Anidolic Optic Applied on Solar Water Pasteurization

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Abstract

Consuming non-drinkable water is, in most cases, the only available solution in the developing World. The consumed water is very frequently biologically contaminated, which leads to the propagation of innumerable diseases that are responsible for millions of deaths every year. The simplest solution to avoid these casualties is water pasteurization, which consists on heating water up to 65°C for a few minutes. After this procedure the most harmful pathogens are inert and the water is safe to drink. A portable pasteurizer has been designed based on a CPC, which acts on a bottle of water, requiring only solar energy. Several bottles and isolating materials have been tested, comparing the maximum obtained temperatures and the time needed to reach pasteurization. The objective of this project was to obtain the most efficient solution in terms of production cost and capability to prevent waterborne diseases, leading to a product suitable of being manufactured and distributed worldwide.

Keywords: Water pasteurization, CPC, solar energy, waterborne diseases, developing World.

1 Introduction

Waterborne diseases are a very serious issue in almost all countries of the developing World. In these countries, mostly situated in Africa, southern Asia and South America, drinkable water is very scarce. There is little or even no waste treatment at all and people use rivers and lakes to get rid of all kinds of waste, like animal and human faeces and other materials that pollute the surface surrounding water. The majority of the population in the developing World is not aware of the real threat that these practices represent to human health. As a matter of fact most of the drinkable water becomes biologically contaminated due to the deficient sanitation, combined with the carelessness of the population.
Even when the population is aware of the dangerous risks of disease, there is no other solution but drinking the water that is available, because clean and safe water is, in most cases, too far away or simply unavailable.

In figure 1 we see the percentage of population that has access to drinking water. The global percentage of population with access to improved water resources is 79.8%. This means that 20.2% out of 6.800 million people – approximately 1.374 millions – are exposed to unsafe water resources and therefore have a higher risk of contracting waterborne diseases. Obviously, the lack of sanitation is strongly related to the distribution of wealth, that is why waterborne diseases have a bigger impact on the poorer countries.

![Fig. 1: Drinking water availability worldwide (in %).](image)

According to the World Health Organization (WHO) there are about 4.000 million cases of diarrhoea every year, resulting in 2.2 million annual deaths. Diarrhoea fatally strikes mostly children of ages 5 or younger, representing 15% of infant mortality. It is estimated that each children suffers from diarrhoea about 2.6 times per year.

If we take into account other diseases like cholerae or typhoid fever, the situation gets even worse. It is estimated that cholerae is responsible for about 5% of all deaths in the african continent and typhoid fever accounts for about 200 000 deaths worldwide every year [1].

Apart from the current dramatic situation, where 3.4 million people die every year due to waterborne diseases, there are studies that support that global warming will increase the probability of propagation of these diseases. The rise of temperature will, in most cases, be favourable to the development of pathogens in water, resulting in a higher morbidity and mortality from waterborne diseases.

We developed a solution to solve this problem requiring no more than solar energy, which is usually a very abundant natural source in the developing countries.

2 Solar water pasteurization

To purify water and make it safe to drink there is no need to boil it. Pasteurization, which is applied in several food processes, can also be used in drinking water. This process is done by heating, but involves much lower temperatures (typically 60–70°C) than the boiling point. The cheapest way to attain pasteurization is to use a solution based on solar energy.

Solar energy has the particularity that is the only renewable energy source that allows the design
of a small and portable solution. Other renewable energy sources imply larger designs in order to be efficient. The goal is to develop a solar pasteurizer that is practical enough for people to carry it wherever they go and use it like a water purifying toolkit. This product must be simple and affordable, so that it can be produced and distributed in a large scale. The application of a solar pasteurizer in the day-to-day habits of the population in developing countries would largely improve their health and lifetime expectancy.

Figure 2 shows the behaviour of the most harmful pathogens as a function of the water temperature. To eliminate the risk of contracting waterborne diseases, one must guarantee that water reaches the safe zone before being consumed. We will require the water to be heated up to 65°C, because at this temperature all the pathogens shown in Fig. 2 have $D$-values shorter than 1 minute [5, 6]. The $D$-value of a given pathogen is the time needed to reduce its population to 1/10. After the water is pasteurized it can be drunk without risk of contracting diarrhoea, cholera, typhoid fever, taeniasis, ascariasis, dysentery, gastroenteritis, hepatitis A, among others.

The use of solar energy has also been proposed under the form of solar ultraviolet radiation. Unfortunately this method is often not sufficient by itself, since the solar UV radiation is not sufficiently energetic for fast and certain results. Also the plastic or glass recipients where the water is exposed to the radiation are really not too transparent to the UV. However, several proposals exist and are being used for cheap systems based on this technology [4]. More sophisticated ones using catalysts (photocatalysis) have been proposed with better performance [7], but still lacking development to generate real products on the market.

However the device that we propose will certainly benefit from whatever UV that gets through the optics and into the water to be heated.

3 The design of the pasteurizer

The product prototype was constructed with CPC design (compound parabolic collector) which allows for the maximum concentration that can be achieved, providing the highest efficiency for light collection. Through this design, one can have smaller sizes and attain the same results, when
comparing to other solar concentration techniques. Using CPC optics, one can also provide a stationary collector without the usual need to track the apparent hourly motion of the sun, without performance loss. The CPC is characterized by the fact that every light ray that enters it is concentrated on the absorber, which can have any shape we want. This happens as long as the light rays come with an incidence angle smaller than $\theta_C$ — the half-acceptance angle. Figure 3 illustrates the collector performance.

![Fig. 3: CPC’s light ray admission as function of the incidence angle.](image)

Independently of the absorber’s shape, the CPC can be constructed using the same technique — the string construction method [2]. We want to concentrate the solar energy in a bottle, so we will use a circular absorber. A small portion of the bottle’s bottom will be excluded because the bottle needs to be supported on the CPC itself. The smaller the half-acceptance angle is, the larger the concentration will be:

$$C = \frac{1}{\sin \theta_C} \quad (1)$$

For smaller $\theta_C$ (larger concentration) the CPC will be bigger. To build the *Sun Pasteurizer* we have chosen $\theta_C = 30^\circ$, which means that the bottle’s surface will be bathed with twice the incident solar radiation. Nevertheless, the upper parts of the CPC have little influence, so the CPC was truncated, reducing the concentration from 2 to 1.7 and saving about 40% of mirror.

![Fig. 4: Truncated CPC used for the *Sun Pasteurizer*.](image)

### 4 Testing the prototypes

Having chosen the prototype design, two laboratorial prototypes were built, to test the *Sun Pasteurizer* performances in different conditions.

![Fig. 5: *Sun Pasteurizer*’s laboratorial prototype.](image)

The CPC’s were tested as shown in figure 5, with a thin transparent plastic isolation and with a 3mm acrylic isolation. The isolation was included
because the heat losses needed to be reduced in order to attain the required 65°C. All the tests were made on perfectly clear days, to minimize the weather influence, so the radiation intensity was almost constant (approximately 1000 W/m²). Table 1 shows which kinds of bottles were tested:

<table>
<thead>
<tr>
<th>Plastic (PET)</th>
<th>Glass</th>
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<tbody>
<tr>
<td>Transparent</td>
<td>Painted Block</td>
</tr>
<tr>
<td>0.75L</td>
<td>0.7L</td>
</tr>
<tr>
<td>1L</td>
<td>1.5L</td>
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</table>

Table 1: Bottles used in the tests.

After several tests, an optimal configuration to the **Sun Pasteurizer** could be determined. Its maximum performance was obtained when using:

- 1 liter dark green glass bottles;
- back mirror to improve reflection;
- transparent acrylic casing isolating the CPC.

This configuration was able to pasteurize 1 liter of water after 40 minutes of solar exposure. The acrylic casing revealed to be of major importance to reduce the heat conduction and forced convection. The back mirror allowed the pasteurizer to be used horizontally, which reduced the water convection and accelerated the pasteurization. Figure 6 shows one of the tests that were realized, figure 7 shows the heat exchange mechanisms with and without the acrylic isolation, and figure 8 shows the advantage of using the pasteurizer horizontally with the back mirror.

We calculated the energy efficiency and energy losses of the pasteurizer with several bottles.
The efficiency ($\eta$) is the ratio between the absorbed energy ($\Delta Q$) and the incident energy ($E_I$).

$$\Delta Q = mc\Delta T, \quad E_I = A_{col}\int_{t_i}^{t_f} I(t) \, dt \quad (2)$$

where $m$ is the mass of water, $c$ is the water specific heat, $\Delta T$ is the temperature rise, $A_{col}$ is the top area of the CPC, $I(t)$ is the radiation intensity and $t_i$ and $t_f$ are the beginning and end of the test.

Fig.9: Efficiency as function of time.

The efficiency shows a decreasing tendency with the exposure time, because the energy losses increase as the water temperature rises, reducing the pasteurizer performance. From each of these curves we extracted the efficiency value at the time that pasteurization was achieved, which varied from bottle to bottle (see Fig. 10).

Fig.10: Pasteurizer’s efficiency.

The 1 liter painted black glass bottle proved to be the most efficient one, even more than the 1 liter dark green that we chose for the final product. That is because the data was gathered during different days and the radiation conditions were different. To dismiss this issue we tested both bottles side by side and water heated equally fast in the two bottles. We chose dark green glass instead of painting it black, since the dark green glass is transparent to some UV radiation and it simplifies the production of the device. With this configuration we may expect an efficiency as high as 54%.

When analysing the energy losses we tried to prove that they where proportional to the bottle area, but instead of linearity we only registered a correlation. In order to describe the energy losses we may solve the diffusion equation for the heat conduction, and study convection currents both in the water and in the air inside the acrylic isolation [3]. However, apart of this analysis, the energy losses had a common behaviour that could be fitted with an exponential adjustment:

$$E_{\text{Lost}}(T) = Ae^{T/\tau} + y_0 \quad (3)$$

where $A$, $\tau$ and $y_0$ are fitting parameters. Figure 11 shows the energy losses as function of the water temperature, calculated for one of the tests.

Fig.11: Typical energy losses vs. water temperature.
The final user will not have the experimental apparatus that we used, so we tested the \textit{Omega}$^\text{®}$ RLC-50-30/90 temperature indicators, to include them with the final product. This indicators are re-usable and showed a very good temperature response. Also a \textit{WAPI} unit will be provided with the \textit{Sun Pasteurizer}.

5 Commercial perspective

The invention culminated in a patent application by the company \textit{Ao Sol}$^\text{®}$. The product intends to be portable, so a folding mechanism was developed. A pre-commercial prototype and a logo were created.

In order to estimate the \textit{Sun pasteurizer}'s production costs the companies \textit{SoliDUS}$^\text{®}$, \textit{MUR-PLS}$^\text{®}$, \textit{Alanod}$^\text{®}$, \textit{Omega}$^\text{®}$ and \textit{Porto do Vidro}$^\text{®}$ were consulted. The costs can be estimated in 15.30€ (Fig. 13). The initial costs relate mostly on the plastic injection mold designing and production and in the organization of an assembly line. These costs can be estimated in the 50.000–80.000€ range. If each unit is sold for 25€, for instance, approximately 8250 units must be sold in order to make the project profitable (Fig. 14).

This represents an order of approximately 200.000€ in \textit{Sun Pasteurizers}, which is a very reasonable value taking into account that \textit{UNICEF}$^\text{®}$ spent 76 M€ in mosquito nets to prevent malaria, in 2008 alone.

![Fig.13: Production costs of a Sun Pasteurizer unit.](image)

![Fig.14: Break-even of the Sun Pasteurizer's project.](image)

In order to fund the \textit{Sun Pasteurizer} production and distribution, the project has been proposed to the \textit{BES}$^\text{®}$ National Innovation Contest and will be evaluated from the 1st of July to mid October 2010. There are other programs supported by the European Union that can also fund the project, such as the \textit{Competitive and Innovation Framework Program} or the \textit{EUREKA’s Eurostars Programme}. 

7
6 Conclusion

The concept of solar water pasteurization has long proved to be effective, specially in situations where improved water treatments are not available. A solar pasteurizer has been designed and tested, proving to be very efficient (up to 54%), and producing 1 liter of biologically purified water every 40 minutes. This device is then able to produce up to 8-10 liters a day and sustain a family of 4 or 5 people, which will be protected from diarrhoea, cholera, typhoid fever and many other waterborne diseases. The production cost was estimated in 15.30€, but can be 30 – 40% lower if we intend to produce millions of units. It can be commercialized for 25€ or less, which is a very affordable price if we think about the health improvement it can provide during 3 or 4 years of intense use.

References

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