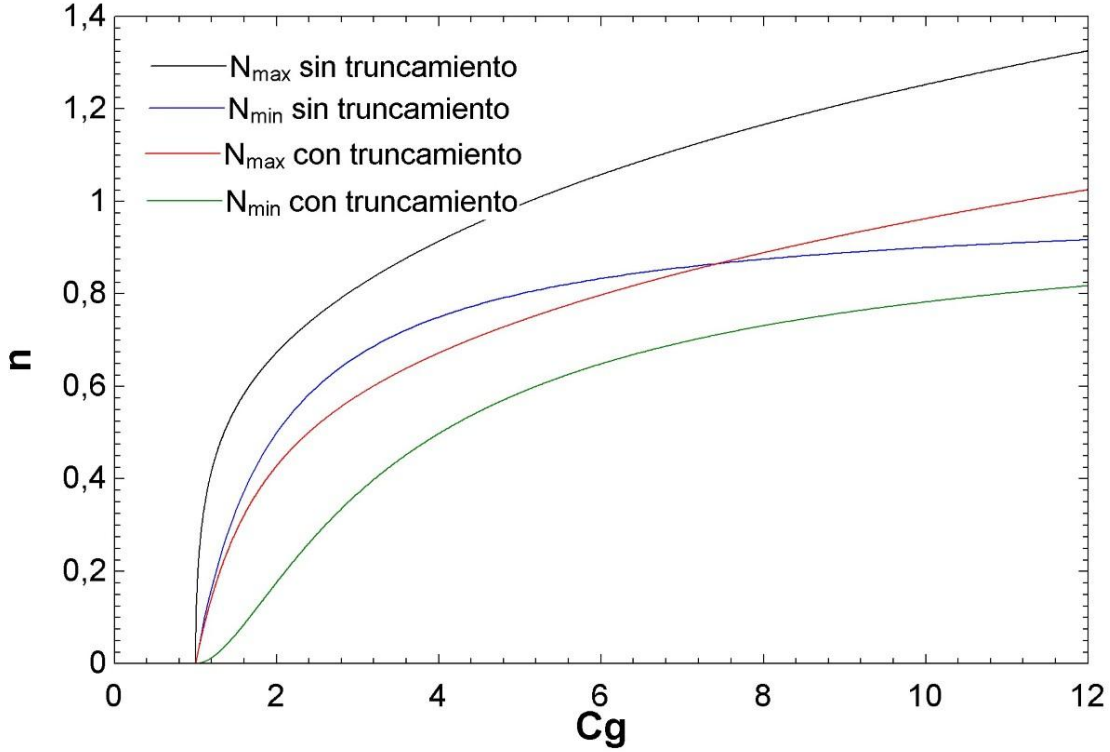
Mazin AL-Shidhani, et al., 2018
Design and testing of 3D printed cross compound parabolic concentrators for LCPV system. DOI: 10.1063/1.5053489

TRAZADO DE RAYOS PARA EL ESTUDIO DE CONCENTRADORES SOLARES DEL TIPO CPC





Trazado de rayos con un ángulo de incidencia de 0º y 30º sobre un CPC con semiángulo de aceptación de 30° truncado al 20%

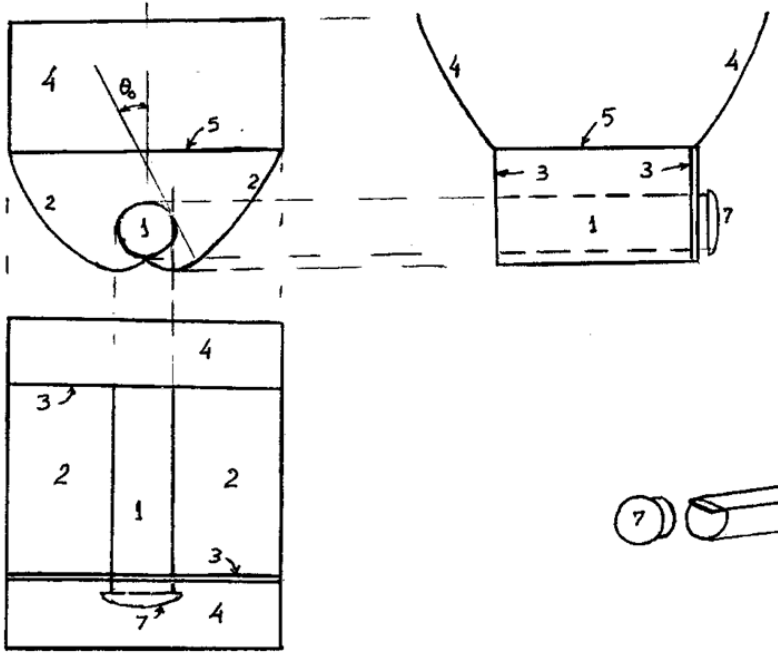


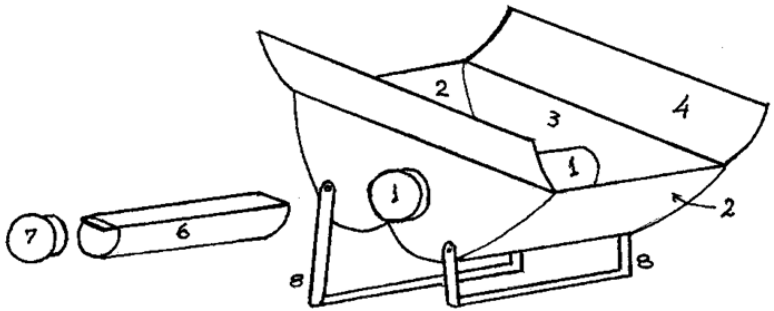
Medium number of reflections n as a function of Gg for a 2D CPC with a flat absorber

(It is an important factor for the optical efficiency)

ESTUFA SOLAR CON CONCENTRADOR MULTICOMPUESTO *

* Compuesto por ocho espejos (cuatro pares de ellos), como se muestra en la figura

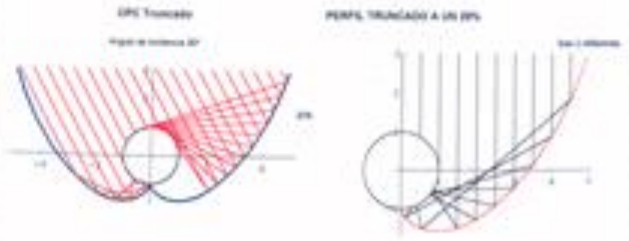




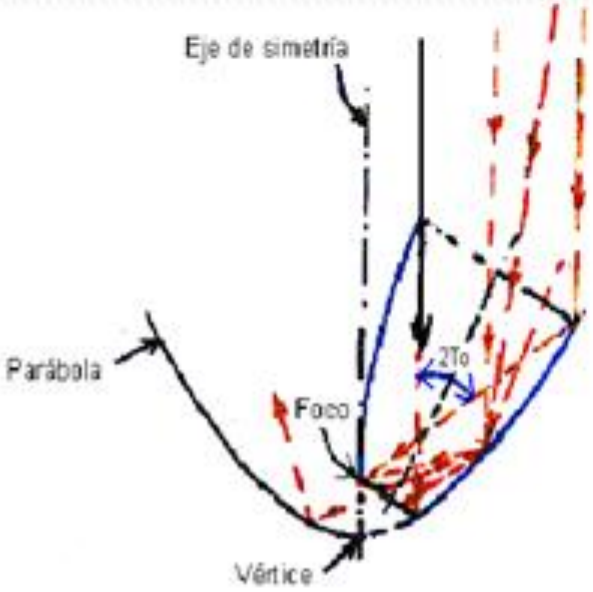
Número de par	Geometría de sección transversal
1	Involuta de circunferencia
2	CPC para absorbedor circular
3	Recta (espejos planos)
4	CPC para absorbedor plano

1. Horno hermético
2. Espejos planos principales
3. Espejos planos laterales
4. Espejos curvos secundarios
5. Cubierta transparente
6. Recipiente para alimentos
7. Tapa del horno
8. Patas ajustables

TRAZADO DE RAYOS PARA EL ESTUDIO DE CONCENTRADORES SOLARES DEL TIPO CPC



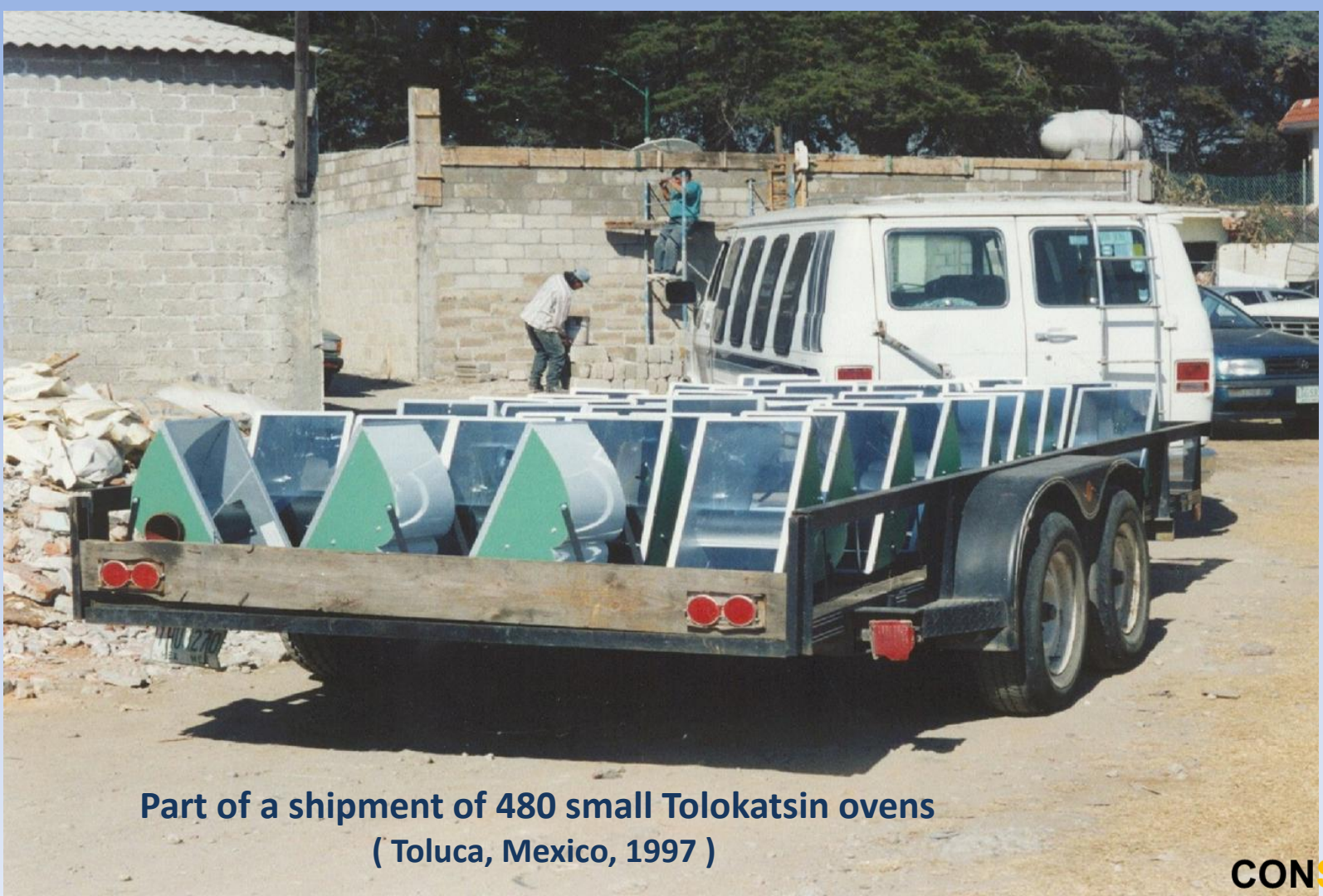
Trazado de rayos con un ángulo de incidencia de 0º y 30º sobre un CPC con semiángulo de aceptación de 30° truncado al 20%



¡ EL HORNO SOLAR *TOLOKATSIN* COMBINA CPCs PARA ABSORBEDORES CIRCULAR Y PLANO !

De esta manera se logra una concentración tridimensional a partir de encorvar espejos planos

›



Part of a shipment of 480 small Tolokatsin ovens

(Toluca, Mexico, 1997)

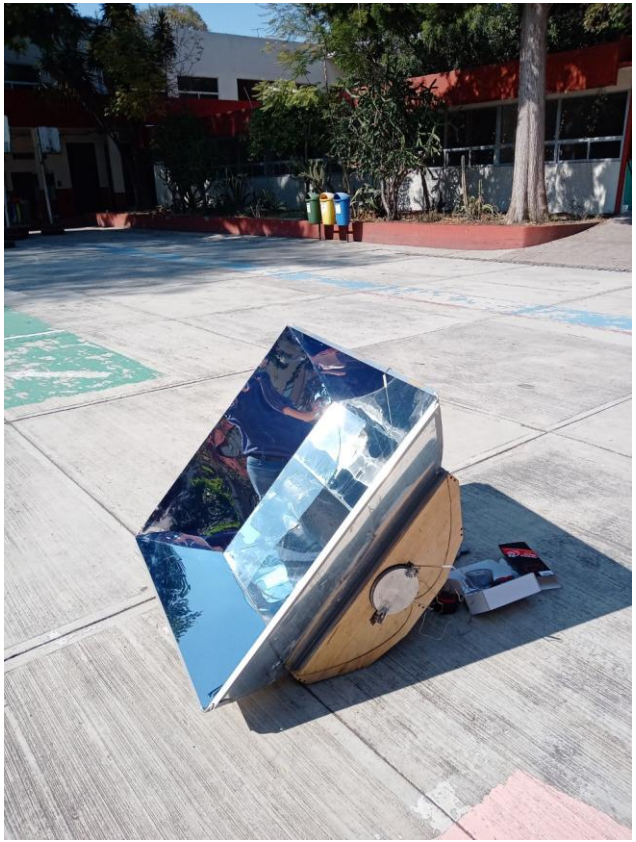
Solar cooking for 260 people realized in San Juan del Río, Querétaro, México

April 22 , 2005

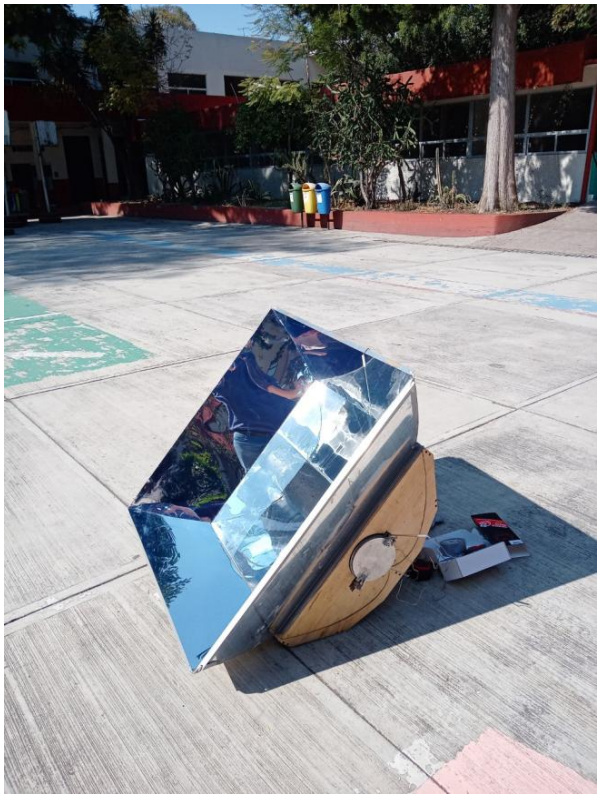
www@com.pl

The improved solar cookers:

Original Tolokatsin design 1996



Tolokatsin V (15 L, Cg 2.7), 2019



Acceptation area: 1 m²

Cg = 2,75

Stagnation Temp: 170° C, @700 W/m²

$\eta_o \approx 0{,}73$; $\varepsilon \approx 0{,}46$; $\alpha \approx 0{,}92$; $n \approx 0{,}4$

Two trays of 4 L each

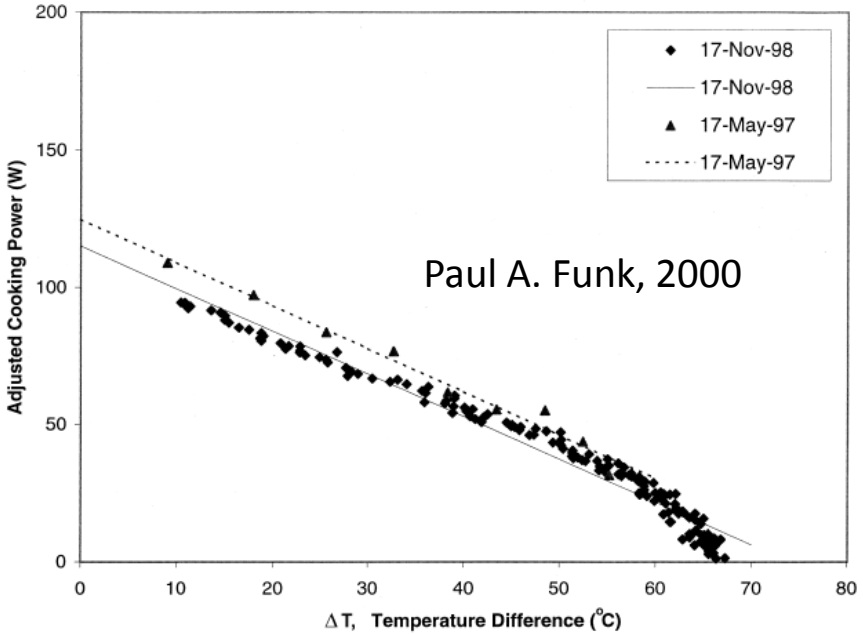
Nominal volume: 15 L

CONSOLFOOD2020

Solar cookers test standards

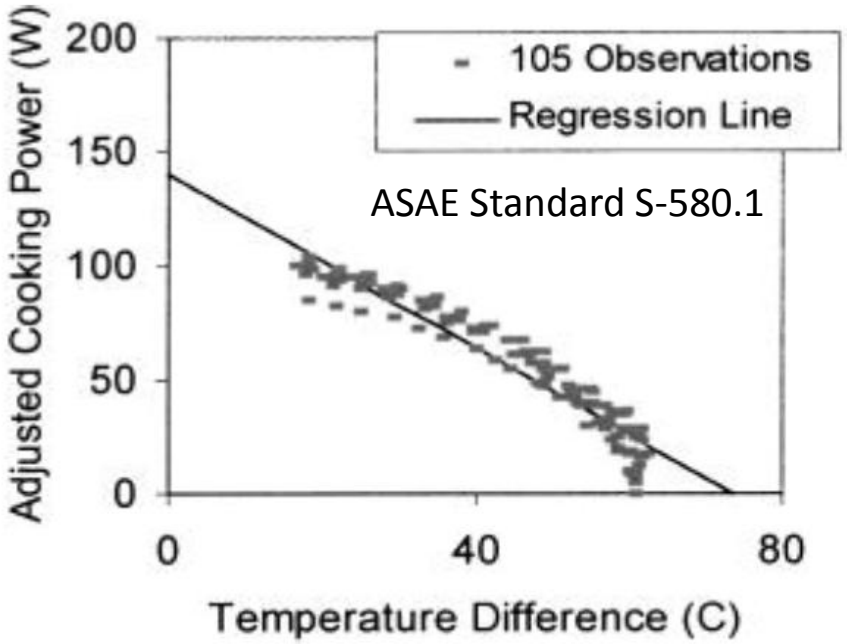
“ The one figure best representing thermal performance is effective cooking power, which accounts for both different cooker sizes and heat gain rates. The unit of power with which most people are familiar is the Watt ”

Third World Conference on Solar Cooking
Avinashilingam University, Coimbatore, India, 6 – 10 January, 1997



Paul A. Funk, 2000

A comparison of cooking power curves for the same cooker at two different times and locations.



ASAE Standard S-580.1

Experimental sample

January 15, 2020, Plantel del Valle UACM

m_{H_2O} = 7 kg in 2 trays; 3,5 kg each

	Hour	G_s (W/m^2)	T_{amb} (°C)	T_{H_2O} 1 (°C)	T_{H_2O} 2 (°C)	$T_{H_2O} - T_{amb}$ (°C)	Adjusted Power (W)
1	10:20	**518,6**	19	20	20	1	197,62
2	10:40	**584,3**	20	30	23	6,5	233,86
3	11:00	**631,6**	21	40	28	13	214,72
4	11:20	**696,8**	21	51	36	22,5	245,19
5	11:40	**699,7**	23	61	45	30	244,12
6	12:00	**752,8**	23	71	56	40,5	227,01
7	12:20	**736,0**	24	80	69	**50,5**	**232,44**
8	12:40	**733,3**	24	88	82	**61**	233,62
9	13:00	**733,6**	25	**95**	**93**	**69**	117,21

Conclusions

Tolokatsin solar ovens have almost 25 years of successful operation

They have cooked dozens of foods with very different recipes, including bread, beans, cakes, rice, pasta, lamb barbecue…

Modifications of the original design were done for other applications like sterilization of surgical materials

With the acquired experience the new Tolokatsin V, a more efficient, reliable, and easy to use design, is been presented here at CONSOLFOOD 2020

Some slight adjustments are still needed in order to optimize its performance, to be evaluated (by other colleagues) according to all solar cooking standards.