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Solar Cooking Assessment: Efficiency and Feasibility using a Parabolic Solar Reflector in the Municipality of San Francisco de Yojoa, Cortés, Honduras

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Abstract– This study focuses on the implementation and construction of a prototype solar stove with the objective of evaluating its viability in the rural area of San Francisco de Yojoa, where firewood predominates as the main source of energy for cooking. The prototype has a reflective area of 1.27 m2 that incorporates mirror fragments and maintains temperatures above 180 °C from 8 am to 3 pm, providing a significant window of solar resource utilization on a daily basis. Compared to conventional gas and electric stoves, the solar stove achieves temperatures ranging from 40 to 92.5 °C, with a maximum power output of 444.74 W at midday. Thermal power experiments corroborate its competitiveness. The focal point, covering 530.93 cm2, concentrates 33% at 186 °C, decreasing to 85.6 °C in regions farther away from the center. From an economic perspective, the initial investment of $206.08 is recovered in 1 year and 8 months, which represents a saving compared to the monthly consumption of LPG gas ($10.15 per cylinder) for a family of 5 members.

Keywords-- List at most 5 key index terms here.

I. INTRODUCTION

This study addresses the implementation and construction of a solar cooker prototype to evaluate its viability in the rural area of San Francisco de Yojoa, where firewood is the main source of energy for cooking. Developing countries focus on energy consumption of 36% of their global consumption [1], which is a considerable percentage and requires the attention of researchers and entities in charge of regulating and applying energy [2].

New technologies that provide a solution to this issue [3]. The negative impact of deforestation is highlighted in developing countries, such as Honduras, where approximately 11 million cubic meters of firewood are burned per year [4].

The proposal for a solar cooker seeks to harness solar energy and reduce the environmental and health effects associated with burning firewood. The study methodology is based on Research and Development (R&D), with an experimental approach that includes the design and construction of a solar cooker prototype.

The range of temperatures reached in the receiver will be demonstrated, averages that were taken during 30-minute intervals that, starting in the early hours of the morning, high temperatures will be observed until hours close to sunset, this allows a time range in which it can be done. use of the kitchen covering important hours for the preparation of breakfast and lunch.

Throughout the day the solar resource decreases due to the movement of the Earth, which directly affects the energy that can be obtained for the solar cooker, which is why through solar tracking it has been possible to keep the focal point concentrated in an only point where its temperature varies depending on how far it is from the center, the maximum being 186 (°C). Knowing this information is important, since gas and electric stoves have selectors that allow the flow of energy and thus control the power, in the solar cooker receiver it can be controlled by the action of moving the container. a little to the center or to the edges.

As an energy experiment and in order to calculate the thermal power provided by the solar cooker, one liter of water was used and for 10 minutes it was exposed to the heat of the receiver in order to observe and measure the final added temperature. This experiment was done in the same way with gas and electric stoves, in this case to compare the temperatures reached.

The process includes identification of requirements, collection of solar irradiation data, analysis of expected results, prototype design and validation. The study also includes an economic analysis, where the monthly cost of using an LPG gas cylinder is compared with the initial investment of the solar cooker. It is highlighted that the investment is recovered in 1 year and 8 months, presenting significant savings from the perspective of a gas stove.

II. CONTEXT

San Francisco de Yojoa is a rural community where its largest source of energy for cooking food comes from firewood and LPG gas, as is the case in Honduras by 2019, 82% of the energy consumed for the preparation of food came from firewood [5], causing deforestation and an increase in greenhouse gases, it is necessary to search for and implement friendlier alternative energies.

A. Background Research

According to data from Solar Cookers International (SCI), there are around 4 million solar cookers installed in the world, directly supporting 14.3 million people who take advantage of solar energy and avoiding the emission of 5.8 million tons of (CO_2) per year, in the Central American region there is no registered solar cooker with a parabolic reflector and the existing ones are all box type.

Solar cookers are a key solution in regions with limited access to electricity and gas [6]. Countries such as India and China take advantage of sunlight as a main source of energy, efficiently channeling it towards thermal or electrical purposes [7]. Although the exact origin of studies on solar cookers is uncertain, the Swiss-French physicist Horace de Saussure documented in the 18th century a prototype with mirrors that managed to reach temperatures of 88 (°C), marking a significant advance for the time.

The depletion of resources such as firewood and oil have motivated inventors and researchers to look for alternatives [8]. The constant increase in the consumption of oil and firewood has generated crises throughout history, making solar cookers an alternative to reduce dependence on conventional energy sources [9].

Fig. 1 shows the development through the simplified history of solar cookers, from its beginnings to the current panorama around the world.

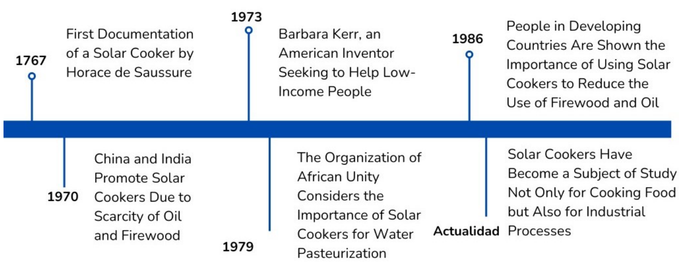

Fig. 1 Solar Cooker History.

B. *Reflective Material*

In developed countries, such as China and India, significant research has been carried out to optimize the utilization of the solar resource. Interest in areas with greater sun exposure stands out. Among the various solar cookers developed, the Scheffler model stands out for its focus on the use of local materials [10].

The main challenge with solar cookers has been to maximize solar collection throughout the day. However, the implementation of tracking systems [11] [12], especially in parabolic reflectors is necessary and important use reflective materials that help with the solar concentration [13]. The table 1 was created with the data of L. Saravia and H. Suárez; R. D. Echazú et al, where shows the different reflectance of some materials used to build solar cookers [14] [15].

In the case of aluminum foil and white PVC, they are used and tested for box-type solar cookers, in which the materials are less exposed to gusts of wind or objects that affect the physical integrity of the reflective material. They are also used for very small prototypes and more for demonstrations.

TABLE I
REFLECTIVE MATERIALS USED IN OTHERS RESEARCH

Item	Reflective Materials	
	Material	Reflectance
1	Stainless Steel.	0.63
2	Aluminum Foil.	0.75
3	Aluminum.	0.9
4	2 mm mirror thickness.	0.95
5	3 mm mirror thickness.	0.93
6	4 mm mirror thickness.	0.92
7	Galvanized Steel.	0.71
8	White PVC.	0.85

C. *Parabolic Solar Reflector*

For a solar cooker with a parabolic reflector, the advantage is that it captures more solar energy, which is directly proportional to its area. A larger solar reflector can concentrate more energy in the solar receiver. It must be considered that any type of system will be found. losses; The types of losses that can be found are convection and radiation losses [16].

Through previous research, it was decided to use a solar cooker with a parabolic reflector because its temperatures are higher, and it has greater thermal efficiency [17].

A solar cooker is a thermal device whose main function is to concentrate the rays of sunlight through a solar collector or reflector that focuses the sunlight on a focal point, where the light energy of the sun is converted into thermal energy capable of generating energy enough for cooking food [6].

III. METHODOLOGY

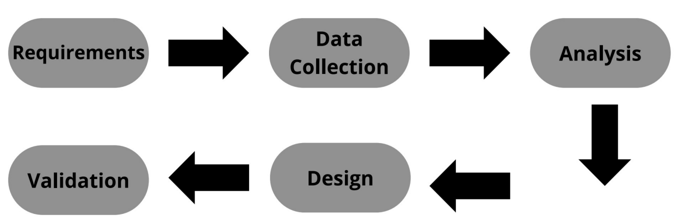

Fig. 2 Metodology (R&D).

This chapter will elucidate the methodology employed during this research.

A. *Process Summary*

In this research, a Development and Research (R&D) methodology will be used, which includes work in a systematic way to increase knowledge and will consist of a more experimental development due to the manufacture of a prototype of a solar cooker that will be the object of study that will provide important data for this research, it is worth mentioning that it will be a guideline. The fig. 2 shows its stages:

B. Requirements and Data Collection

The materials for the construction of the kitchen are provided by a hardware store in the community of San Francisco de Yojoa in Honduras, which reduces shipping costs or an increase in the value for the mobilization.

Solar irradiance data must be taken at the location of the solar prototype throughout a day to have an estimate of the solar energy that can be used, make a comparison of the temperature increase in electric or gas stoves, the temperature it can reach and how it is affected by changes in the selector.

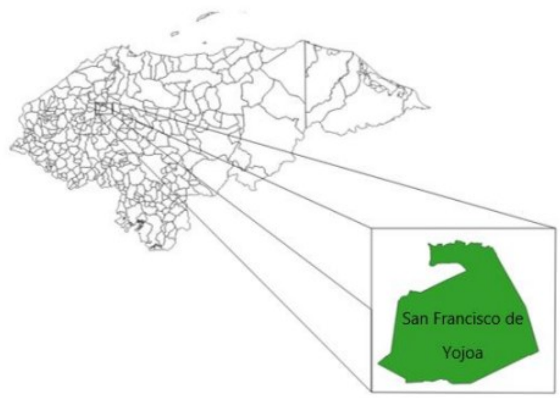

Fig.3. San Francisco de Yojoa, Honduras.

To determine the energy that the solar cooker can produce, a mathematical model that already exists will be used to evaluate the heat that is added to a liter of water to reach its boiling point and also through irradiance and how this affects the production of thermal energy, constant observation is needed to monitor the increase in temperature since for the analysis of added heat the change in temperature is extremely important. One liter of water will be the fluid subjected to the experiment and its behavior will be analyzed.

C. Design and Validation

For the manufacture of the solar cooker with a parabolic reflector, a free-use construction manual is used that can be found on the Solare-Brueke.org website, which is responsible for promoting solar energy projects for rural development and has the necessary guidelines for the construction of solar cookers, it is also sought to adapt a design with local materials.

For the construction of the prototype, the list of materials was initially made according to the manual and had to be adapted to local materials because the measurements were in the metric system and in Honduras the English system is used in the area of welding or metal structures and for Certain pieces of the prototype require short segments of material and hardware stores sell it in batches, which makes it more expensive to make a single prototype.

Next, the purchase of materials was made and the construction of the base of the solar cooker and the base of the solar reflector and their respective assembly continued.

The size of the reflector has an approximate area of 1.30 (m^2). The parabolic reflector is made of square fragments of 10 (cm) for each side, the reason is to follow the curved surface of the parabola design. The receiver has a height of 1.25 (m), built with 4 metal angle segments and with 4 supports on its lower plate which gives stability to the structure, it has the dimensions of 25.4 (cm) x 25.4 (cm) in the distribution area with a thickness of 2 (mm) made of brass, in the same way the same sheet was used on the sides and a mirror was incorporated internally with an inclination of 45 (°) so that all the sunlight reflects perpendicularly to the sheet of brass as shown in fig. 4.

Fig.4. Prototype of Solar Cooker

It is of utmost importance that the solar reflector can follow the direction of the sun and also keep the focal point firm. For this purpose, an existing structure was used that consists of a screw coupling and a thick steel sheet that covers the tube. galvanized steel pipe; By simply resting the tube, the reflector allows it to move in a circular manner as a type of filming. In the case of the Tilt, a bolt was used that is fixed to the parabolic dish and that crosses the steel sheet and through two nuts allows its movement and this moves the solar reflector.

By using a rectangular base that supports the entire weight of the reflector and keeps it firm, it was built with two metal angles measuring 104 centimeters long by 92.5 centimeters wide in its center where a 2.5-inch diameter galvanized steel tube was placed. on which the entire structure rests in a parabolic shape.

IV. Results and Discussion

This chapter will address the budget for the development of the prototype, the data provided by the solar cooker prototype, data such as the temperature in the receiver, temperature changes in a liter of water exposed to the receiver in 10 (min) and a comparison with conventional stoves.

A. Average thermal power

The receiver of the solar cooker is the one that directly receives the concentrated sunlight. It is built of steel and has an area of 645.16 (cm^2) and in its center is where the highest temperatures are concentrated and then distributed around it.

They took measurements every half hour for 5 days. Fig. 4 shows that at 7:00 a.m. temperatures of 184.5 (°C) are already reached and it remains constant for a long time until falling around 9:00 a.m.

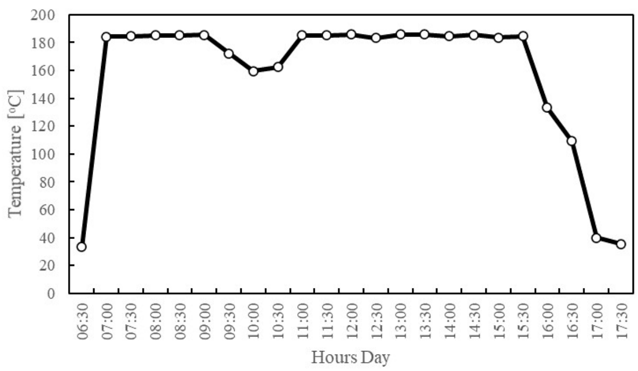

Fig.5. Receiver Temperature

The average power in the place is shown in fig. 6 the graph of the average power recorded over the 5 days is shown, having a start at 7:00 a.m. and an end at 4:00 p.m., giving a considerable range of use being the maximum value of 444.74 (W) for twelve noon.

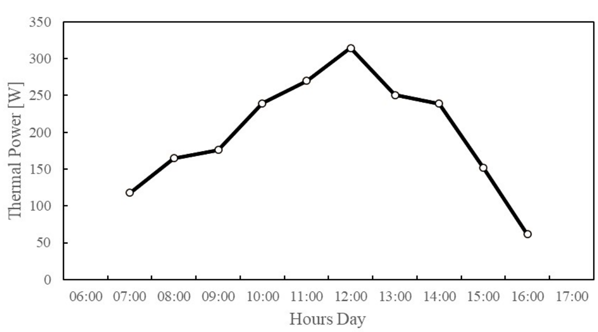

Fig.6. Average Thermal Power

B. Temperatures at the focal point

There is a solar concentration in an area of 530.98 (cm^2) in which the temperature of the focus varies across different areas.

The highest percentage of area is where the high or maximum temperature recorded in the measurements is located and this map helps to use it for temperature control, the more the center of the area, the higher the temperature and the less time will be required to cook some food or the opposite case, if you intend not to burn or give more preparation time, you can move away from the central area.

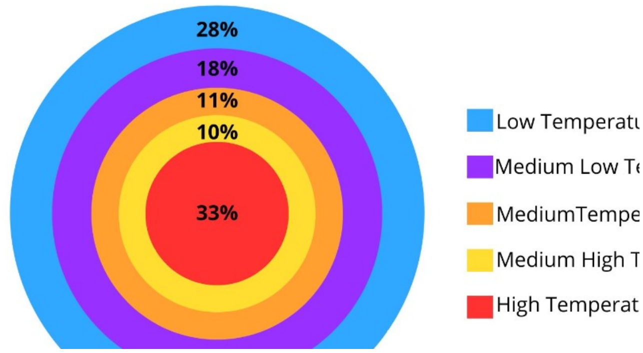

Fig.7. Temperature at the Focal Point

C. Temperatures reached in a liter of water

For this research, it was tested how much temperature could be added to a liter of water for 10 minutes. The tests were done repetitively for 5 days during a time from 7:00 a.m. to 4:00 p.m. The solar resource during those hours is more considerable.

TABLE II
Maximum Solar Cooker Temperatures

Hora	T_o (°C)	T_f (°C)
06:00		
07:00	31.4	42.14
08:00	31.3	53.36
09:00	31.7	55.84
10:00	35.73	78.61
11:00	29.87	73
12:00	28.7	92.5
13:00	31.6	79.1
14:00	28.8	70.8
15:00	28.87	46.45
16:00	29.3	35.4
17:00		

In fig. 8 there are 3 graphs, the minimum temperature that could be added to the water, the average and the maximum, this to have an overview with the day being the one that provided lower temperatures added and day 5 higher temperatures; the average is based on the 5-day data.

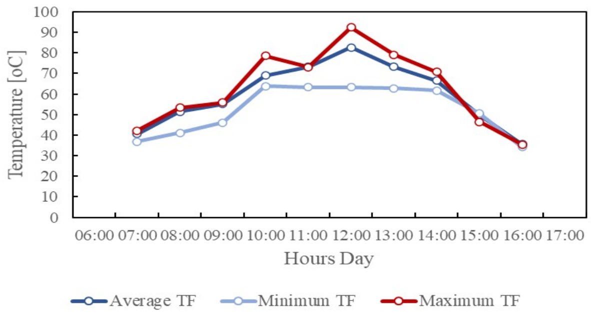

Fig.8. Average Aggregate Temperature

The maximum temperature added to the water recorded throughout the entire experiment has been 92.5 (°C) with an initial water temperature of 28.7 (°C), and the minimum temperatures are always found at the extremes in this case at 7 a.m. and 4 p.m., being hours that the solar cooker cannot be used to prepare food.

D. Comparison of Solar Cooker, Gas and Electric Stove

The comparison between conventional stoves with the prototype of a solar cooker is important, because with this the cooking speeds can be determined, in this case a liter of water was exposed to different points of the selector of an electric stove in the points 3, 6 and Hi; In the case of the gas stove, it was set to low, medium and high flame.

In fig. 9, a comparison between the solar cooker and the electric stove shows that the operate in a similar range from 45 (°C) to 80 (°C), where the electric stove at its maximum power raises the temperature of water up to 80.3 (°C) and the solar cooker achieved a maximum of up to 92.5 (°C).

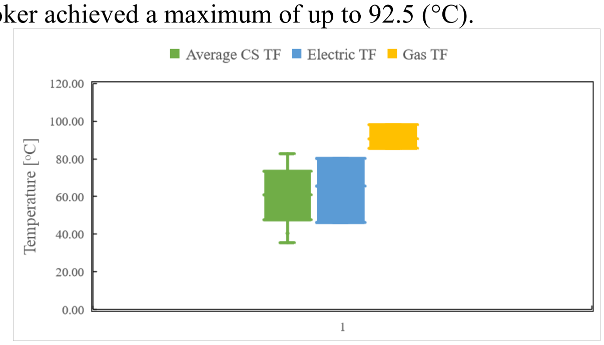

Fig.9 Comparison Between Solar Cooker, Gas Stove and Electric

If you focus on the maximum temperature data of the solar cooker, it is equal to the gas stove in the low flame and the medium flame, since in the low flame the liter of water reached 85.4 (°C); In medium flame the water reached a temperature of 90.4 (°C). In the following tables it can be seen in more detail:

TABLE III
ELECTRIC STOVE TEMPERATURE

Position	T_o (°C)	T_f (°C)
Selector 3	28.8	46.1
Selector 6	29.3	65.4
Selector Hi	29.1	80.3

TABLE IV
GAS STOVE TEMPERATURE

Position	T_o (°C)	T_f (°C)
Low Flame	28.2	85.4
Half Flame	35.3	90.4
High Flame	35.3	98

So, it can be demonstrated that a solar cooker operates in a temperature range similar to a gas stove and an electric stove, for which considering that the last two mentioned require an energy source that must be paid monetarily by the user, it puts into question advantage to solar cooking. And these temperatures can now be ensured for food preparation.

E. Solar Cocker Efficiency

The calculation of the efficiency was carried out by means of the output thermal power dividing it by the power input, data that was obtained from the irradiance. It should be noted that this calculated efficiency is with respect to the rate of energy added to one liter of water in 10 minutes.

In fig. 10 shows the average efficiency over the 5 days and hourly and in which it can be seen that in this case the common bell shape is not followed, but throughout the day said efficiency decreases.

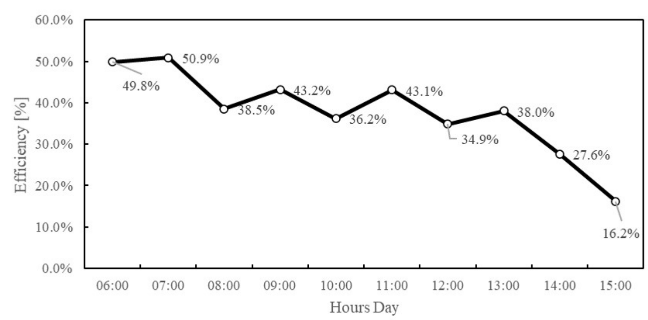

Fig.10 Average Thermal Efficiency

With the average thermal efficiency, it can be observed that the efficiency decreases as the day goes by. This is due to the fact that initially, when the receiver was placed with the focal point of the solar cooker, it was found in an optimal position for which it favored what was the moment of concentration or use. Greater than that occurred in an instant, then, as the day progressed. The rotation of the Earth what it formed was that this optimal point was decreasing each time, decreasing until it reached the afternoon.

V. CONCLUSIONS

A prototype of a solar cooker with a parabolic reflector was manufactured with mirror fragments measuring 4 inches wide by 4 inches long, having a total available area of 1.27 (m^2) with a manual and tilt solar tracking system to maintain the focal point at 1.25 meters high and at a horizontal distance of 84 centimeters from the support of the solar reflector, which proved to be a viable solution for food preparation, reaching temperatures similar to those of an electric and a gas stove, having a maximum efficiency of 60% and with hourly coverage from 7 am to 4 pm. It is also concluded:

For the construction of a solar cooker in the Municipality of San Francisco de Yojoa, with local materials, an estimate of $ 205.95 is needed where the material with the highest cost is obtained from mirror fragments that are used as reflective material.

A prototype of a solar cooker with a parabolic reflector was built where its reflective material for the concentration of sunlight was the mirror with a thickness of 3 (mm) and dimensions of 4 inches wide by 4 inches long, this size for that could follow the curved shape of the parabolic dish.

In the coordinates where the kitchen prototype was implemented with latitude 15.014959° and altitude -87.963189°, minimum solar irradiance data of 16 (W/m^2) was recorded for 6 in the morning; for midday a maximum irradiance of 739 (W/m^2); and for the afternoon minimum data of 31 (W/m^2) for 5 p.m.

The focal point has an area of 530.93 (cm^2) of which 33% of its area located in the center has a high temperature of around 186 (°C); 39% of the area from 7.5 (cm) from the center to 11 (cm) from it has a temperature range that goes from 145.6 (°C) to 100.1 (°C), and 28% of the area has a temperature of 85.6 (°C).

The temperatures reached in a liter of water in 10 minutes in a solar cooker range from 40 (°C) to 92.5 (°C); for an electric stove it is 46.1 (°C) to 80.3 (°C), and for a gas stove it is 85.4 (°C) to 98 (°C). Where the gas stove adds a higher final temperature to the water, however, the temperature ranges of the solar cooker remain higher than the electric stove and somewhat close to the gas stove (maximum values).

The return on investment of a solar cooker with a parabolic reflector is obtained after one year and 8 months of use, considering that for the municipality of San Francisco de Yojoa currently the 25 pounds cylinder of domestic LPG gas has a price of $ 10.15.

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