A SUMMARY OF WATER PASTEURIZATION TECHNIQUES

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Introduction

In developing countries the burden of disease caused by contaminated water and a lack of sanitation continues to be staggering, particularly among young children. According to the United Nations Children's Fund (UNICEF) diarrhea is the most common childhood disease in developing countries. Dehydration resulting from diarrhea is the leading cause of death in children under the age of five, annually killing an estimated five million children.[1] (Footnotes refer to references at the end of this document.)

Contrary to what many people believe, it is not necessary to boil water to make it safe to drink. Heating water to 65° C (149° F) for 6 minutes, or to a higher temperature for a shorter time, will kill all germs, viruses, and parasites.[3] This process is called pasteurization.

In this document we describe several pasteurization techniques applicable to developing countries. Pasteurization is not the only technique that can be used to make water safe to drink. Chlorination, ultra-violet disinfection, and the use of a properly constructed, properly maintained well are other ways of providing clean water that may be more appropriate, particularly if a large amount of water is needed. Conversely, if a relatively small amount of water is needed, pasteurization systems have the advantage of being able to be scaled down with a corresponding decrease in cost. In other words, if you have only a little money, you can use pasteurization to get a little clean water, perhaps enough for a family but not a village. As always, the selection of the right system should be based on local conditions.

This document describes techniques used to pasteurize water, but it is also necessary to educate people about the need for clean water and how to keep their water clean. Among many people in the developing world clean water is not perceived as being important. Also, since many people do not understand how germs are transmitted, many cased have been reported where people unthinkingly recontaminate their clean water by putting it into a contaminated container.

Basic Methods of Solar Water Pasteurization-Solar Cookers

A simple method of pasteurizing water is to simply put blackened containers of water in a solar cooker.[3] There are many types of solar cookers, but a solar box cooker is sketched in Fig. 1.

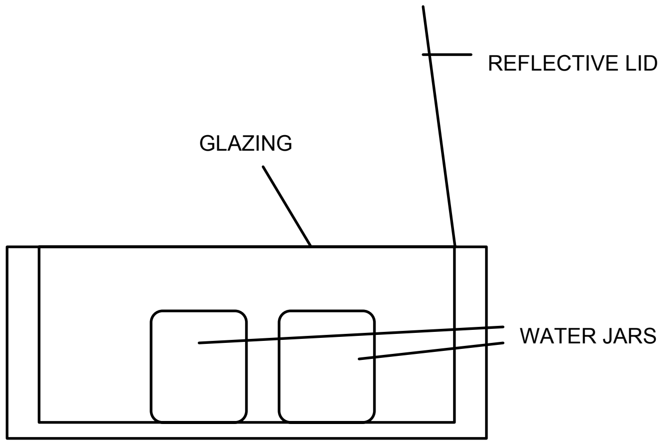

Figure 1: A solar box cooker being used to pasteurize water.

Regardless of the type of solar cooker used, a way of knowing that the water reached the pasteurization temperature is needed. An inexpensive device that does this was developed, and is shown in the Fig. 2. It is a plastic tube with both ends heated, pinched, and sealed, and with a particular type of soybean fat in one end that melts at 154° F. The tube itself is buoyant, but is weighted with a washer so it sinks to the bottom (coolest) part of the water, with the fat in the high end of the tube. If the fat is found in the low end of the tube at any time after, the water reached the proper temperature, even though the water may have since cooled down. A nylon string makes it easy to take the tube out without recontaminating the water. The tube is reused by flipping it over and sliding the string through the other way. This device works in any size water container, costs about $6 or less, and is available from Solar Cookers International, www.solarcooking.org. This device also works with fuel-heated water. Since heating the water to the pasteurization temperature rather than the boiling point reduces the energy required by at least 50%, the fuel savings offered by this simple device alone is considerable.

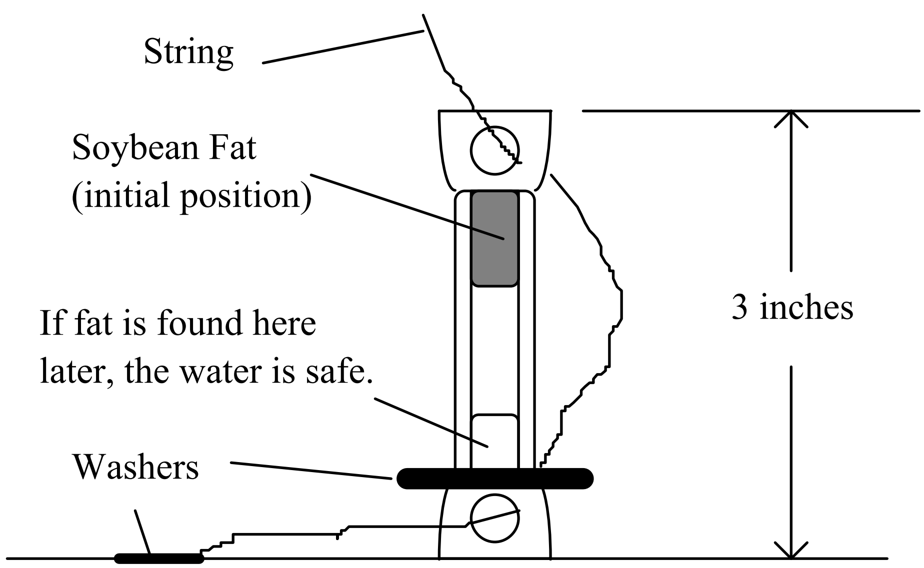

Figure 2: One type of WAPI (Water Pasteurization Indicator). The indicator would sit at an angle in the bottom of a water container.

Flow-Through Pasteurization Devices

Another way to pasteurize water is a flow-through device. Water flows through a solar collector, one end of which is connected to a thermostatic valve and the other to a storage tank for the untreated water supply. This storage tank also contains a sand/gravel/charcoal filter that does the preliminary filtering. The thermostatic valve opens at the correct temperature, allowing the pasteurized water to drain out of the tubing and into a second storage vessel for treated water. As the treated water drains from the solar box cooker, contaminated water from the storage tank automatically refills the tubing. Once this cool water reaches the valve the valve shuts and the pasteurization process begins anew.

This flow-through device has several advantages over the simpler batch processes. First, potable water becomes available throughout the day as new increments of treated water are added to the clean storage vessel. Second, this type of unit can adapt to variable solar conditions which takes the guesswork out of filling the jugs in a batch process. This is also a totally automatic process, freeing time for other chores and decreasing the likelihood of an accident occurring when transferring water in and out of a batch unit.

Dramatic improvements can be achieved by recycling the heat in the outgoing pasteurized water. Once the water has been pasteurized and released the energy in this water can be used to preheat the incoming water. This process is shown in Fig 3.

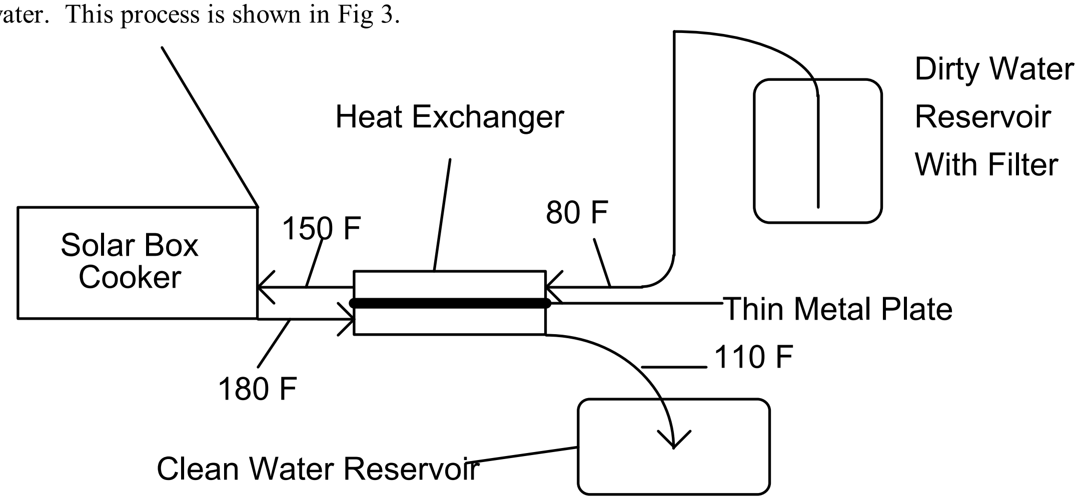

Figure 3: One type of flow through water pasteurizer with heat exchanger. Typical temperatures are shown in degrees F.

A simple device which accomplishes this preheating is a counter-current heat exchanger. The hot water flows on one side of a metal plate, while on the other side of the plate cooler fluid flows in the opposite direction. The energy from the hot water is transferred to the cold water, thus preheating the incoming contaminated water by lowering the temperature of the outgoing pasteurized water. There are many ways of building a counter-current heat exchanger. In the initial trials, for an increase in cost of about 15% the heat exchanger provides about a 400% increase in water output.

Other Sources of Heat

A heat exchanger can produce benefits with any source of heat, including the exhaust heat from an engine, a fire (that may be used to cook food at the same time,) and heat from other types of solar collectors. We have done some engineering analysis and generated an equation to determine the water output of a particular system of this type.[4] This analysis can also be used to determine the relative benefits of a better heat exchanger, vs. a bigger solar collector vs. a better insulated collector.

The Solar Puddle-A Low Cost Large Area Device

While many factors determine the usefulness of a water pasteurizer, an important figure of merit is the water delivered per unit cost. A device which is made only of low cost materials is being called a "solar puddle" and it is essentially a puddle in a greenhouse. One form of the solar puddle is sketched in Fig. 4, though many variations are possible.

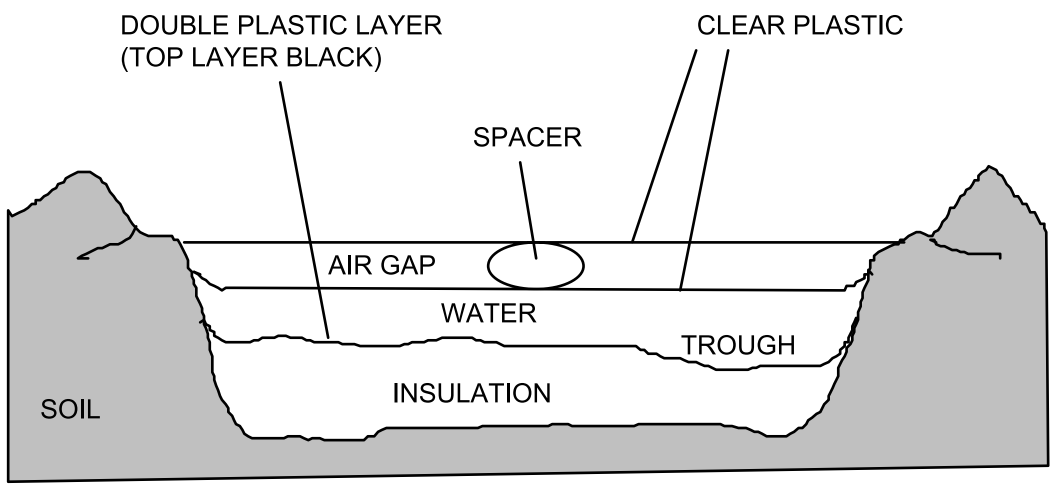

Figure 4: A basic solar puddle. Horizontal dimensions are shown compressed for clarity. A puddle can alse be built with wooden sides on top of a table or roof.

The only expensive materials used to make the puddle are a pasteurization indicator, a siphon tube, and 4 sheets of plastic (about \$2 for the size tested). The initial tests were done in the spring and summer of 1994 in Berkeley, California. On days with good sunshine the required temperature was achieved even with 68 liters (17 gallons) of water corresponding to a depth of 62 mm (2 1/2 inches). With thinner water layers higher temperatures can be reached. With 24 liters (6 gallons) corresponding to a depth of 21 mm (1 inch) 80° C (176° F) was achieved on one day. More details of our results, as well as a detailed analysis of the solar puddle can be found in Reference 5.

Instructions for Building a Solar Puddle

Many variations of the puddle are possible. The basic form is built into the ground as shown above, though the puddle can be built above ground with sides made of wood or a similar material. The shape of the puddle is up to the builder, puddles that are square, round, or rectangular have been built. The instructions below cover a puddle built into the ground.

One begins by digging a shallow pit about 5-10 cm (2-4 inches) deep. The smallest practical size is probably about 2 feet (0.6 m) by 2 feet. If the puddle is larger there is more water to pasteurize, but there is also proportionately more sunshine collected. The bottom of this shallow pit should be made as flat and level as possible, by eye. There should be one deep spot (marked “trough” in the sketch) perhaps ½ inch (12 mm) deeper than the rest, and this area should be about 3 inches (75 mm) by 3 inches.

The pit is lined with some sort of insulation. If the insulation is of a commercial type such as foam rubber or some other type of foam, then only ¼ to ½ inch (6-12 mm) is needed, though more is OK too. If the insulation is non-commercial stuff, then perhaps an inch (25 mm) is needed. The original puddle used wads of paper as the bottom insulation. Various organic materials might also be used, leaves, straw, dry brush, etc. Successful puddles have been made using grass clippings for insulation. The insulation should be fine (grass, straw leaves, pine needles) rather than coarse (stalks or twigs). If convenient, the sides should be lined also. Some types of polystyrene will melt at pasteurization temperatures, and obviously shouldn't be used. The insulation should also not be too soft, such as a thick fiberglass batting layer. If the insulation is too soft it will compress unevenly under the weight of the water.

This layer of insulation should be made generally flat, except for a low spot in the trough. Then the puddle is lined with plastic. If good quality black plastic is available, a single black layer can be used as the bottom of the puddle. (If this plastic leaks a little bit it is not a problem, the water will just drain through the insulation into the ground.) If only low quality plastic is available (typically cheap polyethelene which is not UV stabilized) then 2 layers of plastic should be used with the top one black and the bottom one any color. If no black plastic is available, clear plastic can be used, in which case the insulation serves as the absorber. This is not the ideal method, but has worked fairly well with black foam rubber or dry grass clippings as the insulation. The edges of this layer(s) should stick out past the edges of the pit

Pour a little water into the puddle and use this water to level out the bottom again. If the water depth is uniform everywhere to within about ½ inch (12 mm) this is good. A pasteurization indicator and drain siphon go in the trough. The drain siphon may have to be to be weighted to keep it from pulling out. The drain siphon must be kept clean, it must not be used as the fill siphon.

A layer of clear plastic goes over the water, again with the edges extending beyond the edges of the pit. An insulating air gap 5 cm (2 inches) or more thick is formed by putting one or more spacers (such as a wad of paper about 2 inches in diameter) on top of this layer of plastic and then by putting down another layer of plastic, which must also be clear. Again, cheap polyethelene is OK, but higher quality plastic is better. Finally, dirt or rocks are piled on the edges of all the plastic sheets to hold them down.

Another variation would be to add an additional layer of plastic and form a second airgap. This could again be done with spacers, or could be done with a tentpole type of arrangement. The tent should be low and flat. This type of puddle performs better than a single airgap puddle, but of course is harder to build.

Puddles have been built using 1 or 2 layers of clear bubble wrap instead of the top layers of plastic. These generally do not perform as well, since the transmissivity of the bubble wrap is less than that of clear plastic.

As with any solar device, sunny open locations are best. Care may need to be taken to keep animals and children out of the puddle. Once the puddle is built it would be used by adding water each day. This can be done either with a fill siphon, or by folding back the top layers and pouring water in. The fill siphon must not be used as the drain siphon, as the fill siphon is recontaminated each day.

As a rule, the puddle will not pasteurize water on a cloudy day, but it will heat the water significantly. On a day that is partly cloudy, not more than 1 inch (25 mm) of water should be used. On a mostly sunny day up to 2 inches (50 mm) of water can be pasteurized. On a very sunny day with high air temperatures up to 3 inches (75 mm) of water can be pasteurized. The above numbers are probably the best than one can expect, so if there is doubt, it is probably best to put in less water rather than more.

The solar puddle works even under conditions that are not ideal. Condensation in the top layer of plastic doesn't seem to be a problem. Small holes in the top layers don't make much difference (this is because most of the heat loss is through radiation rather than convection). The device works in moderate wind, or if the bottom insulation is damp. The water temperature is uniform throughout the puddle to within 1° C (2° F).

The puddle may need to be taken apart and cleaned and dried after some time. After some months the top plastic layers weaken under the combined effects of sun and heat and have to be replaced, but this can be minimized by avoiding hot spots such as places that are exposed to the sun but not cooled by the water and by using higher quality UV-resistant plastics.

Small Pasteurizers-Commercial

Solar Solutions, in San Diego, is currently building a small solar pasteurizer (about 1 gallon) as a 1-piece unit somewhat like a bag with a handle, and has a built in pasteurization indicator. It is called an Aquapak, and it can be filled and set into place, requiring no set up. This is described at www.solarsolutions.info.

The Aquapak is made of 3-ply plastic, a layer of nylon between 2 layers of polyethylene, and the plastic is UV stabilized. The plastic is very tough, and the unit can withstand a 10-foot drop even when hot. The plastic material is more expensive than typical polyethylene, typically about $0.04 per square foot, but lasts much longer.

Solar Solutions also produces a very nice compact pasteurization indicator.

Two Other Types of Small Pasteurizers

A number of tests have been done with two other types of small pasteurizers. One of these is virtually free in terms of material costs, and the other has virtually no manufacturing cost. Both of these pasterurizers use a bed of fine organic materials (grass, leaves, straw, etc.) that is about 25 mm (1 inch) thick as the base. Numerous tests have shown that this organic material works essentially as well as the black foam rubber used in the AquaPak as both a solar absorber and as a base insulation.

Tests are ongoing with a series of bottle pasteurizers using various types of bottles as the water container. 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 2002-2006 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. See the photo below. The top of the bottle was stuffed with cotton to slow the evaporation. 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, grass 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.

Figure 5: A typical bottle pasteurizer with a 22-oz. brown beer 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.

Similar tests have been done with 40-oz (1134 ml) beer bottles and with 2-liter plastic bottles. Pasteurization has been achieved, but this appears to be at the limit of what can be achieved in the Ohio summer. More often, the bottles do not reach pasteurization. Of course, at lower latitudes successful pasteurization is more likely.

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.

While the thermal performance of the bottle pasteurizers is good, the amount of water produced is obviously quite small. These pasteurizers will probably stay as educational tools or as curiosities rather than practical methods of producing clean water.

Another type of small pasteurizer cuts the manufacturing labor to near zero. In its simplest form the sack pasteurizer is nothing more than 2 pieces of plastic cut to size and shape. One sheet is circular and is bunched up to form a sack to hold water as shown in Fig. 6. The top of the sack is tied shut to prevent evaporation. The sack should be made of good quality plastic, such as the type used to make the Aquapak.


Fig. 6: The sack from a sack pasteurizer filled with water and tied shut.

The fill and drain spout (nozzle) shown in the photo is optional, and could be used to hold the pasteurization indicator, or the indicator could be inserted from the top. Experience with the AquaPak shows that this spout is not an expensive addition, though it takes some manufacturing expertise. The sack is laid on a dark insulative surface such as the organic layer mentioned above and flattened out as much as possible. Black foam rubber as thin as ¼ inch (6 mm) has also been used. A single cover layer of clear plastic is used to form an insulative air gap above the water sack. This cover layer would be laid over the top of the sack and held down around the edges with whatever materials are available such as stones or dirt.

A table of sack pasteurizer performance is given below. This pasteurizer was made of a circular sheet of plastic for the sack, about 42 inches (1.1 m) in diameter. The cover sheet was about 0.7 m square (28 inches). All days had strong sun, ambient temperatures typically around 30° C, and all tests were conducted in Ohio, 40° N latitude.

Date	Max. Temp. (° C)	Bottom layer	Water (liters)
8/13	70	Black plastic on bubble wrap	3
8/20	65	6 mm black foam	3
8/21	74	black plastic on 6 mm foam	3
8/30	67	black plastic on 50 mm grass	3
9/4	71	50 mm grass	3
9/5	65	50 mm grass	4

On most days, the sack pasteurizer achieved peak temperatures a few degrees higher than an AquaPak with an equal amount of water. As with most small pasteurizers of the puddle type, light wind and condensation in the upper layer seemed to make little difference. Also as with most puddle-type pasteurizers, they did not perform nearly as well on partly cloudy days.

While the sack pasteurizer works, it will probably remain something of a curiosity more than a practical way of producing clean water. The thermal performance is good, but it is difficult to get the plastic sack to "behave" in terms of not spilling water. It is also difficult to get the water out of the sack and into a more usable storage container. A siphon would help in this regard.

Cost Summary

The table below shows an approximate cost summary of the basic methods of water pasteurization described in this document. The initial cost is the amount of money that needs to be spent to get the system running. The water produced per dollar of long term cost is based on a 5-year lifetime, and includes expected maintainance costs and replacement parts. In some cases, a), b), and c) in particular, the maintainance costs are small. For the solar puddle, cases e) and f), the replacement costs for the plastic layers that degrade in the sunlight make up the majority of the long-term cost.

The assumption used in these calculations are:

1) The fuel cost is $0.02 per liter of <u>boiled</u> water (cases a) and b)). This number comes from a recent issue of the Solar Cookers International newsletter, and is the amount of money that some people in the developing world are willing to pay for the fuel to boil drinking water.
2) Pasteurization indicators must be replaced twice in 5 years (cases b), c), e) and f)).
3) Thermostatic valves must be replaced once in 5 years (case d)).
4) For the solar puddle the top 2 layers of plastic are replaced every 3 months, while the bottom 2 layers are replaced every 6 months (cases e) and f)).

System Name	Initial Cost (US dollars)	Liters of Water per Dollar (long term)
a) Flame-heated water pot (heated to boiling with no pasteurization indicator)	Small	50
b) Flame-heated water pot with pasteurization indicator	3	96
c) Solar Box Cooker with pasteurization indicator	23	375
d) Flow through unit with recuperator	65	580
e) Solar Puddle ("family size")	6	1800
f) Solar Puddle (community size, 10 ft. by 25 ft.)	25	3500

It can be seen that the systems using fuel have low initial cost but high long term cost. The pasteurization indicator is an inexpensive way of nearly doubling the water produced per unit of fuel, though the long term costs of such systems are still high due to the cost of the fuel. The solar puddle has low initial cost and low long term costs, but involves the work of replacing the plastic layers frequently.

Acknowledgements

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