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Construction of a parabolic trough concentrator for solar water disinfection

Construcción de un concentrador cilíndrico parabólico para desinfección solar del agua

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Introduction

In the context of the current global environmental situation, one of the most relevant problems is undoubtedly that of water, not only because of the strong inequalities imposed by its geographical distribution, both in time and space, but also because of the economic and political decisions that determine our social relationship with this vital liquid (Peña, 2007).

One of the biggest problems in the world today is the lack of access to fresh and drinking water. Add to this the problem of water pollution, and the picture gets worse. Pollution is caused by discharged waste, fertilisers, pesticides or chemicals that flow into fresh water and end up polluting salt water as well. In this regard, more than 1 billion people will suffer from water scarcity in the future due to pollution, overpopulation and climate change, which affect the sources of this essential resource (UN, 2020).

Where water is not easily accessible, people may not consider hand washing a priority, increasing the likelihood of the spread of diarrhoea and other diseases, currently including the covid-19 coronavirus. Diarrhoea is the best-known disease linked to food consumption or water contamination. However, there are also other dangers: nearly 240 million people are affected by Schistosomiasis, a serious and chronic disease caused by parasitic worms contracted through exposure to infested water (Vázquez, 2017). In the state of Nayarit, Mexico, there is a high mortality rate due to gastrointestinal diseases (INEGI, 2017).

The solar disinfection method (SODIS) is a disinfection treatment by exposing water to solar radiation in transparent containers, which acts on pathogens by eliminating them through ultraviolet (UV) and infrared (IR) rays. This makes this system a low-cost, environmentally friendly and chemical-free treatment, as it only uses solar energy incident on the earth's surface (Bermudes, 2015, p. 29). The SODIS process uses mainly two components of light for water disinfection: the first is UV radiation, which has a germicidal effect, and the second component, infrared radiation, which is responsible for raising the temperature and generates a pasteurisation effect when it reaches the range of 70 to 75°C.

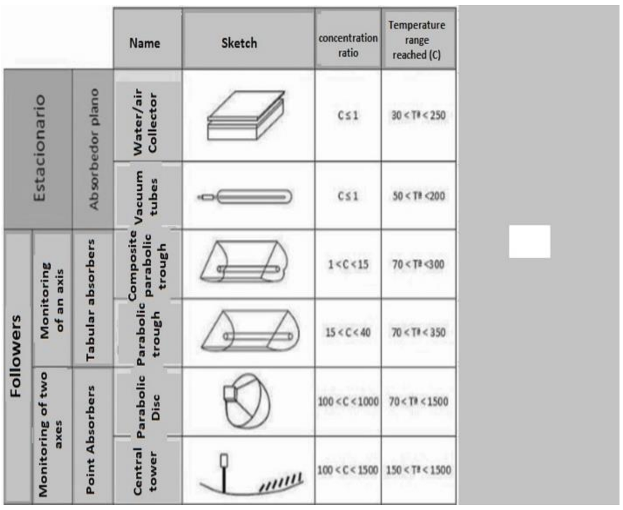
Mexico enjoys a privileged situation in terms of solar irradiation, with an annual average of 5.3 kWh/m^2 per day.

Currently, different solar energy collector devices are employed for two end uses: the generation of electrical energy, where the heat obtained from a collector field is coupled to a thermodynamic power generation cycle, or the design of lighter, smaller-scale, low-cost structures, where their most common application is the production of process heat and commonly for domestic use (Kalogirou, 2009, p. 136).

In order to achieve high temperatures in a solar collector, it is necessary to modify the collection system to increase the concentration. This is achieved through the use of solar concentrators. These are classified according to two basic characteristics, the geometry of the absorber (linear or point concentration) and the shape of the concentration (reflection or refraction) as shown in Table 1.

The construction of a parabolic trough concentrator (PTC) is intended to solve the problem of poor water quality without using any type of chemical or treatment that could be harmful to health and without compromising the quality of the water to be used by people.

The aim of this work is to design, build and characterise a low-cost parabolic trough concentrator (PTC) for water disinfection (removal of microorganisms and pathogens) using solar energy.



			Name	Sketch	concentration ratio	Temperature range reached (C)
Estacionario		Absorbedor plano	Water/air Collector		C≤1	30 < T° < 250
Estacionario		Absorbedor plano	Vacuum tubes		C≤1	50 < T° <200
Followers	Monitoring of an axis	Tabular absorbers	Composite parabolic trough		1<C<15	70 < T° <300
Followers	Monitoring of an axis	Tabular absorbers	Parabolic trough		15 < C < 40	70 < T° < 350
Followers	Monitoring of two axes	Point Absorbers	Parabolic Disc		100 < C < 1000	70 < T° < 1500
Followers	Monitoring of two axes	Point Absorbers	Central tower		100 < C < 1500	150 < T° < 1500

Table 1 Classification of solar collectors or concentrators (Paredes, 2012)

Methodology for the construction of the CCP

The construction of a parabolic trough concentrator (PTC) with recycled and inexpensive materials for water disinfection was carried out. The materials used for the construction of the prototype, as well as their costs, are shown in table 1. The total cost was $ 1494.00 Mexican pesos.

For the construction of the CCP, a 200 L metal drum was used and cut in 4, and one of the resulting pieces was used to build the concentrator and covered with Reflectech paper. For the base, which corresponds to a tube diameter of 6 cm and a length of 75 cm, 4 legs of 31 cm long and 4 cm wide were welded in order to give support and stability to the equipment. It is worth mentioning that the tube was cut with a diagonal at 21^0, placing the concentrator at the same angle, simulating the inclination required at this latitude (Tepic) for the best use of solar energy. For the absorber or container where the fluid (water) is placed, a PVC container was used, to which a water tap is connected.

Finally, an acrylic lid was placed on the concentrator, which was sealed to prevent heat loss, and hinges were placed to make assembly and disassembly easier. Figure 2 shows a picture of the developed prototype.

The experimental tests were carried out in Tepic, Nayarit, in the Jardines de la Cruz colony, from 21 to 25 August 2020, where the CCP was placed on a rooftop (shadow-free area). This allowed the tests to be carried out using the SODIS method. The tests were conducted following the following steps:

- Tests were started at mid-day sun.
- 10 litres of water were placed in the absorber.
- Thermometers were placed in the concentrator and in the absorber.
- The device was oriented to the geographic south. No reorientation was done.
- The values of ambient temperature, water temperature in the absorber and concentrator temperature were recorded hourly.
- Temperatures were monitored 4 times a day for 5 consecutive days (Monday to Friday).

Material	Quantity	Description	Diagram	Cost (MXN)
Used drum+ cut	1	Empty metal tank with lid and rim. This is the typical 200 litre drum that stores any material (there are some corrosive exceptions).		$300.00 (drum)+ $200.00 (cut) =$500.00
Metal base	1	¾" tube connected to 4 joints		$350.00 (including welding)
PVC elbows ½	4	Corrosion resistant material. Can withstand temperatures up to 140°F or 60°C. Resists damage from the sun and outdoor elements.		$1.50 c/u

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PVC (Polyvinyl Chloride) Container	1	Thermoplastic, withstands temperatures up to 200ºC.		$110.00
PVC pipe	50 cm	Higher hydraulic capacity. Flexibility.		$35.00
Digital thermometer with sensor	1	Temperature range: 0-110 °C		$120.00
Water tap	1	Tap for water outlet, PVC ½		$34.00
Connector	1	Corrosion, rust, scale and weather resistant.		$9.00
Reflec-tech	44.5x200 cm	Highly reflective and durable silver polymer coating		$280.00
Cover	55x42cm	Clear acrylic sheet		$50.00

Table 2 Materials and Costs Table

Figure 1 Photo of the developed prototype (CCP)

Results

Tests carried out with the CCP

During the 5 days, no winds above 8 km/h were recorded, humidity percentages were high (approx. 90%), and the ambient temperature ranged from 19°C to 29°C. Temperature values were taken every hour from 12:00 to 15:00 hours during the whole week. The temperature of the concentrator was measured, and it was observed that on day 4 it reached a maximum temperature between 81 and 85oC, respectively, corresponding to between 14:00 and 15:00 hours.

Of the temperatures obtained in the absorber, 76.3oC was reached on day 4, with good performance on the last three days in the period from 14:00 to 15:00 hours. Graph 1 shows the graph with the temperatures reached in the absorber (container with water).

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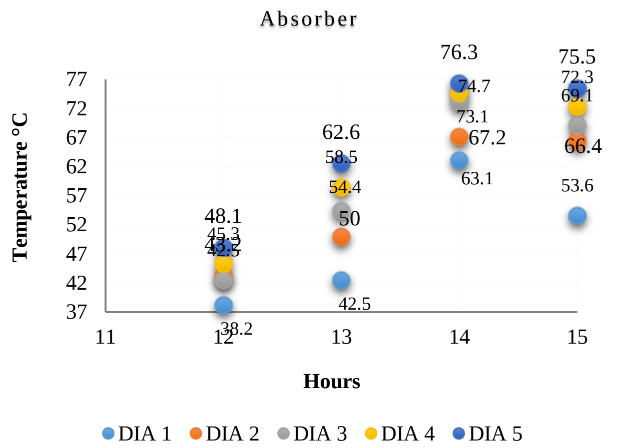

Graph 1 Temperatures reached in the absorber (container with water)

Conclusions

The design and construction of a parabolic trough concentrator (PTC) was carried out in which temperatures higher than 75 °C were reached, optimal for the elimination of bacteria in the water using solar radiation and without the use of any chemical that could be harmful to health. The prototype was developed with a low investment cost, easy to operate and simple to maintain.

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