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TOWARDS PROFESSIONAL KITCHEN WITH SCHEFFLER REFLECTORS

Standard Test of a Basic Solution

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Abstract: The purpose of this study is to evaluate the performance of a new design of concentrating-type solar cooker using a Scheffler reflector. Indeed, Scheffler-type cookers seem to be promising among solar cookers because they allow to keep the parabola and the focus point at stationary positions throughout the year, and they can provide high enough power and temperature for various cooking processes.

A similar example of the cooker being studied is already in use in the “solar guinguette” of the company Le Presage. After several years of experimentation, Le Presage is now aiming to build a green building to host a restaurant using two of these cookers as the main energy source for cooking. With this idea in mind, it is important for the chefs to know the available power and to identify the potential for improvement of their current system.

The system under study harvests solar energy with an 8 m² Scheffler reflector and focuses it to a flat metal mirror. This mirror reflects the concentrated light under a cast iron slab which is used as a French cooktop by the chef. In addition, the system is equipped with an automatic sun tracker. The test took place in Marseille (5.4374°, 43.3449°), France, on 17 December 2021, between 11:54 and 14:11 solar time. It followed the main guidelines of the standard provided by the American Society of Agricultural and Biological Engineers (ASABE). The experimental procedure consists of heating 22 kg of water from ambient temperature to 95 °C. The water temperature and the ambient temperature are recorded each second while the direct normal irradiance is recorded each minute all along this heating phase.

The standardized power P_s is plotted against the temperature difference T_d between the water temperature and the ambient temperature. The linear regression model obtained from this data is $P_s = 968 - 6.8 \times T_d$ (W) where the determination coefficient noted r^2 is $r^2 = 0.84$. The standard cooking power for a temperature difference of 50 °C is 628 W.

The results reveal that the standard power is quite small for such a large system. This observation shows that there is a high potential for improvement although some professional cookers are already using it such as in the restaurant Le Présage. The results also raise questions about the standard procedure, in particular the quantity of water that should be used with respect to the parabola size, the number of pots and the estimate of the heat stored/released by an internal heat storage.

Keywords: standard test, Scheffler reflector, solar cooker design

Introduction

Standard parabolas suffer from a defect: they are not able to keep focusing on the same point all along the year without being relocated. This is a big issue for a community kitchen powered by solar energy: the kitchen cannot be moved, and neither can the parabolas, because they are often heavy and cumbersome.

In the 1980's, Wolfgang Scheffler successfully developed a design of a new reflector with the aim of giving a simple, robust, economical, and clean concentrating-type cooker to the third world. A regular setting of the inclination and curvature of his new flexible parabola has allowed him to keep focusing sunlight on the same point throughout the year, without moving the structure of the parabola [1].

The system has gradually spread itself around the world: for cooking but also for many other applications such as extracting essential oils [2]. Scheffler reflectors have been particularly successful in India where they are used to feed canteens of some schools, temples, and companies. In this kind of systems, Scheffler reflectors are used to produce steam which is transmitted to the kitchen through pipes [3, 4].

Although the Scheffler reflector has been largely studied, its combination with a secondary reflector and a cooktop has not. That is the interest of this work done in collaboration with the restaurant Le Présage.

The project of the company Le Présage is to open a restaurant which is innovative in many ways, one of which is to use solar energy as the main energy source for the kitchen. The photos in Figure 1 show their current cooker.

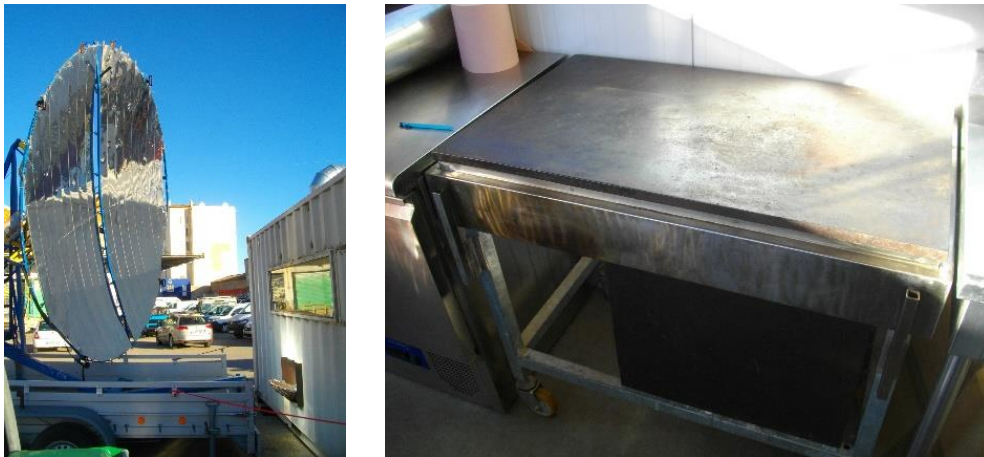


Figure 1: Photographs of the Scheffler-type cooker of the restaurant Le Présage.

The main reflector focuses the sunlight on the secondary reflector which reflects it under a simple cast iron slab, used by the chefs as a French cooktop. Unlike a plancha, a French cooktop is used with pots and pans, and its surface temperature is not homogeneous. In restaurants, chefs are used to handle it: they grill their vegetables and meat in the middle and let their sauces simmer on the side.

The main objective of Le Présage is to serve about 50 customers every lunchtime and some evenings, all along the year. To do this, they need to have a well working solar French cooktop. Its temperature must range from approximately 400 °C on the middle, to 100 °C at the edges. Moreover, it must be able to provide a thermal power greater than 1 kW and must be usable during opening hours. Finally, the solar cooktop must be installed inside the building.

The members of Le Présage have also set themselves the additional constraint of maintaining the original “low-tech” spirit of the project. They want to build something that is: useful, accessible and above all, sustainable [5]. Here, the word “accessible” is used in the sense that people should be able to understand, build and repair the system with common materials and technics.

The goal of the present work was to perform a first standard test in order to assess the global performance of the cooking system. Methods and results are described in the following sections.

Methodology

In the context of this study, an experimental bench similar to Le Présage’s cooker has been built. It consists of an 8 m² Scheffler reflector equipped with an automatic sun-tracking system, a flat secondary reflector, a cast-iron slab, and a 30 L cooking pot.



Figure 2: Picture of the test-bench.

The system has been tested with a flat secondary mirror, instead of a curved one, because it is easier to find and therefore closer to a “low-tech” approach. It is important to note that the aim is to obtain an initial estimate of the power supplied by the cooker before making any improvements.

In order to situate this system in relation to the literature, the main guidelines of the test protocol defined by the ASABE standard [6] were followed. The experiment took place in Marseille (lon. 5.4374 °, lat. 43.3449 °, alt. 120 m), on 17 December 2021. The day was perfectly clear and sunny. The intercept area ($A_{int} = 6.9 \text{ m}^2$) and the standard load ($m_s = 48.2 \text{ kg}$) were

calculated with the average elevation angle of the sun ($\theta = 21.7^\circ$) and the current inclination angle of the dish to horizontal ($\alpha = 81.0^\circ$). As the amount of water was too large for the pot, we arbitrarily chose to use a mass m of 22 kg of water instead. As specified by the standard, the ambient temperature and the water temperature were measured. The sensors were thermocouples type K and the acquisition frequency was 1 Hz.

In traditional box cookers, most of the captured power is transferred to the water. In the case studied, the cooktop acts as an internal heat storage: a part of the power captured by the system can be absorbed by the plate and released later. As there is no phase change in the slab, the heat is stored only in sensible form. Thus, when the cooktop stores energy, its temperature rises. For this reason, seven sensors have been placed on the cooktop to measure its surface temperature. This makes it possible to consider the energy stored or released by the cast iron slab. Ideally, the cooktop should have a constant temperature throughout the experiment: this would mean that all the power is transferred to the water.

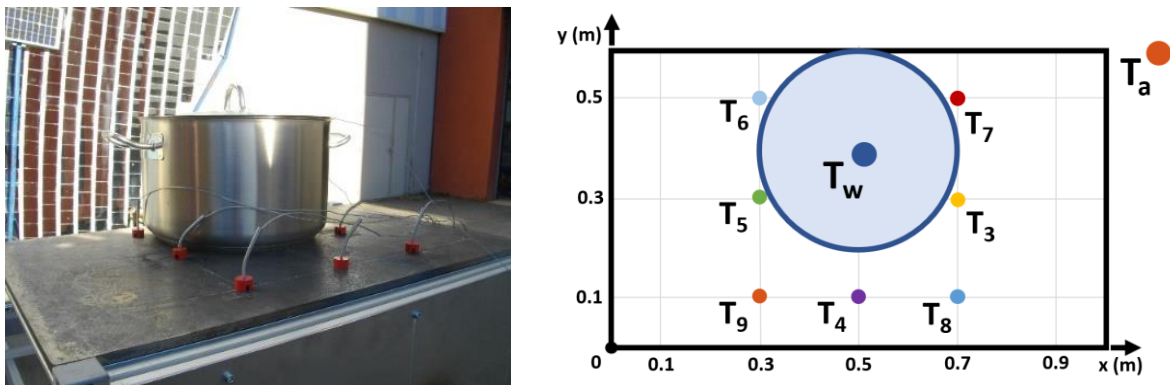


Figure 3: Locations of sensors on a picture (left) and on a top view diagram (right).

The direct normal irradiance I was measured by a weather station located 40 metres away on the roof of a nearby building.

Results

The Scheffler reflector was oriented towards the sun from 11:21 to 14:10 solar time. In Figure 4, we can see that the bold blue curve, representing the water temperature, rises smoothly from 20°C to 95°C , whereas the red bold curve, representing the air temperature, remains around 16°C with a small noise. The thin lines curves represent the temperature of the cooktop. The peak observed on the thin red and yellow curves is due to an untimely stop of the sun tracking system. This 5 min stop led to a small shift of the sunspot under the cooktop from the middle to the right (Figure 3). Fortunately, the stop was short, and the rest of the system was little affected.

To reduce the influence of the heat storage in the cooktop on the results, we have chosen to calculate the standard power only over the time interval delimited by the black lines (Figure 4). Over this period, the average ambient temperature $\overline{T_a}$ was 16°C . This is slightly below the range $[20; 35]^\circ\text{C}$ indicated by the standard. The irradiance I has varied from 700 W/m^2 to 813 W/m^2 , whereas its average \overline{I} was 794 W/m^2 , value which is inside the range $[450; 1100]\text{ W/m}^2$ of the standard.

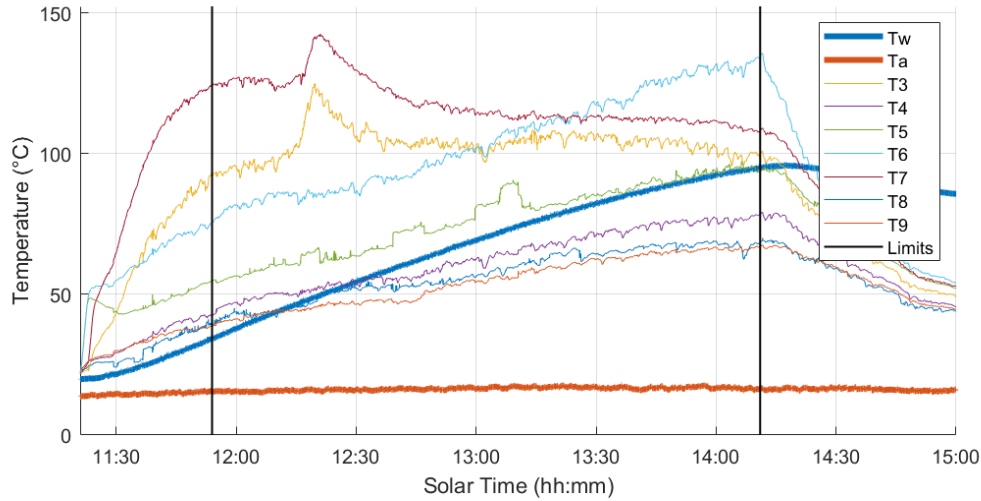


Figure 4: Evolution of the temperature of each sensor according to solar time.

The standard power P_s was calculated according to the standard

$$P_s = m \cdot c_p \cdot \frac{(T_w(t + \Delta t) - T_w(t))}{\Delta t} \cdot \frac{DNI_s}{DNI(t + \Delta t)}$$

with m the mass of water, c_p the heat capacity of water, $T_w(t + \Delta t)$ the temperature of water at time $t + \Delta t$, $T_w(t)$ the temperature at time t , Δt the acquisition time step, DNI_s the standard direct normal irradiance and $DNI(t + \Delta t)$ the direct normal irradiance at time $(t + \Delta t)$.

The standard power is then plotted against the temperature difference $T_d = T_w - T_a$ between the water and the air. The determination coefficient, noted as r^2 , is obtained with the linear regression. Here, this coefficient qualifies the proportion of the variation of the standard power predictable from the temperature difference. The determination coefficient tends towards 1 if the prediction is perfect, and towards 0 if the prediction is not possible at all.

As requested by the standard, the linear regression model describing the standard power evolution according to the temperature difference is

$$P_s = 968 - 6.8 \times T_d \text{ (W) with } r^2 = 0.84.$$

This corresponds to the red line on the Figure 5.

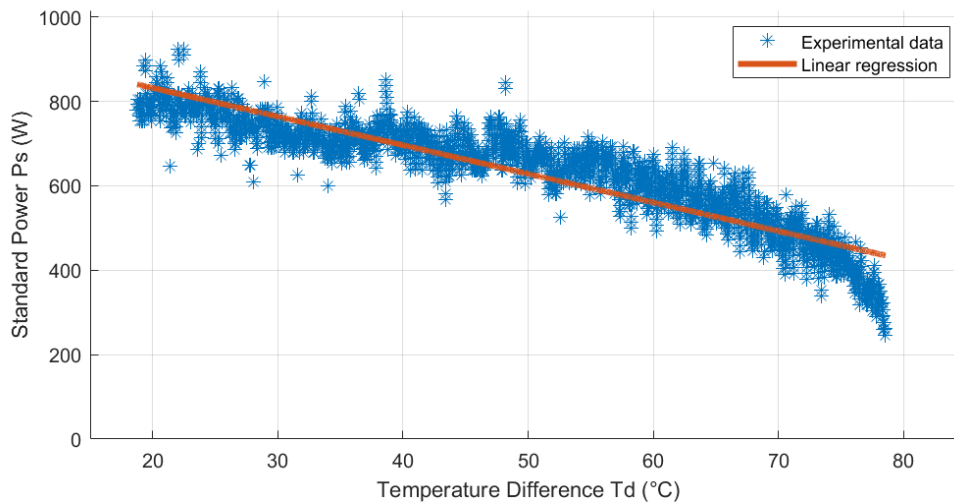


Figure 5: Experimental data (blue points) and regression model (red line) describing the standard power evolution according to temperature difference.

The experimental points clearly show a trend with a significant dispersion around the trend line. This is quantified by r^2 , whose value is just above the limit defined by the standard ($r_{\min}^2 = 0.75$). Three explanations can be given. First of all, the observed phenomenon can only be considered linear if the temperature difference remains small. However, the ambient temperature was low, which implies a significant temperature difference when the water reaches 95 °C. And indeed, the experimental points drop when the temperature difference exceeds 75 °C. This illustrates why the standard recommends an ambient temperature of over 20 °C: it limits the temperature difference to 75 °C. Secondly, the temperatures were recorded each second and the standard power was calculated over each interval. Over such a small-time interval, the random error and resolution of the temperature sensors have a major impact on the results: they cause large variations in the power values. So, we had to smooth the measurements using a centred sliding average over a window of 601 s. However, increasing the resolution and decreasing the random error on the temperature measurement would probably improve the result considerably. Lastly, despite its short duration, the shutdown of the sun-tracking system could explain the small drop between 25 °C and 35 °C and could have an impact on the linear regression model.

Nevertheless, none of these defects are prohibitive, and the standard power found for a temperature difference of 50 °C is 628 W.

Discussion

The reflector aperture was approximately 6.9 m², associated with a standard irradiance of 700 W/m². So, the standardized solar power collected by the main reflector was about 4.8 kW. At the same time, the equation shows that the standard power supplied by the cooker goes from almost 1 kW when the content of the pot is at ambient temperature, to 500 W when the temperature difference increases to 70 °C. This implies that most of the collected energy never reaches the pot.

This phenomenon can be explained as follow. First, the Scheffler reflector is made of numerous small mirrors fixed between rails and the area covered by these small rails could count for 25 % of the surface of the dish. Then there are optical losses due to misalignment of these small mirrors, and some other optical losses are due to the location and size of the flat secondary mirror. Lastly, the French cooktop, as it is in this experiment, is intrinsically anti-thermodynamic since it loses energy on all its surface.

Sources of error have also been identified. The uncertainty on the temperature difference is plus or minus 3.5 °C. A calibration of the sensors could reduce this uncertainty. As this work is still in progress, the wind speed was not measured, and the results relate to only one experiment. Moreover, the lid of the pot should be sealed to neglect evaporated water compared to the total mass of water.

However, some elements of the standard raise questions. Firstly, with 7 kilograms of water per square meter of aperture, the test should have been carried out with nearly 50 kg of water. Whereas the test would work well with box-type cookers, it could become time-consuming, if not impossible, with concentrating-type cookers, as their heat losses are much greater. A smaller quantity of water could be defined for testing poorly insulated cookers.

Secondly, the standard states that the cooker should be tested under conditions close to the conditions of use. But the way to use a French cooktop varies from one restaurant to another, thus the “normal conditions of use” give only a few information on the utensils to use. By covering the whole cooking top with several pots instead of one, losses would be reduced and more energy would be collected [7].

Finally, it raises the question of the preheating procedure of the cooker that should be included in the standard: should the test start with a receiver at the ambient temperature, or should the slab be in a steady-state regime before putting the pot on the top of it?

Conclusion

In this work, a cooker similar to the one used by the restaurant Le Présage and consisting of a Scheffler-type reflector, a flat secondary reflector and a cast-iron cooking top, was tested according to the ASABE's standard. The test took place in Marseille, on 17 December 2021 with an average DNI of 794 W/m² and an average temperature of 16 °C. For an aperture of 6.9 m² and a mass of 22 kg of water, a standard power of 628 W has been found. This relatively low value can be explained by the surface of the rails, which is not reflective, by optical losses and by thermal losses. This test also brought questions on the quantity of water, on the preheating and on the number of pots involved by the standard.

Perspectives

As perspective, we need first to complete and enrich the present work, looking for answers to the previous questions. Then, two main ideas emerge.

The first one is to look for ways to improve the system. This means that optical losses have to be reduced and the problem of combining the flat secondary reflector with the Scheffler reflector must be resolved. To this end, non-imaging optics could be useful. It also means that thermal losses should be reduced. Some ideas like adding a window, using selective paint, or

focusing the light on a smaller area, would reduce losses on the underside. For the top, it is more complicated since we need to keep an interface compatible with the kitchen but using a low-emissivity finish could reduce radiation losses.

The second idea is to improve the instrumentation. Thermography measures with inverse methods could help a lot. We have already worked on a simplified case [8] which gives encouraging results and we plan now to implement it on our test bench.

Declaration of Interest

Guillet's PhD thesis is 90 % financed by the Region Provence-Alpes-Côte d'Azur (a French public body) and 10 % by the restaurant Le Présage, as part of the "Emplois Jeunes Doctorants" scheme. Thus, the authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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