Small Solar Water Pasteurizers-Further Tests and Recent Developments

Frank Husson
Solar Solutions
10080 Willow Creek Rd.
San Diego, CA 92131
fhusson@solarsolutions.info

Dale Andreatta
Sherri L. Hankal
SEA Ltd.
7349 Worthington-Galena Rd.
Columbus, OH 43085
dandreatta@SEAlimited.com
shankal@SEAlimited.com

ABSTRACT

This paper covers recent developments and tests of a series of small water pasteurizers designed to provide clean drinking water in the developing world. All of these pasteurizers produce relatively small amounts of water, 1-25 liters per day, but have very low initial costs, from a few US dollars down to virtually nothing. Pasteurizers were tested in various forms; thermally sealed plastic bags (the AquaPak and tube pasteurizers), in 3 versions of the solar puddle design, and pasteurizers made of beverage bottles under a single layer of glazing. All pasteurizers of these types work well on sunny days, though less well as the level of cloudiness increases.

1. INTRODUCTION

The lack of clean drinking water is a major health problem in the developing world. Over one billion people live without access to potable water and over 6,000 children die every day from drinking biologically contaminated water. One way to purify drinking water is to pasteurize it, that is, to heat it to a temperature of 65° C (149° F) for a few minutes, which is sufficient to kill all pathogens (Ref. 1). This paper covers a number of low-cost devices that use solar energy to pasteurize water. While pasteurization is not the only method of providing clean drinking water, it has the advantage that pasteurization systems can be scaled down to sizes where the initial cost is very low.

2. THE AQUAPAK

The AquaPak solar water pasteurizer has been specifically designed so that it can be mass-produced in "copy exactly" manufacturing facilities in developing countries. These enterprises will not only address the water crisis in the area, but will also create job opportunities and boost the local economy. Furthermore, the AquaPak can easily be manufactured in developing countries for less than a dollar per unit. In the past, no one has been able to produce a solar pasteurizer cheaply enough to be widely deployed in poor areas.

Fig. 1: The AquaPak.

The AquaPak is a ready-to-use product constructed of FDA approved UV inhibited polyethylene which is quite durable. The current size is about 0.35 meters (14 inches) square. The AquaPak is comprised of several layers of materials that can easily, reliably, and inexpensively be assembled using a tapered thermal impulse sealing machine. An inner chamber filled with 2-5 liters of water lies above a 6 mm (1/4 inch) layer of foam (the bottom insulation) and lies below a chamber with a thin layer of bubble pack. The bubble pack forms the glazing layer. The bubble pack itself, not counting the layers of plastic above and below, has a solar transmissivity of about 0.82. The sealing process bonds the edges of the plastic tightly enough for the AquaPak to pass a 10-foot (3 meter) drop test when filled with 3 liters of 80°C water. A water spout, filter and built in pasteurization indicator are formed into bottom of the unit.

The AquaPak was described in detail in Ref. 2. Since 2003 the AquaPak has been sent to 30 countries and tests are ongoing. Some recent technical improvements are the introduction of small vent holes in the bubble pack to eliminate the buildup of condensation, the use of thinner layers of bubble pack (which provides a thinner profile with only a small penalty in performance) and the use of a 36-month UV inhibitor in the plastic film.

3. THE SOLAR PUDDLE

The solar puddle was first introduced in 1994 (Ref. 3) and was further described in Ref. 4. It is generally a larger device that can provide tens or even hundreds of liters of water per day, much more than the AquaPak. The solar puddle is made from sheets of plastic laid on top of each other and held down by weights (soil, rocks, logs, etc.) to form what is basically a puddle under a glazing. In the earlier publications an in-ground unit was described but the puddle can be built above ground and in larger or smaller sizes. The depth of the water in the puddle and the vertical dimensions of the puddle are the critical parameters, while the horizontal dimensions can be adjusted as necessary. In this study 3 variations of puddles were studied. Figure 2 shows a generic cross section of a puddle, with the layers used in the 3 variations described in Table 1.

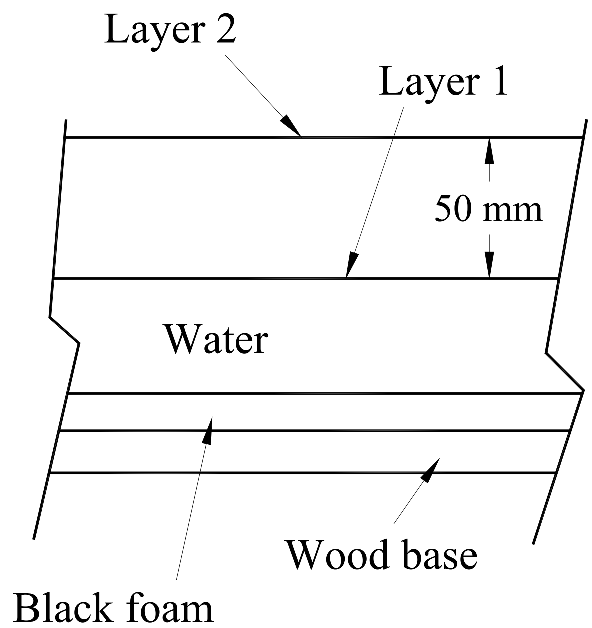

Fig. 2: A cross section of a typical solar puddle that was tested in San Diego.

These were tested in San Diego, latitude 33° N. The puddle had a plywood base with wooden sides (sides not shown in cross section). The base was 36 inches square (0.89 meters square). On top of the wooden base was 6 mm (1/4 inch) of black foam, on top of which was a layer of black plastic which held the water. In most cases, 24 liters of water was placed in the puddle, giving a water depth of about 30 mm (1.2 inches).

TABLE 1: DESCRIPTION OF THE LAYERS OF THE SOLAR PUDDLES THAT WERE TESTED

Variation	Layer 1	Layer 2
1	Clear plastic	Clear plastic
2	Bubble wrap	None
3	Bubble wrap	Clear plastic

Variation 1 was similar to previously tested puddles, having 2 clear plastic layers over the water with an air gap of at least 50 mm between them. Figure 3 shows a variation 1 puddle on the right before the top layer was added. In these tests, the air gap was always 50 mm, while in previous tests, larger air gaps were used. As with previously tested puddles, pasteurization temperatures were achieved on days with good sun, and not on days that were mostly cloudy. Later in the season, just past the fall equinox, pasteurization temperatures could not always be achieved even on days with good sun. Peak air temperatures were typically about 38° C near the solstice and 25° near the equinox. Some detailed data from the testing is given in Figs. 4 and 5.

Fig. 3: Two variations of the solar puddle under construction.

Variation 2 was the simplest variation, using a single layer of bubble wrap and no air gaps or spacers. This is shown under construction on the left side of Fig. 3. This variation was tested a number of times on sunny days near the equinox where the peak ambient air temperature was about 30° C. This variation did not achieve a temperature in excess of 61° C. While this variation would presumably work at lower latitudes, or closer to the summer solstice, or with higher air temperatures, this variation does not seem to perform well enough to be a reliable source of water.

Variation 3 was tested several times close to the summer solstice and on days with either strong sun or on mostly overcast days. On the overcast days the temperatures were well below pasteurization, while on the sunny days the temperatures were well over pasteurization, around 70° C. On all days, however, a variation 1 puddle being tested simultaneously produced significantly higher temperatures. This is presumably because the bubble wrap has a lower transmissivity that a single layer of plastic. It must be concluded that variation 3 is inferior to variation 1 in performance, while at the same time it is more complex.

4. OTHER SMALL PASTEURIZERS

Two other types of pasteurizers were studied. The first was the tube pasteurizer, which is similar to the AquaPak except it is further simplified. This device is also described in Ref. 2. Basically, 2 chambers are formed from the same type of thermosealed plastic sheets used in the AquaPak,, but there are no separate insulation layers on either the bottom or the top. The lower chamber is the water chamber, and has a fill spout with a cap. The upper chamber is inflated by lung exhalation to form a stagnant-air insulating chamber. The device would be laid on a bed of fine organic materials (grass, leaves, straw, etc.) that is about 25 mm (1 inch) thick. The organic material forms both the absorber and the bottom insulation. Numerous tests have shown that this organic material works well as both an absorber and insulator, essentially as well as the black foam rubber used in the AquaPak. See Fig. 4 for details of the performance of the tube pasteurizer.

The final type of pasteurizer that was part of this study was a series of very small pasteurizers which might be called bottle pasteurizers. Tests are ongoing with these types of pasteurizers, but several variation are capable of reaching the pasteurization temperature on a sunny day in a warm climate. One set of small pasteurizers used various sizes and colors of glass beer bottles, while others used 2-liter plastic cola bottles.

Testing was done in the summers of 2002-2004 in Columbus, OH, latitude 40° N. One type of pasteurizer used beer bottles of 12 and 22 oz. sizes (340 and 624 ml). The bottles were tilted at about 70° then filled as much as possible without spilling. The lower end of the bottle would be oriented toward the sun at noon, that is, the lower end would be to the south in the northern hemisphere. The bottles sat on a thin bed of dry organic material, glass or hedge clippings, with the area of the bed considerably larger than the bottle. The bottles would be covered with a single layer of clear plastic, arranged with suitable spacers such that an air gap of at least 10 mm was present all around the bottle. Temperatures were measured in the water near the bottom of the bottle. In some tests a “mixed” temperature was also measured by stirring the contents of the bottle and measuring the temperature. The mixed temperature was usually slightly higher than the bottom temperature, leading us to believe that the coolest water is at the bottom of the bottle.

On sunny days the pasteurization temperature was achieved with 3 different colors of 12-oz. bottles and with brown 22-oz. bottles. Surprisingly, all colors performed about the same. The peak temperatures achieved by the 22-oz. bottles were not considerably lower than those achieved by the 12-oz. bottles being tested simultaneously, suggesting that heat loss is the limiting factor in achieving the desirable temperature rather than thermal mass. Future work will include 40-oz. (1134 ml) bottles.

Two-liter plastic bottles were tested and achieved pasteurization under similar conditions, that is, lying down on a dark bed and covered with a single sheet of clear plastic to form a glazing. Other tests were performed on 2-liter bottles wrapped in 1 or 2 layers of bubble wrap and with the lower 180° of the perimeter of the bottle painted black. These failed to reach the proper temperature even under optimum weather conditions in Ohio, typically falling about 10° C short of the pasteurization temperature.

A peculiar aspect of work with the plastic 2-liters bottles is that the bottles tend to shrink by a small amount with each heating cycle. Another feature of the performance of all the bottle-based pasteurizers that are covered with a single sheet of plastic is that the top of the absorber layer heats rapidly (the absorber being a low density material) to temperatures above the pasteurization temperature. A significant amount of heat would be transferred to the bottom by radiation and convection from the absorber to the bottle, in addition to the direct solar gain. This is especially true when the bottle is cold.

5. <u>TESTS WITH REFLECTORS</u>

Limited tests were done in 2004 in San Diego using AquaPaks with reflectors on the north sides. The reflectors were foil-covered bubble wrap angled 110° from the horizontal. Looking at days with clear weather Table 2 summarizes the results, giving the time in hours to attain 67° C with a given amount of water in the AquaPak.

TABLE 2: SUMMARY OF AQUAPAKS TESTED WITH REFLECTORS

Month	2-liters no reflector	2-liters small reflector	4-liters large reflector
June	3.5	No data	No data
October	5	4	No data
November	Temp. not attained	5	2.5
December	Temp. not attained	Temp. not attained	3

It can be seen that the large reflector makes a considerable difference both in temperature that was attained and in the time it took to attain that temperature. With the reflector, multiple batches per day could be produced.

6. <u>DETAILED TESTING OF SMALL PASTEURIZERS</u>

Past publications (Refs. 3 and 4) have concentrated on the workability of the various solar devices, in other words do they work at least under some conditions. Here we begin to present more detailed measurements of the performance of some of the pasteurizers. It should be noted that the 65° C pasteurization temperature will kill every pathogen in drinking water within a few minutes. The most heat resistant pathogen is the hepatitis A virus (Ref. 1). Lower temperatures may be acceptable if hepatitis A is not present, or if longer times near the peak temperatures are achieved.

In San Diego, latitude 33° N, a number of tests were performed measuring the water temperature in various pasteurizers simultaneously with air temperature and insolation, which was measured with a commercial pyranometer designed for measuring hemispherical solar radiation. Two sets of results are given in Figs. 4 and 5. All of these pasteurizers are shallow enough that water temperatures are essentially constant throughout the water.

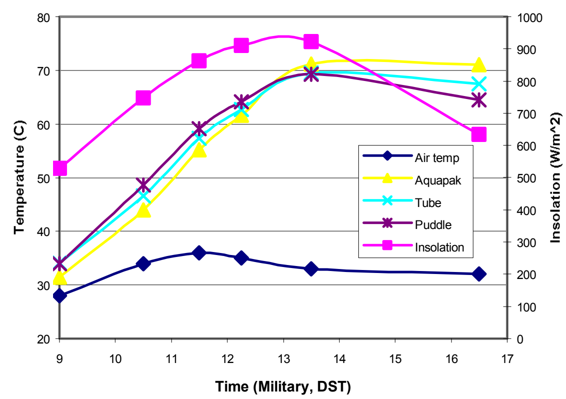

Fig. 4: Performance curves for 3 types of pasteurizers. Data from July 21, 2004.

In Fig. 4 the puddle was of variation 3 described in Section 3. It contained 24 liters of water, giving a water depth of 30 mm. The AquaPak contained 4 liters, giving a water depth of about 34 mm. The area of the tube pasteurizer was about twice that of the AquaPak, and the water was also twice as great. Two tube pasteurizers were tested side by side, the temperatures for the other tube pasteurizer were slightly lower. It can be seen that for all the pasteurizers the temperature drops slowly from its early afternoon peak, thus temperatures under 65° C would probably be acceptable.

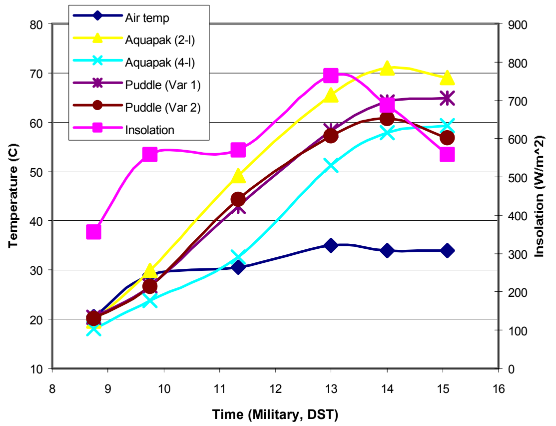

Fig. 5: Four types of pasteurizers tested on October 8, 2004.

Figure 5 shows 2 variations of the solar puddle, variations 1 and 2, along with 2 AquaPaks filled with different amounts of water, 2 liters or 4 liters. The variations of the solar puddle are described in Section 3. This data comes from October 8, 2004, well after the summer solstice. Variation 1 of the solar puddle contained 23 liters of water (water depth was 29 mm) while variation 2 of the puddle contained only 12 liters (water depth was 15 mm). It can be seen that variation 1 outperformed variation 2, even though variation 2 had much less water. It can also be seen that the AquaPak with 2 liters of water reached and exceeded the pasteurization temperature while the AquaPak with 4 liters did not. Comparing Fig. 4 with Fig. 5 shows that the October sun was considerably weaker than the July sun, as would be expected at that latitude.

7. FUTURE WORK

It is expected that in the summer of 2005 further work will be done to try to quantify the performance of the various pasteurizers on partly cloudy days. Other bottle-based pasteurizers will be tested using larger (40 oz.) glass bottles and using small reflectors under the plastic sheet but above the bottom insulation. Further 2-liter bottle tests will be conducted under similar conditions.

8. ACKNOWLEDGEMENTS

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