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A COMPARATION BETWEEN A SOLAR COLLECTOR AND A PARABOLIC SOLAR CONCENTRATOR TO HEART WATER IN THE SEMI-ARID REGION

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Abstract. *Front of a need for residential comfort with regard to heating water, whether for bathing, washing clothes or cutlery, and observing that many existing commercial heaters have a high cost of implementation or maintenance, this work brings the proposal to study of a low-cost water heating unit using solar radiation in order to achieve a better quality of life for people with lower purchasing power. This does not prevent its use by others people who believe in conscious energy consumption in order to better preserve the non-renewable energy sources currently used in most water heating systems. According to Pereira (2017), the annual average of irradiation in Brazil is around 4750 Wh/m²·day, with the highest numbers recorded in the Northeast and Midwest regions, where a experimental studies of a solar collector and a parabolic solar concentrator will be done in order to make a thermal and economic comparison of each one, thus having an analysis of the possibilities of implementation in communities that choose to have the comfort of heated water without the use of electricity. The comparison is given through temperature analysis through thermal sensors coupled in different parts of the systems, which are checked throughout the day, both devices being tested together under the same conditions. Solar water heating systems are a good alternative for domestic use, aiming to reduce energy consumption because it is sustainable, since this system uses renewable energy from solar radiation.*

Keywords: *Solar Energy, sustainability, water heating*

1. INTRODUCTION

In the world, there is currently much talk about renewable energy sources and how to use them to improve the quality of human life in a sustainable way. Among these sources, solar energy has been gaining more prominence in recent decades because it comes from the light and heat of the sun and it's widely used to generate both thermal and electric energy. In 2020, the Brazil had a power generation of approximately 8 TWh using only renewable energy sources (BRASIL, 2014).

The Brazil is a privileged country when it comes to solar energy. According to Pereira (2017), the country has a high solar irradiation throughout the year, making it advantageous for installing solar collection systems.

According to the Energy Research Company (EPE), in Brazil in the year 2022 the residential consumption has a energy value of 139,265,556 Mwh.

Considering these data, and knowing that electricity is widely used for water heating, alternative and sustainable means can be sought to achieve the same result. Solar energy can be used through solar water heaters, either through a collector or a concentrator.

In 2021, approximately 62.9 million Brazilians had a per capita income of up to R$ 497 per month, representing 29.6% of the country's population (NERI, 2022).

The purpose of this study is to conduct experimental studies on a low-cost solar collector and a parabolic solar concentrator in order to make a thermal and economic comparison between the two.

1.1 Solar energy

Solar energy is an alternative energy source, where solar radiation on a terrestrial scale is an inexhaustible source of energy. When it comes to energy sources, solar energy has the greatest potential to be explored, both for electricity and thermal energy, which comes from electromagnetic radiation from the sun (BRASIL, 2014).

According to Pacheco (2022), there are two forms of radiation: direct radiation, which directly reaches the Earth's surface without changing direction, and diffuse radiation, which results from reflections that occur in the atmosphere. The sum of these radiations is referred to as global radiation.

According to Pereira (2017), the annual average irradiation in Brazil is approximately 4750 Wh/m²·day, with the highest numbers recorded in the Northeast and Central-West regions.

1.2 Heat transfer in solar heating systems

In solar heating systems, heat transfer occurs by three mechanisms, namely conduction, convection and radiation.

1.2.1 CONDUCTION

According to Çengel (2013), conduction is the energy transferred through more energetic particles of an element to less energetic particles.

To quantify the energy transferred through conduction, Fourier's law is used, where the thermal flux (q''_x), is given in Watts per square meter, being the heat transfer rate in a given direction (x) per unit area (INCROPERA et al., 2014).

1.2.2 CONVECTION

According to Çengel (2013), convection is the energy transferred between a solid surface and through a moving fluid.

Convection can be given of two types, being natural or forced, where the natural consists of the fluid flowing over the surface due to buoyancy forces, while the forced consists of the fluid being forced to flow over the surface (INCROPERA et al. , 2014).

1.2.3 RADIATION

According to Çengel (2013), energy is transferred through the emission of electromagnetic waves or photons.

Emissivity (ε) is the property that defines the radiation that can be emitted by the surface of a material and the rate at which energy is released per unit of area, given in Watts per square meter (INCROPERA et al., 2014).

Still according to Incropera et al. (2014), in the case of radiation that falls on a surface from the neighborhood, it comes from a special energy source, which may be the sun or any other source that is close to the surface.

1.3 Types of water heating systems

There are several types of water heating systems, where each type of system has its own appearance. The most common are the electric ones that have a low installation cost, the gas heaters by passage and by accumulation and the ones with solar heating (MEDEIROS, et al, 2022). The idea of this work is to focus on thermal systems.

1.3.1 SOLAR HEATING SYSTEM

The solar heating systems are classified into two types, concentrators and flat collectors.

1.3.1.1 Solar concentrators

According to Pigozzo Filho et al. (2018), concentrator collectors consist of using mirrors to make the solar radiation focus on a single point, thus reaching high temperatures by heating the fluid.

Also known as Concentration Thermosolar Systems (CTS), the solar concentrator is a system that aims to convert direct solar radiation into another type of energy that will be used immediately or stored. In view of the existing types of concentrators, the ones that stand out are: trough-type parabolic cylindrical concentrators, tower systems and parabolic discs. The first consists of concentrating solar radiation on just one axis, while the other two concentrate on just one point which is called focus (FILHO, 2008). The Figure 1 shows a parabolic concentrator.

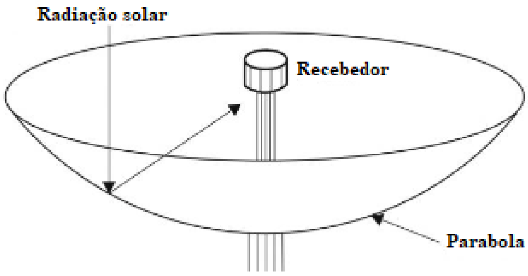

Figure 1. Parabolic solar concentrator. (KALOGIROU (2009), adapted by the author)

1.3.1.2 Flat collectors

According to Lenz (2016), a solar heating system is divided into three subsystems, the first being the energy capture subsystem that is composed by a solar collectors positioned so that they take advantage of the sun's rays as much as possible. The second being the storage subsystem, which has a thermally isolated reservoir supplied with water from the mains, in which the supply occurs at the bottom of the reservoir, causing the water circulation on the collector. And the third consumer subsystem.

The main elements of a solar heating system, according to Gomes 2010, apud Silva, 2016, are: collectors, pipes, absorption plate and thermal reservoir. The Figure 2 illustrates the direct system, which the flow occurs through thermosiphon or natural convection.

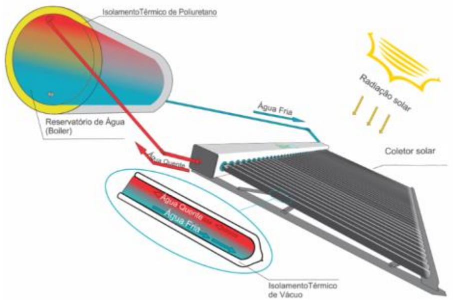

Figure 2. Illustration of a conventional solar water heating system. (Brassolar, 2020).

1.4 Aluminum

According to the Brazilian Aluminum Association - BALA (2023), in 2022 the Brazil produced 810.9 tons of aluminum.

The aluminum, according to Callister (2016), is characterized by having a low density, high electrical and thermal conductivity and good corrosion resistance. Also according to the author, the aluminum has a density approximately three times lower than that of steel, with a density of 2.7 g/cm³ while the steel present a value of 7.9 g/cm³, and also has a thermal conductivity three times greater than the steel, and when it comes to electrical conductivity, it resembles copper, and is also a great electrical conductor.

Table 1. Physical-mechanical properties of aluminum.

Density	2.7 g/cm^3
Electric conductivity	3.8 x 10^7 / Ω-m
Elasticity Modulus	69 GPa
Shear Modulus	25 GPa
Poisson Coefficient	0.33
Fusion point	660 ºC
Traction Strength Limit	90 Mpa
Ductility	40 AL% (em 50 mm^2)

Fonte: CALLISTER (2016).

2. METHODOLOGY

Laboratory tests were carried out for the development of prototypes for a solar water heating system with a flat solar collector and a parabolic solar concentrator. The experiment tries to use the sun's rays to heat water.

2.1 Collector construction stage

For the construction of the collector, aluminum tubes taken from car radiators and 1"x25mm crystal hose were used to build the collector coil, which was finned using aluminum cans. A 25 mm PVC pipe was also used along with two reductions, from 25 mm to 20 mm, to make the connections. The collector box was made from wood and a transparent PVC plastic film was used in order to cause the greenhouse effect inside the collector. The Figure 3 shows the finished collector.

Figure 3. Finished collector. (Elaborated by the author, 2023).

2.2 Construction stage of the solar concentrator

For the construction of the concentrator, a parabolic antenna was used to make use of its curvature. For the reflection of the sun's rays, cut mirrors were used, which were fixed to the parabola with high-resistance contact glue. After the mirrors were glued, the radiation receiver was made, which is made of an iron material, with an inlet and outlet for the circular fluid. For the construction of the base of the concentrator, wood was used to which the concentrator was fixed. The Figure 4 shows the finished parabolic concentrator.

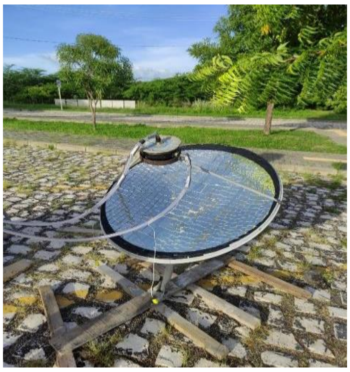

Figure 4. Completed parabolic concentrator. (Elaborated by the author, 2023).

2.3 Stage of thermal insulation of the reservoirs

The reservoir consisted of a bucket with a capacity of 60 liters. The thermal insulation of the reservoir, in which the insulation was made from a mixture of plaster and EPS (styrofoam) taking into account the proportion of 1:1. It is important that the reservoir was insulated so that we can maintain the temperature inside the reservoir and thus achieve better efficiencies without energy losses to the environment. The Figure 5 shows how the isolation step took place.

Figure 5. Reservoir insulation step: (a) mold making, (b) start of thermal insulation, (c) end of isolation, (d) fully insulated reservoir. (Elaborated by the author, 2023).

2.4 Assembly of the systems

The systems were assembled by making connections from the collector/concentrator to the reservoir using crystal hoses. Figure 6 shows both systems assembled and ready for experimental testing.

Figure 6. Finished heating systems. (Elaborated by the author, 2023)

2.5 Experimental procedure

The systems were tested at UFERSA Campus Caraúbas, with 5 days of data collection. The tests started at 08:00 am, where each data collection occurred in an interval of 30 minutes, and ending the last collection at 16:00 pm. For data treatment, it was decided to exclude the periods that presented the highest temperatures and those that presented the lowest temperatures and finally making an average of all the data, in order to ensure that the results presented do not have discrepancies of values.

To check the temperature, a digital thermometer model TH-1300 from the instrutherm brand was used, which used type “k” thermocouples properly positioned to collect the analysis temperatures (ambient temperature, collector inlet, collector outlet, collector's internal greenhouse, reservoir inlet, reservoir outlet and three internal reservoir temperatures for tracing the water temperature gradient).

The solar water heating system by concentrator, on the other hand, had the following thermocouple arrangements: room temperature, receiver inlet, receiver outlet, concentrator focus, reservoir inlet, reservoir outlet and three internal temperatures of the reservoir for tracing the water temperature gradient.

3. RESULTS

This topic deals with the analysis of the data obtained, both in the comparison of economic viability, and in the issue of the comparison between water heating systems.

3.1 Economic viability of solar water heating systems

To analyze the economic viability, the cost of each material used was taken into account. The Table 2 shows the cost of each material used, the materials obtained through donations, and finally the total cost for building the solar water heating system per collector.

Table 2. Costs to develop a solar water heating system.

Prototype Components	Donated	Purchased	Price (R$)
Wood	-	X	R$ 70.00
aluminum tubes	X	-	R$ 80.00
Hose	-	X	R$ 40.00
PVC pipes	-	X	R$ 10.00
PVC plastic film	X	-	R$ 18.00
plastic bucket with lid	-	X	R$ 55.00
PVC flange adapter	-	X	R$ 18.00
Threaded PVC glove	-	X	R$ 8.80
hose adapter	-	X	R$ 7.20
colorless acetic silicone	-	X	R$ 40.00
Matte black spray paint	-	X	R$ 60.00
Polystyrene	X	X	R$ 35.00
Plaster	-	X	R$ 40.00
Agave	-	X	R$ 5.00
		Total general	**R$487.00**
		Total donated	**R$ 112.00**
		Total bought	**R$ 375.00**

Fonte: Elaborated by the author, 2023.

Already the Table 3 shows the cost of each material used to build the concentrator solar water heating system.

Table 3. Costs to develop a solar water heating system.

Prototype Components	Donated	Purchased	Price (R$)
Antenna	-	X	R$ 100.00
mirrors	X	-	R$ 230.00
plastic bucket with lid	-	X	R$ 55.00
Pan	X	-	R$ 40.00
Plaster	-	X	R$ 40.00
Hose	-	X	R$ 40.00
PVC flange adapter	-	X	R$ 18.00
Agave	-	X	R$ 5.00
Polystyrene	X	X	R$ 35.00
Glue	-	X	R$ 17.00
screws	-	X	R$ 8.00
nuts	-	X	R$ 4.00
Insulating tape	-	X	R$ 2.00
epoxy putty	-	X	R$ 12.50
		Total general	**R$566.50**
		Total donated	**R$ 285.00**
		Total bought	**R$ 281.50**

Fonte: Elaborated by the author, 2023.

So, when analyzing the overall costs of both prototypes, it is possible to note that the solar water heating system by collector has a lower cost. And both showed a cost below commercial prices.

3.2 Temperature analysis

When analyzing the Figure 7, it is observed that the data obtained in the experiments related to the temperatures reached in the concentrator and in the collector, were significant, in which the focus of the concentrator presents higher temperatures than the collector, this due to the direction of the radiation by the surface reflective, the collector reached considerable temperatures.

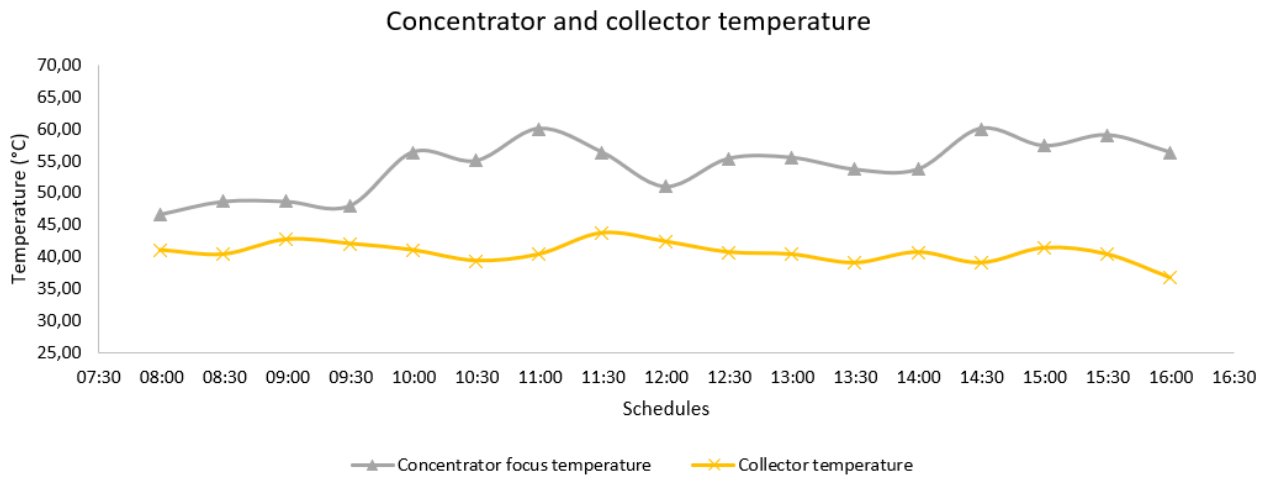

Figure 7. Shows the comparison of concentrator focus temperature and temperature inside the collector

When analyzing the temperatures in the pipes, Figure 8, it is noted that the collector presented a better performance in terms of heating the fluid in relation to the concentrator, which did not present many temperature variations throughout the test period. In Figure 9, it is possible to observe that there were no significant heat losses in any of the systems, and the piping related to the collector reached higher temperatures than the concentrator piping, being approximately 7° C. Still in Figure 9, it is possible to notice, in the collector piping, that in the last investigations, the flow of the fluid tends to occur in the opposite direction due to the reservoir having a higher temperature than the collector outlet piping, due to the specific mass of the fluid is directly linked to its temperature, since the flow occurs due to the density difference, which does not occur with the concentrator pipes, since it did not reach such temperatures.

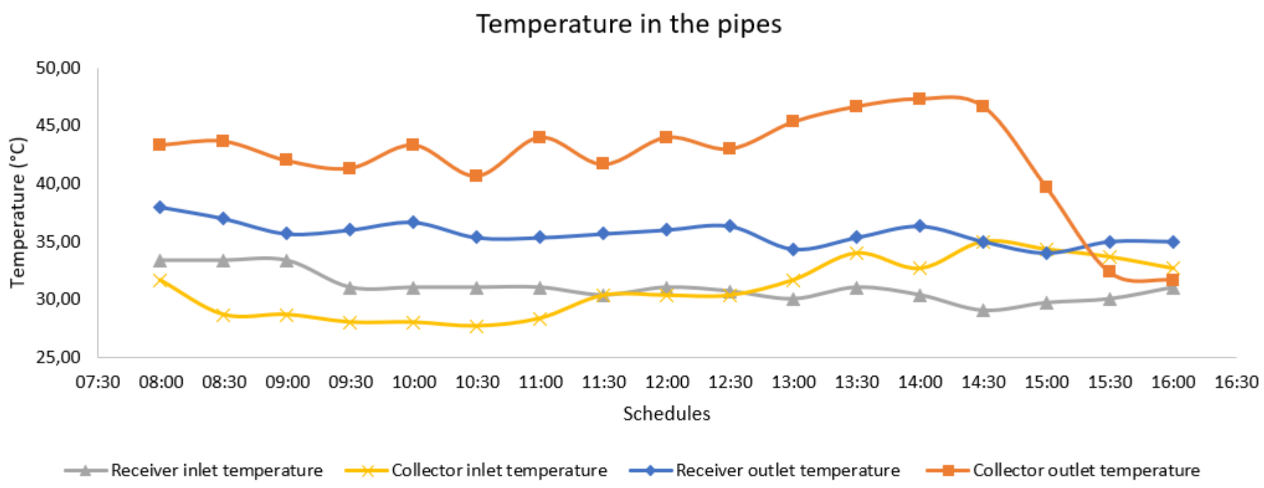

Figure 8. Shows the temperatures measured in concentrator and collector pipes, in Celsius, over a total of 8 hours.

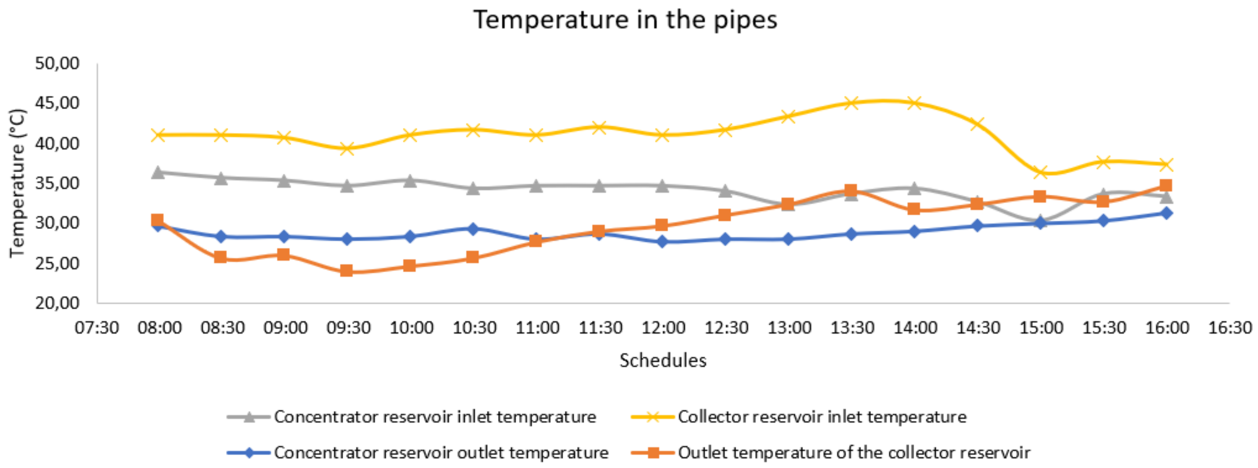

Figure 9. Shows the comparison of temperatures measured in concentrator reservoir and collector reservoir piping, in Celsius, over a total of 8 hours.

After the analyzes, it can be noted that the solar water heating system by collector presented a higher temperature than the system with the concentrator, both in its pipes and in its interior.

3.2.1 TEMPERATURE GRADIENTS OF RESERVOIRS

When analyzing the Figure 10, it is noted that the temperature curves are increasing, showing considerable temperatures and at the end of the investigations tend to align and homogenize due to the decrease in solar radiation due to the time of day. In the Figure 11, it is also possible to observe curves of increasing temperatures, but remaining constant, unlike the curves in Figure 10, and even higher temperatures are observed, both at the top, center and bottom of the reservoir.

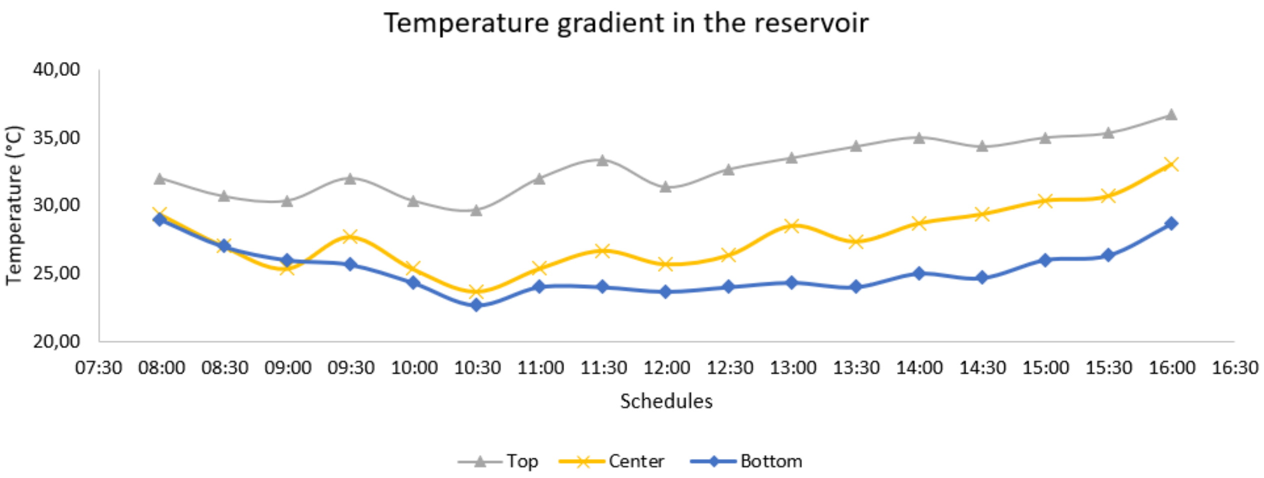

Figure 10. Shows the temperatures measured in concentrator reservoir, in Celsius, over a total 8 hours.

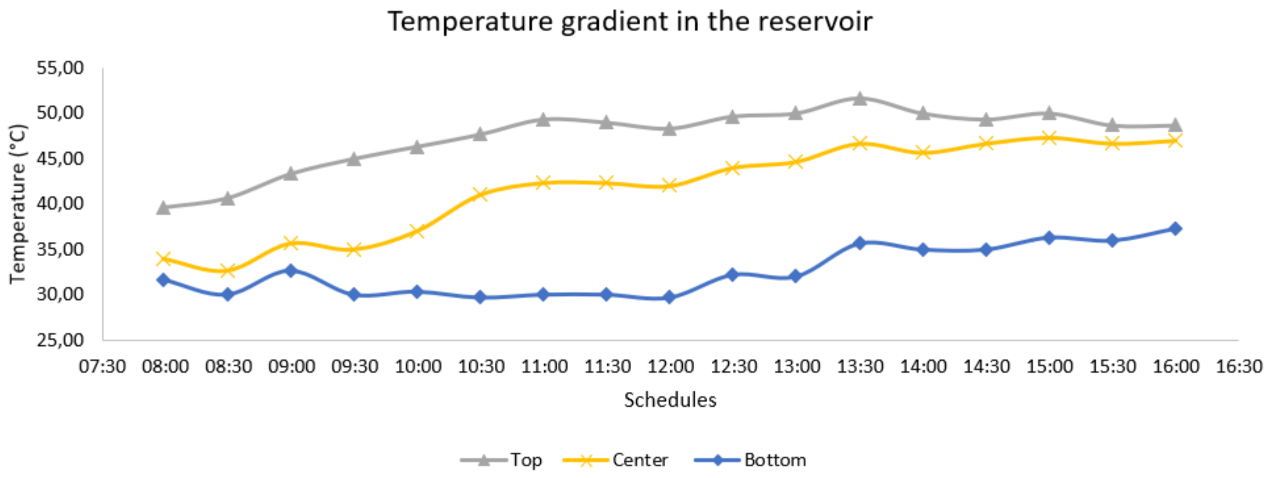

Figure 11. Shows the temperatures measured in collector reservoir, in Celsius, over a total 8 hours.

So, it is noted that the solar water heating system by collector presents a higher temperature in its reservoir than the water heating system by concentrator.

4.2.1.1 Systems efficiency

The efficiency was obtained by calculating the amount of heat, given by Equation 5.

$$\eta = \frac{Qabs}{Q} \tag{5}$$

Where Q was found through the meteriological matrix of the UFERSA Caraubas campus, where the experiment took place.

To determine the amount of heat absorbed by the system, the reservoir was divided into fifty-five partitions so that it was possible to calculate in each part, since the reservoir was not uniform, that is, the diameter of the reservoir was not constant. Therefore, the amount of heat is given by Equation (6).

$$Qabs = mc\Delta t \tag{6}$$

Onde:

m = mass
c = specific heat of water
Δt = temperature variation

With this, we obtained that for the concentrator the Q_{abs} 1.113.731,62 Joules and for the collector the Q_{abs} were 3580293,19 Joules

Starting from Equation 5, the efficiency of the concentrator reservoir was η = 9,50 %. The efficiency of the collector reservoir was η = 30,53%.

Therefore, the solar water heating system by collector presents greater efficiency than the concentrator system.

4. CONCLUSIONS

In terms of economic viability, both systems achieve their low-cost proposal, meeting the financial constraints of the low-income population. In this way, the economic viability of the prototype compared to the commercial product is verified.

Dealing with the systems, regarding the piping, both showed the heating of the fluid, but the collector was able to heat more efficiently, presenting an average temperature of 7°C more than the concentrator.

When dealing with the efficiencies of the systems, the solar water heating system by collector presents an efficiency greater than that of the concentrator, being approximately 3 times greater.

Finally, it is concluded that both in terms of water heating and costs, the solar water heating system by collector presents the best cost-effectiveness in relation to the solar water heating system by concentrator.

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7. RESPONSIBILITY NOTICE

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