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Characterization of a parabolic solar cooker made from recycled materials

Caracterización de una cocina solar parabólica elaborada con materiales reciclados

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Abstract

Currently, in some communities, firewood is still used to cook or conserve heat; this action generates great problems for health and the environment, one of them is the great risk of fires and/or asphyxiation due to smoke inhalation, another is the deforestation that is carried out to obtain firewood and, finally, the generation of methane, ozone precursors and carbon dioxide when burning any of these. This work proposes the use of a parabolic solar stove, made from recycled materials, such as cardboard, self-adhesive contact paper as reflective material, Masking tape®, which allows reducing manufacturing costs, helping low-income families and being environmentally friendly. The results obtained with respect to the time required for cooking various foods, the temperatures reached throughout the process, as well as information on meteorological variables obtained from the IQUERETA29 meteorological station located at the Technological University of San Juan del Río and administered by the Querétaro State Water Commission are shown.

Solar stove, Satellite dish, Recycled materials, Cardboard

Resumen

Actualmente en algunas comunidades se sigue haciendo uso de la leña o boñiga para cocinar o conservar el calor, esta acción genera grandes problemáticas para la salud y el medio ambiente, una de ellas es el gran riesgo de incendios y/o asfixia por inhalación de humo, otra es la deforestación que se lleva a cabo para conseguir leña y, por último, la generación de metano, precursores de ozono y dióxido de carbono al quemar cualquiera de estos. En el presente trabajo se propone el uso de una estufa solar del tipo parabólica, elaborada a base de materiales reciclados, tales como cartón, papel contact autoadherible como material reflejante, cinta Masking tape®, lo que permite reducir los costos fabricación, ayudando a familias de escasos recursos y siendo amigables con el medio ambiente. Se muestran los resultados obtenidos con respecto al tiempo necesario para la cocción de diversos alimentos, las temperaturas alcanzadas a lo largo del proceso, así como información de las variables meteorológicas obtenidas de la estación meteorológica IQUERETA29 ubicada en la Universidad Tecnológica de San Juan del Río y administrada por la Comisión Estatal de Aguas Querétaro.

Estufa solar, Parabólica, Materiales reciclados, Cartón

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1. Introduction

The use of solar energy throughout history has been reflected in different cultures and in different ways, the first reference we have about this is in the year 400 BC where the Greeks began to build their houses with reference to the angles of the sun. The Roman Empire in turn began to implement in their homes windows made of glass, to thus take advantage of the incoming sunlight. Archimedes, an Italian physicist, developed a military invention that consisted of setting fire to enemy fleets using a piece of glass to concentrate solar radiation on a single point. But it was not until 1767 when the botanist Horace-Bénédict de Saussure (1740-1799) invented for the first time a black solar stove, where he achieved the cooking of fruit, reaching approximately 88ºC, which consisted of two wooden boxes isolated from each other with glass covers.

In 1792 Lavoisier built his own solar oven consisting of two large lenses that concentrated solar radiation in a focus, this radiation was used to melt metals.

By 1830 astronomer John Herschel used a solar stove, which he designed himself, during a trip to Africa. Astronomer Charles Abbot built a concentrating mirror with which he was able to reach a temperature of 200 °C, heating oil, thus retaining some of the heat to be able to cook some food even when the sun was not shining. Many organizations are currently working to improve the efficiency of solar stoves. Some of these organizations are the German Agency for Technical Cooperation (Deutsche Gesellschaft für Technische Zusammenarbeit, GTZ) and Solar Cookers International (Solar Cookers International) and others in Europe and North America.

Society has been looking for different ways to satisfy food needs, looking for the easiest and cheapest way to be able to eat those foods that are raw, and for this task it has been looking for ways to be efficient in cooking food. There are several ways to perform this task, among these ways we can find: the wood stove, gas, gasoline and solar stove.

Firewood

The use of firewood is a great benefit, but also a big problem, since firewood is very cheap, but it is very difficult to ignite when it is wet, it depends on the availability in the environment, it generates a lot of smoke and there may be a risk of contamination with the ashes, although it allows reaching high temperatures ideal for cooking, it allows baking, and the cooking speed is very good.

Gasoline

Non-renewable fossil fuel, explosive product with an easy fire risk. Dangerous for people and children if ingested, the wind intervenes a lot in the moment of its operation, it allows the control of the baking and the operation is at the desired moment.

Gas

It requires to be transported, it is a non-renewable fuel, the leakage of this type of fuel can be dangerous and even cause death, among its benefits, you can control the temperature and cooking, the use of this can be at the time required, in relation to its price, this is high.

Solar stoves

On rainy days and in winter it is very difficult to cook any food, the cooking of food takes much longer compared to traditional fuels, they are not efficient in retaining heat, which means that after cooking they can easily lose heat, the advantages of using solar stoves are the reduction of carbon monoxide emissions, the considerable saving of money since this energy is free, the easy use of the stoves without the risk of burns.

2. Types of solar stoves

The most commercial versions of solar stoves are: box, parabolic and panel, being the parabolic stove the most efficient and advanced.

Box solar stove: Its operation is based on solar energy, which is captured, accumulated, concentrated and transferred to the stove. The sun's rays hit the surfaces and in this way heat the pot. It contains an insulating material that prevents heat loss.

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Main components: Cardboard boxes, where the pot will be placed, these boxes should be smaller than each other to allow the insulating material between them.

Aluminum foil: To cover the upper lid where the heat is reflected and this will allow it to concentrate inside.

Black paint: To keep the heat inside the box.

Insulating material: Prevents heat from escaping between boxes.

Glass: Used as the lid of the pot to prevent the heat from dispersing.

The main advantages of this type of stove is that it allows cooking food in two or three hours only with solar rays, the materials for the elaboration are very easy to obtain. Although its efficiency is not so good. It is characterized because it can reach temperatures up to 150ºC, they are stable which does not cause risk for the users and can work even without the user's intervention, although they usually take a long time to heat up.

Figure 1 Box-type solar stove
Source: www.elmundo.es

Figure 2 Solar stove
Source: www.google.com

Its principle of operation is based on using optical concentration where most of the sun's rays are concentrated at the bottom of the pot, they use a reflective material to concentrate the radiation in a focal point.

Some of the main disadvantages of this type of stoves is the size, they take up a lot of space and they must be constantly oriented and because of the size is a bit difficult, the orientation of this can be confusing for people, plus the cost of this can be high for certain people, since they are mainly useful in low-income communities. The main advantage over any other type of solar stove is the high temperature it can reach. One of the main disadvantages is the high cost, due to the materials used, such as aluminum, stainless steel, eloxed aluminum, among others.

Figure 3 Parabolic solar stove, SK parabolic solar stove, Panel solar stove
Source: www.google.com

Figure 4 Parabolic solar stove
Source: www.google.com

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Figure 5 Solar panel stove
Source: www.google.com

Panel solar stove

One of the simplest and cheapest, it is based on a cardboard surface covered with reflective material to focus the sunlight. The main advantage of this type of stove is its simplicity and the materials are so cheap that it is easy to build the stove following a simple plan. The attention for this one is really reduced since it is not necessary to be orienting. Generally the presence of moderate cloudiness does not affect the operation of this stove.

The disadvantages of this type of stove are that it is usually very unstable in moderate winds, and because it is made with materials made at home, its useful life is usually very short and it does not reach high temperatures.

3. Current situation of solar stoves

At present, solar stoves have been developed and perfected to improve their use and efficiency. Favorable results have been obtained for the use of solar cookers, indicating that they could be successfully used for cooking food in areas of medium and high insolation. However, the technical deficiencies and limitations, the influence of negative climates as well as the economy, personal use, culture and many other factors make the use of this type of alternatives become unrealistic solutions. But despite these factors, studies and improvements continue to be made to promote the use and dissemination.

The use of this type of stoves can only occur when users are willing to make different changes in their way of cooking, since the use of solar stoves involves cooking outdoors, which for many users or people could become annoying in addition to the fact that only one pot is used, which for many could be inconvenient. From another perspective, it can be seen as a cooking alternative. A considerable saving of money and help for the environment, taking into account the needs of people, it can be used for specific cooking of food and use your traditional cooking method for the rest of the food.

It has been characterized a solar stove made from two evacuated tubes that are used in solar water heaters to heat water for sanitary use, which are placed on supports, inside the tube has been introduced a tray made of food grade stainless steel, which is used to place the food to be cooked which have lids made with Nylomaq, these evacuated tubes are placed on an aluminum base in parabolic form, the values of the temperature inside the tray where the food is placed, were measured using an EXTECH® multimeter and a ThermaCAM E45® camera, the kitchen has a capacity to prepare food for two people, some foods have been cooked such as; mixiote, chicken in pipian sauce, chicken fajitas, beans, steak with potatoes, bread has been baked, among others, an analysis of their behavior has been made and the effectiveness of the proposed solar stove has been evaluated. (García Carrera Diana Lupian-Ugalde Valeria, 2016).

Solar stoves use clean and affordable solar energy for cooking food, however, currently available solar stoves have some weaknesses, such as being too large to transport, low heating temperature and too long cooking time, to achieve overcome these weaknesses a portable solar stove using a curved Fresnel lens as a concentrator was designed (Yunsheng Zhao. 2018). New ideas, fabrication techniques, and higher performance designs for a box-type solar stove were proposed. A good test standard is an important tool for the market and for user acceptance of stoves. This review is formulated keeping an important feature of existing proposals: simple and available instrumentation that allows taking these tests anywhere in the world, with minimal investment and/or laboratory conditions.(Collares-Pereira, Cavacoa, & Tavaresa, 2018).

The productivity of a phase change material (PCM) solar stove was investigated using a parabolic dish collector fabricated with two concentric cylinders with internal fins and kerosene wax. The average time to reach 90°C water with and without PCM is 120 min and 90 min, respectively (Senthil, 2020).

Solar stoves were evaluated according to ASAE (American Society of Agricultural Engineers) standard S580.1. The performance of the solar stove according to ASAE S580.1, reaches a temperature of 50 °C between ambient air and water temperature of the cooking vessel was 198° C for a parabolic type stove, 65° C for a box type stove and 25° C for a panel type stove (Ebersviller & Jettera, 2020).

The continuous increase in the level of greenhouse gas (GHG) emissions and rising fuel prices are the main driving force for using various renewable energy sources. Solar energy is recognized as one of the most promising options, as it is free of charge and provides clean and environmentally friendly energy. Two identical evacuated tube solar stoves have been designed and constructed to study the influence of inserting metal wires or nanographene particles on the thermal performance of the stove. The metal wires and nanographene particles are inserted inside the vacuum tube, which is filled with the heat exchanger oil. Steel, aluminum and copper wires have been examined, and the number of wires has been varied between 5, 10 and 15. It has been found that copper wires improve the heat transfer rate compared to steel wires, aluminum wires and nanographene particles. It has also been obtained that there is a critical number of wires, i.e. 10 wires, above which the natural convection heat transfer rate decreases and this is due to increased friction which resists natural convection currents. (Abd-Elhady, Abd-Elkerim, Ahmed, Halim, & Abu-Oqual, 2020).

This article demonstrates the importance of the parabolic solar stove. The main purpose of the stove is to concentrate solar radiation and convert it into heat using different effective materials. Some essential factors were considered such as the reflector surface which should be smooth and shiny, and the control variables (load, tracking, temperature sensing) and uncontrolled variables (wind, ambient temperature) should also be considered.

Several parabolic solar stoves use efficient reflector materials such as stainless steel, aluminum foil, and Mylar tape. Multiple tests were conducted with these parabolic solar stoves. In addition, different forms of temperature were measured in this research: concentration surface temperature, vessel temperature, and water temperature.(Masum Ahmeda, et al., 2020).

The performance of a portable vacuum tube solar stove together with a stainless steel tank was investigated. The presented model is validated by comparing the analytical results with those of experiments. The effect of important climatic and design parameters on the performance of the solar stove is evaluated. The parameters studied are the absolute pressure of the vacuum envelope, the absorptivity and emissivity of the absorber coating and the solar radiation (Hosseinzadeh, et al., 2021).

The feasibility of a stand-alone solar stove with heating plate, powered by renewable photovoltaic (PV) energy. The equipment is based on the sizing, design and construction of a PV system. It consists of photovoltaic panels, DC/DC power converters, thermal resistors and a digital block for the control, supervision, acquisition and visualization of meteorological, thermal and electrical quantities of the system (lighting, PWM signals, currents, voltages, powers, efficiency), temperatures, etc.

All the results obtained clearly show remarkable performances, the thermal efficiency of the cookstove is estimated at 86%, an improvement of 59.2% compared to conventional cookstoves (Atmane, Moussaoui, Kassmi, Deblecker, Bachiri, 2021).

To meet the Sustainable Development Goals (SDGs) of the United Nations, it was proposed as a goal to work with a solar stove where a new stove design equipped with internal reflectors and a lower parabolic tracking reflector (TBPR) is proposed that can help in achieving the SDGs. The cooker performance is determined using the cooker optothermal ratio (COR) as the thermal performance parameter (TPP) and glycerin as the test load. Actual cooking tests are conducted for a family of four describing the utility of the proposed solar stove.

An economic analysis using two indicators, Levelized Cost of Heat (LCOH) and Cooking a Meal (LCCM) and there is a reduction of 44% and 18% in LCOH and LCCM respectively (Tawfik, Sagade, Palma-Behnke, El-Shal, Allah, 2021).

The box-type solar stove is an easy-to-use solar energy harvesting system suitable for domestic cooking in tropical countries. It is proposed to add aluminum on the lids of cooking vessels in a solar stove. Four cylindrical aluminum cooking vessels with different lengths of 25 mm, 35 mm and 45 mm were used to heat water. Outdoor experiments are conducted for five days for each case. For the four configurations, it is observed that the water reaches a maximum temperature of 102º C in a closed system. The maximum temperature range maintained is between 90º C and 100º C for approximately 2 to 3 h during the outdoor tests (Vengadesan & Senthil, 2021).

In this paper, the objective is to design a zero-emission cooking device with reduced cooking time and low maintenance cost compared to other conventional solar stoves. The cooking pot consists of two hollow concentric cylinders made of stainless steel. The space between the cylinders will be filled with heat transfer fluid (HTF). Copper tubes filled with phase change material (PCM) are placed diametrically in the outer cooking pot, which allows cooking in sunless hours. The heat transfer fluid from the cooking pot is connected to the vacuum tubes via hoses. This arrangement adds heat to the heat transfer fluid inside the vacuum tube and the hot fluid will rise into the cooking pot from the vacuum tube through a thermosyphon cycle and transfer heat to the cooking pot and PCM (Hebbar, Hegde, Sanketh, Sanith, & Raghavendra, 2021).

A novel solar stove based on adaptive control via an online sequential extreme learning machine (OSELM) is presented and discussed. The solar stove represents a challenging scientific design. The use of a bar plate coated with nanocoating materials helps to stimulate and control the multifaceted performance of the cooking vessels. In addition, it was noted that traditional human methods are not able to stimulate an efficient design for thermal applications because the environment cannot adapt to the variable source.

To overcome these challenges, neural network-based adaptive controls approaches were used that further consider other parameters such as smallest family, measured conjunction, huge feeding period and lower yields (Thamizharasu, et al., 2021).

Contribution(s)

Adaptation of a solar stove made of recycled materials, adding a base for the mobile pot, which allows the readjustment of the parabola towards the sun without the need to touch the pot.

Hypothesis

The placement of a base for the solar stove will allow an easier and more efficient use of the solar stove.

Objective(s)

To test the cooking of food in a parabolic solar stove made from recycled materials. To measure the temperature inside the cooker under conditions of low solar irradiation. Plot temperature, wind speed, ambient temperature and solar irradiation profiles.

4. Materials and methods

Figure 6 UTSJR solar stove
Source: Own Elaboration

Base of the solar stove

A used BF Goodrich®, All-terrain T/A tire was used as a base, the smallest radius is 0.20 m and the largest radius is 0.35 m. The width of the tire is 0.25 m, the height of the tire is 0.18 m, rim diameter is 0.406 m (16 inches).

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Figure 7 Tire used as a base
Source: Own Elaboration

POT SUPPORT

A base made of metal, circular in shape with a diameter of 0.22 m and 0.025 m wide, three supports of 0.05 m long by 0.02 m wide, so that the pot rests on them, 0.10 m below the base has as counterweight 4 metal bars of 0.03 m x 0.2 m with a mass of 0.6 kg each, were used to support the pot. To hold the support inside the stove there is a ¾ inch threaded rod, 0.4 m long with two 3/8 inch nuts and two flat washers that serve to stop the support so that it does not slip.

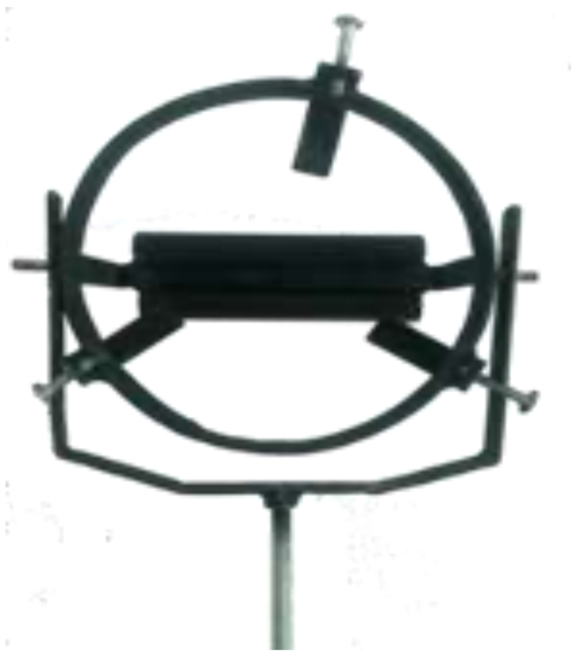

Figure 8 Pot support
Source: Own Elaboration

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POT

An ODISEA® pot is used, number 20, with the following characteristics: diameter of the base 0.20 m, 0.14 m high, thickness 59 x 10^{-3} m.

To measure the temperatures reached by the pot, 12 reference points were used, 5 in front of the pot, 5 at the back, one at the bottom and one at the bottom of the pot. The pot was painted with Truper® matte black paint.

Figure 9 ODISEA® pot
Source: Own Elaboration

Thermometer

To measure the temperature reached by the pot, an Extech® infrared thermometer is used, with MIN/MAX readings that measure up to 650° C, distance to point ratio 12:1.

Figure 10 Infrared thermometer
Source: Own Elaboration

To orient the solar stove, a screw approximately 0.02m long should be placed on one of the sides of the stove.

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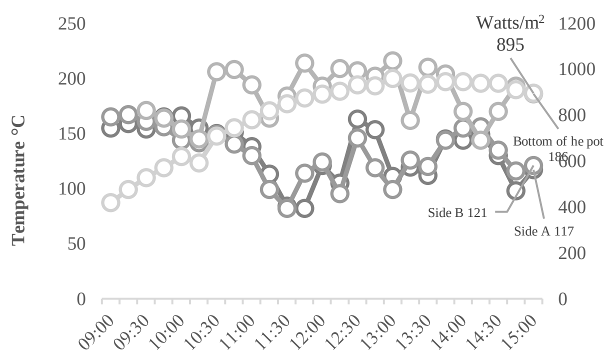
Every hour the stove must be oriented, since for every hour that passes the sun moves 15 degrees, which means that the focal point is not maintained and changes every hour, to orient it the reference point is the screw that is placed, when this screw produces shadow, the stove must be tilted until it no longer produces shadow. Thus successively every hour.

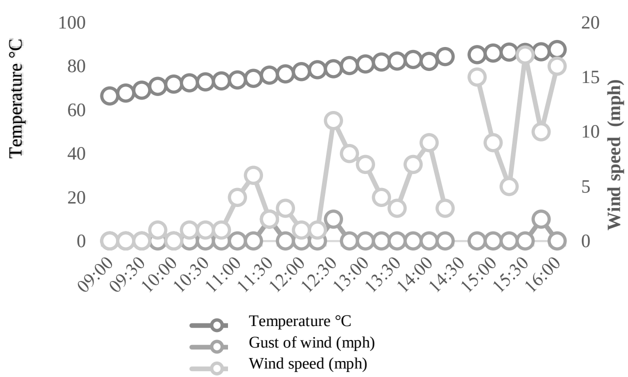
5. Results

Problem statement: To evaluate the performance of a solar stove made from recycled materials, which uses as a reflective surface self-adhesive contact paper with silver finish, placing in the focal point a pot of 0.2 m in diameter with a capacity of 4.3 liters of water, as an alternative for cooking food in urban areas of the city of San Juan del Río, Querétaro. Querétaro.

Analysis and data collection: The following are the results obtained during the food cooking process, on different days during the month of June. On Monday, June 7, only the temperatures reached by the pot were measured, without food. It was measured in three different points of the pot.

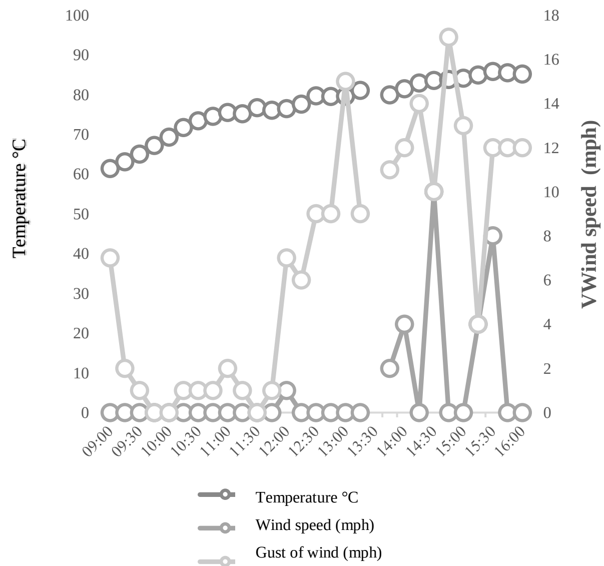


Graph 1 Temperature reached by the pot on June 7, 2022 on June 07, 2022
Source: Own Elaboration



Graph 2 Meteorological variables obtained from the weather station
Source:https://www.wunderground.com/dashboard/pws/IQUERETA29

Tuesday, June 08



Graph 3 Temperature and wind speed for June 8, 2022

Recipe 1: Chicken with achiote

Ingredients:

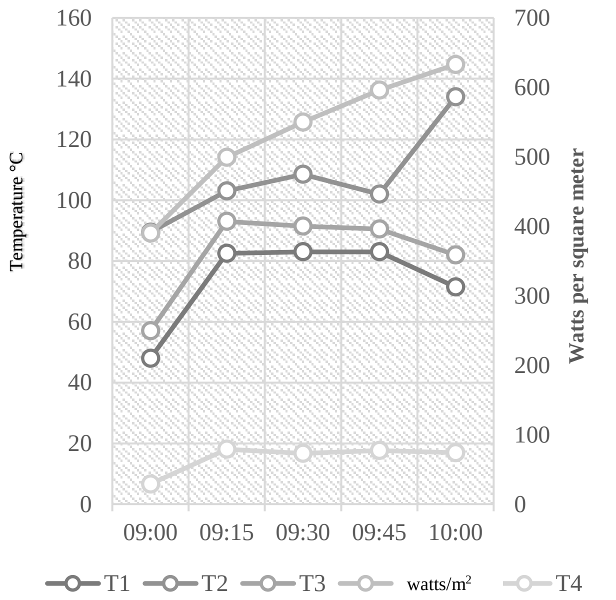
- 250g ranch chicken cut into small pieces,
- 3 cloves of garlic (10g).
- 20g white onion
- 50g of one Lol-Tun® achiote cube
- 50 ml white cane alcohol vinegar, Clemente Jacques®.

Procedure:

Dissolve the achiote tablet in the vinegar to make a thick creamy paste. Add the crushed garlic cloves. Coat the chicken pieces with the paste and place in the pot with the onion slices.

Figure 11 Chicken in achiote
Source: Own Elaboration

This recipe was ready in approximately one hour, with the following temperatures reached by the pot.



Graph 4 Irradiance
Source: Own Elaboration

Recipe 2: Boiled Potatoes

Ingredients:

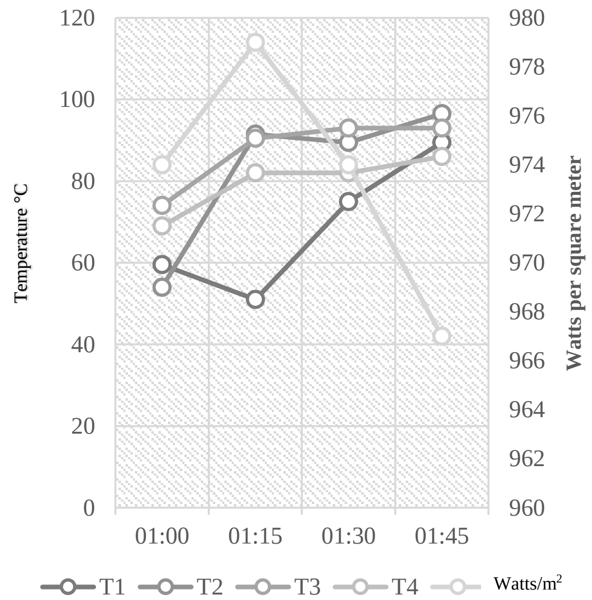
– 300 g of potatoes purchased at the market.
– 250 ml of water

Procedure:

Put water in the pot along with the previously washed potatoes.

Figure 12 Cooked potatoes
Source: Own Elaboration

The potatoes were cooked for 45 minutes, the temperatures reached by the pot were as follows.



Graph 5 Temperature in the pot and solar irradiance for recipe 2
Source: Own Elaboration

Recipe 3: Hard boiled eggs

Ingredients:

– 3 pieces of white eggs
– 250 ml of water

Procedure:

Put the eggs in the solar cooker along with the water.

This recipe was ready in approximately one hour, the temperatures reached by the pan were as follows

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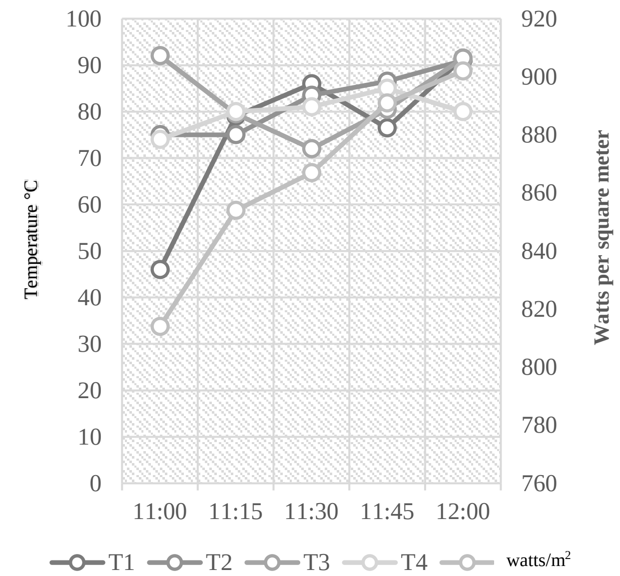
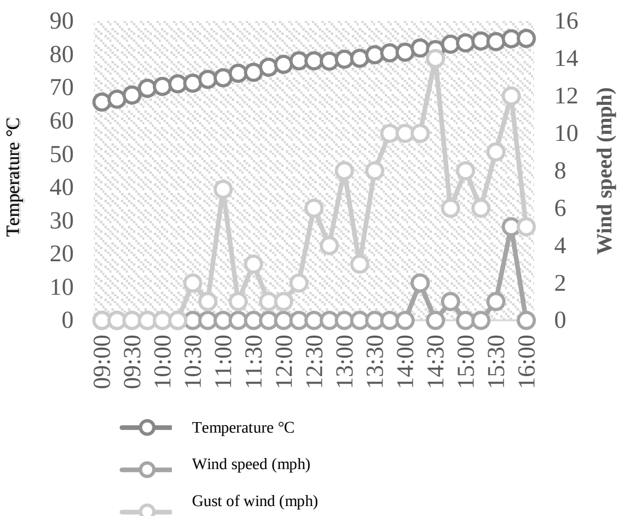


Graph 6 Temperature in the pot and solar irradiance for recipe 3
Source: Own Elaboration



Graph 7 Meteorological variables obtained from the meteorological station.
Source: Own Elaboration, https://www.wunderground.com/dashboard/pws/IQUERETA29

Recipe 4: Chicken broth with vegetables

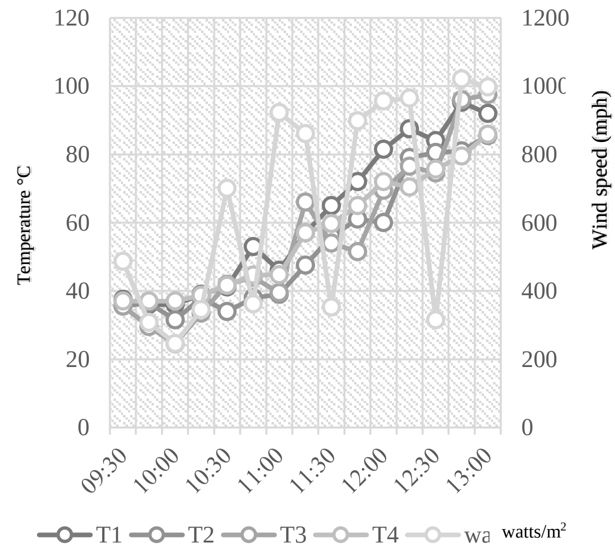
Ingredients:

- 300g washed ranch chicken.
- 30g green chayote
- 40g white onion
- 45g potato
- 20g of pumpkin

Procedure:

Put water to heat, add the chicken and the other previously chopped ingredients and season.

This recipe was ready in approximately three and a half hours, the temperatures reached by the pot were as follows.



Graph 8 Temperature in the pot and solar irradiance for recipe 4
Source: Own Elaboration

Recipe 5: Lentils

Ingredients:

- 100 g of Lentejas sol campestre®, product of the field.
- 30g white onion
- 1 tablespoon of olive oil

Procedure:

Clean the lentil, add in the pot with the other ingredients.

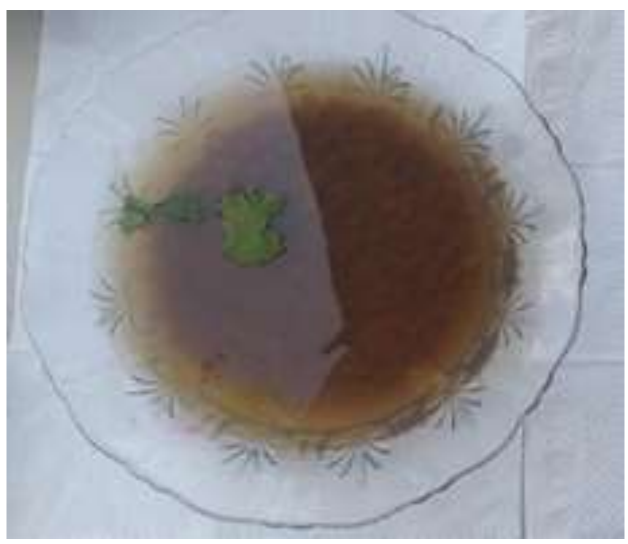


Figure 13 Boiled lentils
Source: Own Elaboration

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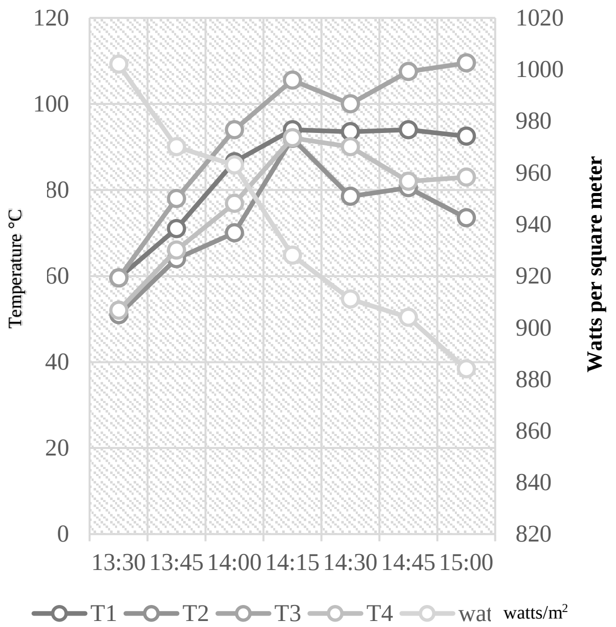
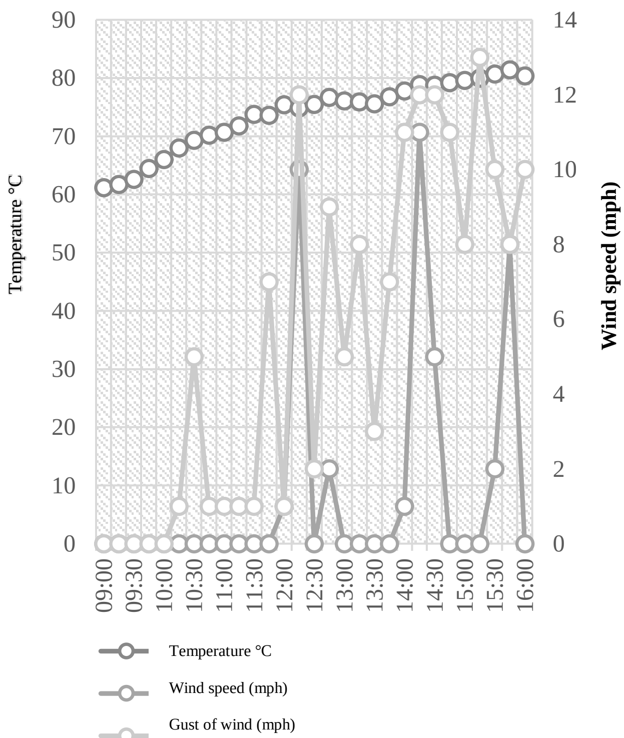
This recipe was ready in approximately one hour and a half, the temperatures reached by the pot were as follows.



Graph 9 Temperature in the pot and solar irradiance for recipe 5
Source: Own Elaboration



Graph 10 Meteorological variables, obtained from the meteorological station
Source: https://www.wunderground.com/dashboard/pws/IQUERETA29

Recipe 6: Mexican style soybeans

Ingredients:

- 100 g Nutricasa® cottura type soybeans.
- 1 clove of garlic (6g)
- 30 g white onion
- 200g of red tomato from the field
- 2 tbsp Nutrioli® Oli Olive Oil, Extra-virgin
- 5g cilantro
- 2 lemons

Procedure:

Hydrate the soybeans with seasonings and water, when ready remove the water and add the remaining ingredients.

Figure 14 Stewed soybean tostadas
Source: Own Elaboration

This recipe was ready in approximately two hours and 15 minutes, the temperatures reached by the pan were as follows.

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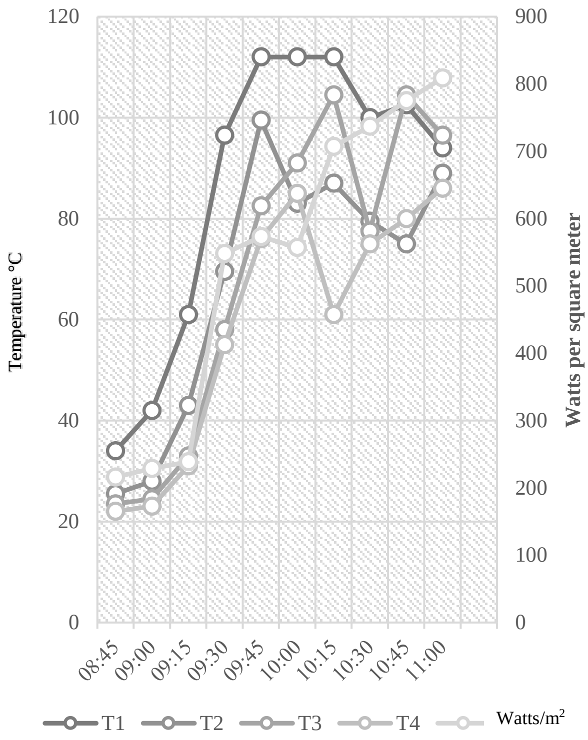


Graph 11 Temperature in the pot and solar irradiance for recipe 6
Source: Own Elaboration

Recipe 7: Beans

Ingredients:

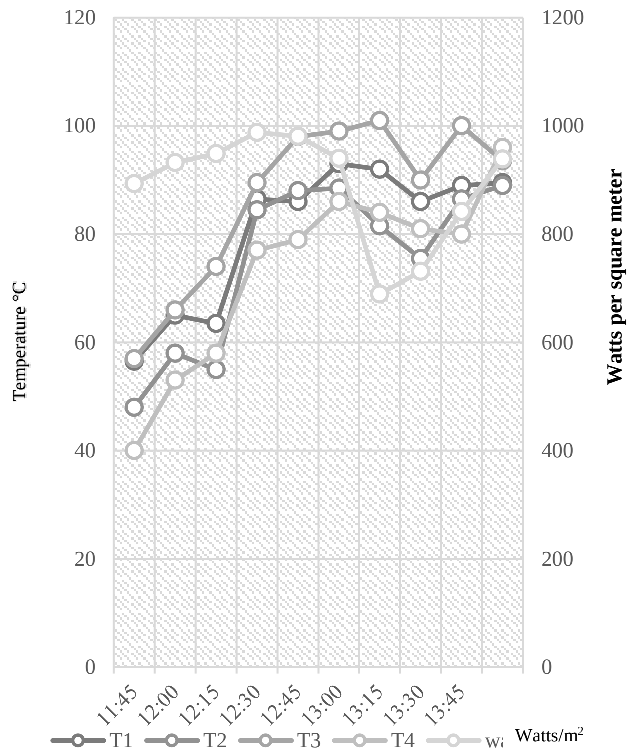
– 300g of green black beans valle®.
– 40g of onion

Procedure:

In the pot place the onion and beans previously cleaned along with water to achieve its cooking.

Figure 15 Black beans served over Sabritas® sabritones
Source: Own Elaboration

This recipe was ready in approximately two hours and 15 minutes. The temperatures reached by the pot were as follows.



Graph 12 Temperature in the pot and solar irradiance for recipe 7
Source: Own Elaboration

Recipe 8: Mexican Steak

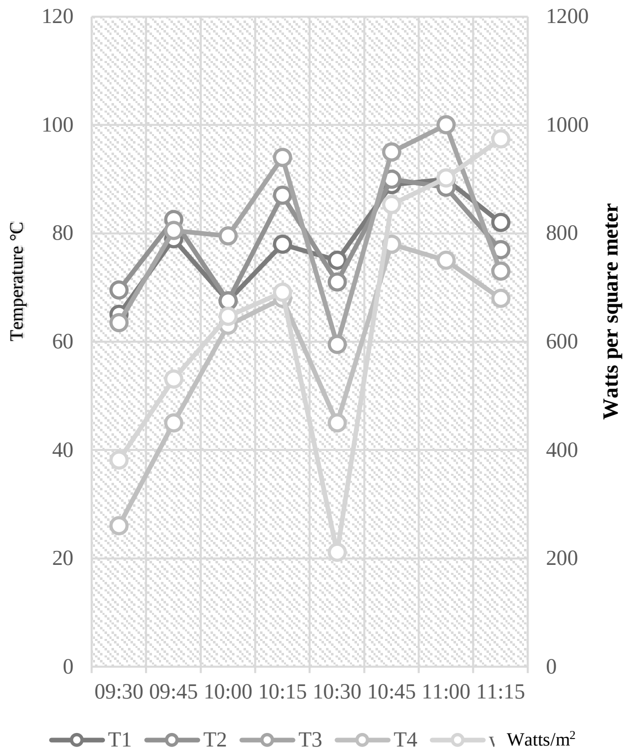
Ingredients:

– 110g red ball tomato.
– 30g white onion
– 6g green serrano chile bell pepper
– 1 clove garlic (6g)
– 250g steak, beef for grilling Res selecta.

Procedure:

Chop the steak into fine pieces, add to the pot with the other ingredients and wait for it to be ready.

This recipe was ready in approximately one hour 45 minutes, The temperatures reached by the pot were as follows.



Graph 13 Temperature in the pot and solar irradiance for recipe 8
Source: Own Elaboration

Recipe 9: Egg Mexican style

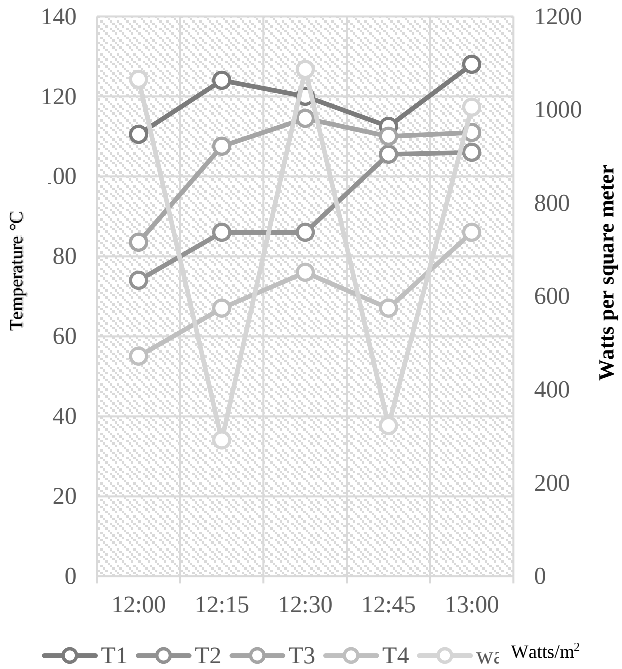
Ingredients

– 120g of white egg
– 30g of red ball tomato
– 2g chili bell pepper
2 tablespoons of olive oil

Procedure:

Let the pot with the oil heat up, when hot add the scrambled egg with the other ingredients.

This recipe was ready in approximately one hour. The temperatures reached by the pot were as follows.



Graph 14 Pot temperature and solar irradiance for recipe 9
Source: Own Elaboration

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7. Conclusions

The results have been shown by conducting practical sessions with students of the Renewable Energy Engineering career, in each experimentation tasting tests were conducted by students and professor advisor of the ES01SM-20 group, of the Technological University of San Juan del Rio, all concluded that the food had reached the proper cooking and had a good flavor, the solar stove has been used for cooking various foods, which allowed to verify the effectiveness of the device and that it can go from practice to commercialization. The temperatures are adequate for cooking the food, the process takes a little longer compared to a gas-burning stove. The results obtained in cooking food are satisfactory; the solar stove made from recycled materials is an alternative for cooking food in urban areas.

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