Experiments Regarding Four Sanitation Solutions

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This brief informal report covers four sanitation solutions and the preliminary experiments to demonstrate that they work. None of the solutions is intended to be universal, but they should work under a range of conditions in a number of areas around the globe. The experiments and development of these ideas is ongoing, and updated reports will be produced as appropriate.

One solution is a digger/bucket arrangement for emptying the product in septic tanks or latrine pits. The second is a mechanical dumping toilet that requires little water and serves as a mechanical seal, similar to the water seal in an ordinary flush toilet. The final two solutions cover the use of simple solar devices for pasteurizing feces (using heat to kill the pathogens) such that they will not spread disease.

Part 1-Digging Device

In clearing the product from pit latrines or septic tanks, a number of options have been tried. Simple buckets are often used, but these involve extensive contact between the worker and the feces. More modern methods have been used, ranging from large industrial septic tank trucks to hand operated mini-tanks. These methods are typically too expensive, and spare parts can be a problem. Simple hand pumps have been used (the Gulper) but these involve feces passing through the valves of the system, and any foreign objects can cause clogging or cause the valves to not do their job. The device presented here is low in cost, simple to maintain, will work in liquid sludge or thick sludge, and handles foreign objects well. An opening slightly larger than digger itself is needed, typically the squatting hole is not big enough.

The origin of this device was a comment made by someone at a conference along the lines of, "Gulpers don't work, buckets work better". (My apologies to Steven Sugden, the inventor of the Gulper, but that's what the man said.) The present solution retains the simplicity of a bucket but adapts the bucket to keep the worker out of the feces. The bucket is on a handle and pivots from right side up to upside down. A rope controls the angle of the bucket, and there are some supports which prevent the bucket from rotating too far in either direction. The basic design is shown in Fig. 1. The operation of the device is shown on youtube at www.youtube.com/watch?v=EkFbFmU7hg4&feature=youtu.be

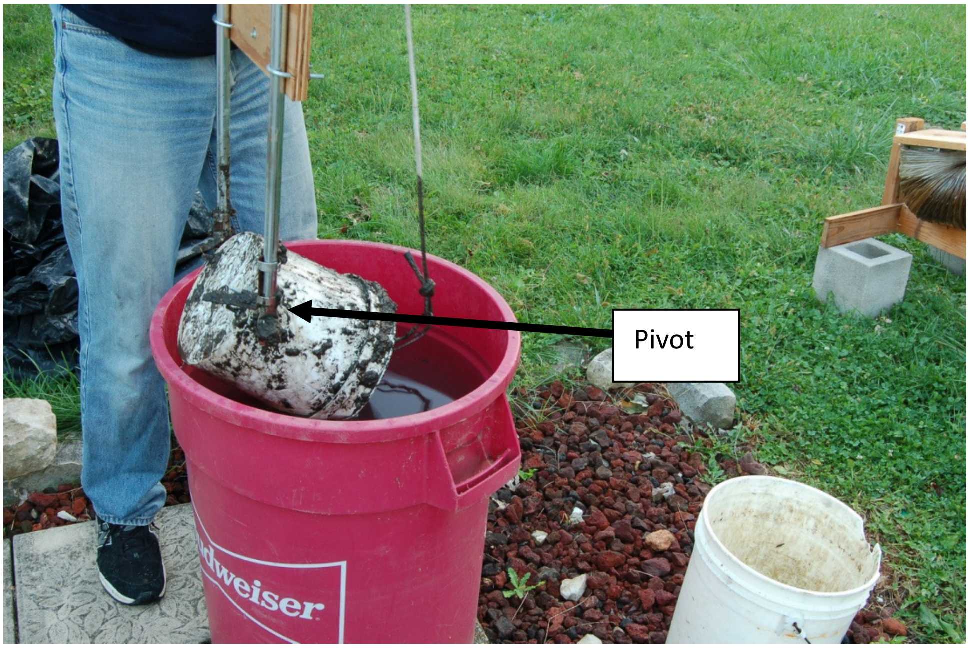

Figure 1: The digger being used in a tub of water, simulating a septic tank or other system with liquid contents. The pivot is indicated. With liquid content, the digger can be used in several ways.

The method of using the digger depends on the liquidity of the contents of the pit. For liquid contents the bucket is lowered into the pit with the opening up as shown in Fig. 2, and forced down into the liquid. The system is pulled up and out of the pit using the handle and rope, then maneuvered over the receiving vessel. By lowering the rope, as in Fig. 3, the bucket is dumped into the receiving vessel.

Figure 2: The bucket loaded with liquid, ready to be pulled out of the pit.

Figure 3: By lowering the rope (in the user's left hand) while holding the handle (in the user's right hand) the bucket is dumped into a receiving vessel for transport.

Figure 4: The system is being used in thicker material. Here, the rope is completely lowered so that the bucket is completely upside down. It is then pushed down into the material, while gently sweeping from left to right. This requires light force, usually not much more than the weight of the system. The bucket has a stop which prevents it from rotating past the fully down position.

Figure 4 shows the system being used in thicker material, which is potting soil saturated with water. (This material has a density of 1200 g per liter, and is typically stickier than actual feces.) The system is slightly different, as there is a small hole in the bottom of the bucket to let the air out when the bucket is pushed down into the feces. The bucket is turned fully upside down before being pushed into the feces. Moving the bucket slightly from left to right in the photo helps keep the bucket upside down.

Figure 5: The rope is pulled up with the left hand while the handle is held in the right. The bucket rotates up. After this, the bucket is pulled up and dumped in the same way as with the thinner material, shown in Fig. 3.

After the bucket is fully embedded in the material, the rope is pulled up to rotate the bucket up, then the bucket is pulled out of the pit and dumped, the same as with the thin material. Not visible in the photos are various objects in the bin and barrel, including bottles, diapers, and corncobs. All of these can be picked up with the bucket. The top of the rope is tied to the top of the handle so the rope doesn't fall into the pit.

The bucket is a 2-gallon bucket, about 7 liters. This is probably the optimum size, any larger and the weight gets excessive but any smaller and the work gets slower. The bucket could be reshaped to fit the pits it works with, for example, if the opening to the pit is narrow then a narrow rectangular bucket could be built. The current diameter of the system is about 30 cm. This could be reduced, if necessary, to fit through the hole in the slab over a septic tank, or to fit through the common keyhole shaped holes seen in many latrine slabs.

Future work to further develop this system includes several items. One is reducing the diameter of the bucket and actually using it on a septic tank. Here in Ohio, holes in septic tanks are typically slightly smaller than 30 cm. A self closing hole in the bottom of the bucket is being developed, with a mechanism for allowing air through when the bucket is upside down and being used with thick contents, but which automatically closes when the bucket is upright. Also under development is a handle which has a hinge for situations where the operator is working under a low ceiling.

Part 2-Dumping Device

The water seal toilet, either using a pour flush or a tank flush, is a common device, and is regularly used with septic tanks, aqua privies, and sewer systems. Under good conditions, it works well. However, the amount of water needed is significant, and anything other than feces or soft paper tends to clog the toilet. In practice, people like to throw household trash, diapers, and menstrual hygiene materials into toilets, especially if they are public toilets. This device would be used in the same applications, but is essentially clog proof and uses much less water, about one half liter per flush.

This device is a basin of a specific shape, pivoting at a specific point, and built with a base around it. Figure 6 is an overall view showing the top of the basin and how it fits into its plywood base and Fig. 7 shows the shape of the basin and the pivot location.

Figure 6: Overall view of the dumping basin with its plywood base. The basin is lined with a Teflon sheet to simulate the fact that ultimately the basin would be made of molded Teflon to resist things sticking to it. In the basin is some potting soil and water is being added to start the dumping process. The water could be the waste water from a hand washing station.

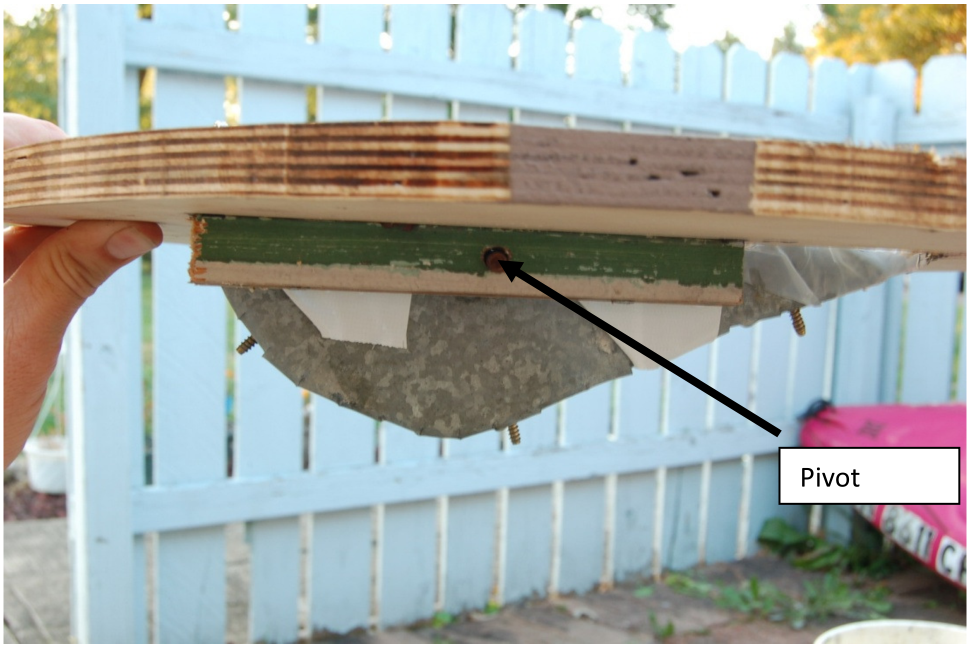

Figure 7: This is a side view of the basin itself, showing the shape of the basin and its pivot location.

When the basin is empty or only partially full the center of mass is to the left of the pivot and the basin is held against a stop. When the basin fills with water the center of mass shifts to the right, and when the bulk of the mass is to the right of the pivot the basin and its contents tip clockwise, as shown in Fig. 8. The contents are dumped into the chamber below, whereupon the empty basin tips counterclockwise, returning to its original position against a stop.

Figure 8: The basin in the process of tipping. The contents are quickly dumped out the right side of the basin into the chamber below.

Various objects have been successfully dumped, including diapers, corn cobs, and bottles. Outside the chamber there is little or no splashing during dumping, and since the basin is dry while the user is defecating, there is no splashing on the user. The current dimensions of the basin are 185 mm parallel to the pivot line and 230 mm perpendicular, but these could be adjusted. A short video of the device in operation with various items is available at youtube at www.youtube.com/watch?v=FSjPO7FOnrM

The basin is currently lined with a Teflon sheet, because most things don't readily stick to Teflon. In its final form the basin could be molded of Teflon.

Since the initial testing, which is shown in the youtube video, the dumper was used for a week by the author. The overall structure with toilet seat is shown in Fig. 9. The system worked well, the average water use was 486 g per "flush". For urination events the amount of water required was 457 g. For defecation events the average was 573. For the empty bowl the amount was 776 g. During the dumping process there was no splashing, and odors were mostly contained within the vessel.

Figure 9: The dumper assembled into a fully functional toilet. This unit was used for a week by the author, with good results.

Some improvements are needed, however. Even with the Teflon sheet the feces stuck to the basin on one test and the basin had to be dumped manually. A manual dump lever should be added. The manual dump level would also allow the system to be dumped manually if the user had no water. Typically, hands-free operation would be preferable, especially in a public toilet, since the user does not need to put his hand where someone else's (potentially) dirty hands have been. The ideal situation is where wastewater from handwashing would be used to accomplish the dumping.

It's too early to use the phrase, "The water loo (flush toilet with water seal) has met its Waterloo", but this mechanical dumper could be an option which is more useful in some places. ("To meet your Waterloo" means to be defeated, as Napoleon was defeated at the Battle of Waterloo in 1815.)

Part 3-Solar Pasteurization of Feces, Two Devices

The basic idea here is that simple solar devices can be used to pasteurize feces, that is, to kill all of the bacteria, viruses, and parasites through the use of heat. The pasteurization of beverages is well known, and it is well known that heat generated in a compost heap can kill pathogens. Feces can be pyrolyzed or desiccated, but these are much more difficult processes that require much more energy and separation of feces from urine and flush water.

Three applications for this idea come to mind, there are probably many more. The first is in rural areas where feces are used as fertilizer, but where the dangers of doing so are known. Feces frequently contain worm eggs, particularly ascaris, (roundworm) and these eggs live a long time in the soil. By pasteurizing the feces farmers may use it on their farms and not catch diseases.

The second application would be in areas where fecal sludge is poorly controlled, where it ends up in the environment despite efforts to contain it. These might include leaky sewage lines, open sewers which theoretically keep the sewage contained but which in fact do not, and waste management facilities (from simple pit latrines up to sewage treatment plants) that are in floodplains and are subjected to flooding. Rosenboom (2013) says that in some areas only 2% of the fecal sludge is properly treated, even though 99% of it goes into some sort of fecal sludge handling system. On many occasions flies and other animals get into or onto the sewage and from there spread disease to humans. If the pathogens are dead, the flies can do anything they like without spreading disease.

The final application is that the mechanism of the tube pasteurizer could be used without the pasteurizing features as the outlet of an above-ground holding tank. This will be described in more detail when the mechanism for dumping the tube pasteurizer is described.

Much data exists about the temperature and time combinations needed to kill a variety of pathogens. Feachem et. al. (1983) published a summary of these numbers, and gives a conservative graph of time temperature combinations. As the temperature increases, the time required decreases significantly. One weakness of the published data is that it does not consider the effects of varying temperature. For example, if sewage is heated from 50°C to 60° and then cools again to 50° over the course of 8 hours, what is the appropriate average temperature to use to determine if the pathogens are dead, or to what extent are they dead?

To answer this question a mathematical relationship was established to determine the 90% kill time at any temperature for the most heat resistant pathogen. Parry and Mortimer (1984) say that this is the Hepatitis A virus, and their data suggests that the numbers from Feachem et. al. are quite conservative in the high temperature end of the scale. This data can be used to generate a differential equation for the rate of reduction of live pathogens as a function of temperature. Then, this is mathematically integrated with respect to time over the varying temperature to give the total kill. Thus, if we know the temperature at all times, we can determine the ratio of live pathogens at the end to the live pathogens at the start. When this ratio is about one millionth (sometimes called 99.9999% reduction or log 6 reduction) the pathogens are effectively eliminated. Even a log 3 reduction (one thousand fold reduction) would be beneficial. Some results will be given later based on the conservative numbers from Feachem. Details of this analysis are available on request.

Two types of pasteurizers were developed, the tube pasteurizer and the bucket pasteurizer. The bucket is the simpler of the two, and consists of one or more buckets under a clear plastic tent, the floor of which is some material that is absorbent to sunshine but somewhat insulative. The buckets would typically be common 5-gallon (19 liter) buckets. The bucket would be used in an outhouse or indoor water closet. The bucket should be covered while not in use, and could also be combined with the dumper in the previous section. When the bucket was nearly full it would be covered and put inside the tent, and a fresh bucket would be put into the outhouse or water closet. Figure 10 shows two buckets with the top layer of the tent removed for purposes of the photograph. With the top cover, it would look much like the tube pasteurizer shown later in Fig. 12.

Figure 10: The bucket pasteurizer with the top cover removed. There are two buckets present, the one on the left holds about 19 liters but it only 80% full. The one on the right holds about 15 liters and is full.

Both buckets are painted black. The bucket on the right of Fig. 10 has a clear top while the one on the left is opaque. The bucket on the left is supported underneath by bricks, while the one on the right is supported by a reinforced bail (wire handle). Both buckets perform about the same. It is important that the bottom of the bucket be mostly uncovered, so that heat radiated from the black bottom of the test can reach the bottom of the bucket.

The tent itself is a single layer of clear plastic. For these experiments a high quality polyethylene plastic was used that is UV stabilized. The bottom layer depends on the climate. In a dry climate a 5 cm or so layer of straw, grass, leaves, or sticks can be used. The top surface of this layer gets hot, but the lower portions insulate the hot layer from the cooler ground. In a wetter climate a plastic layer must be used as a moisture barrier, then there would be straw, sticks, leaves, or similar materials under the plastic. In the tests reported here, straw was used. Much work has been done in the past on similar ideas with regard to drinking water pasteurization (Andreatta et al., 2013) and (Husson et al., 2005).

After the bucket has been in the tent for at least 2 days, it can then be dumped out in the fields or added to compost. If the weather is reasonably good a time-temperature combination will have been achieved to produce log 6 reduction of the pathogens. The smell of feces seems to be a strong function of the temperature, therefore it would be best to do the dumping in the morning when the feces are cool. Overnight the temperature of the buckets drops to just above ambient temperature. One could take the buckets out of the tent in the evening and put them in an insulated container so that they stay hot overnight, further killing the pathogens, but this is an extra step.

Figure 11: Tube pasteurizer without the cover. The inlet end is the high end on the left, with the outlet on the right.

Figure 12: Tube pasteurizer at the test site with cover in place.

The tube pasteurizer is a tube of about 20 cm diameter and at least 1.75 meters in length. The inlet end of the tube would be in the outhouse or water closet, while the bulk of the tube is outdoors and again covered with plastic. Figure 11 shows the tube without its plastic cover, and Fig. 12 shows it at the test site with its plastic cover. The plastic cover was similar to the bucket pasteurizer, except this cover had various pieces of tape repairing holes from a previous test.

Most of the time the inlet and outlet would be covered to prevent evaporation and contain the smell. In the photos small square boards are used for this purpose. The base of the tube pasteurizer is similar to the base of the bucket pasteurizer.

For both of the systems tests were done with cow manure and various amounts of water to simulate urine and/or flush water. The content of the system was thus fairly liquid, though much thicker than water.

One of the key features of the tube pasteurizer is that it is easy to empty. This is done by folding back the top layer (the final version would not require this step) and maneuvering the outlet end of the flexible tube over a receiving vessel using a handle attached to the tube. This is shown in Fig. 13. The handle in Fig. 13 is very small and hidden by the user's hand. A better handle will be developed, but even at present there is no contact between the operator and the feces. Various bits of materials, corn cobs, newspaper, and a simulated flying toilet (plastic bag full of feces) were placed in the tube. The corn cobs were easy to empty, though the tube should be modified to allow the plastic bag to come out easier.

(There is a need for above ground toilets for places with high water tables or frequent flooding. A holding tank could be built above ground, then a system like the outlet of the tube pasteurizer could be used to empty the holding tank, using a technique like that shown in Fig. 13. A small pit could be dug next to the tank to get the bucket as low as possible, so as to drain the tank as much as possible. When not being emptied the tube would be pointed up and covered as in Fig. 11.) A short video of the dumping process is at www.youtube.com/watch?v=0t0xblKOBhc

Figure 13: Emptying the tube pasteurizer. The small handle is hidden inside the operator's hand. The portion of the tube being touched by the operator is never in contact with feces, and is therefore should be clean. A better handle will be developed and will completely eliminate any possible contact.

Typically, a tube pasteurizer would be set up such that it took at least two days for the material to pass through it, and all feces would be subject to at least two daily cycles of heating. The tube could be of any length, such that any number of users could be filling the tube. The diameter should not be much more than 20 cm, as this would produce a slower heating of the contents. If the tube clogs, it could be straightened at the outlet end, and a stick shoved into the outlet to remove the clog. Assuming the stick is long enough, this would not require contact between the operator and the feces.

Both pasteurizers were tested on a farm near Columbus, Ohio, USA, latitude 40.1° N. Daytime temperatures in the summer were around 30°C, but lower later in the year. Ongoing tests were done between late June and late September, 2014, with little good weather. In June and July when the sun is as high in the sky as in a tropical region there were no completely sunny days. On many days it was sunny in the morning and evening but cloudy or partly cloudy in the afternoon. Later in the year when the sky was clearer the sun was lower in the sky. In September when there was frequently good sun the sun was still lower in the sky, and both the daytime and nighttime temperatures were much lower than in most tropical regions. The designs of both types of pasteurizers evolved over the summer, thus there was very limited good weather to test the final designs.

Temperature logging equipment was used to measure a variety of temperatures at 5-minute intervals. For the buckets the temperatures were measured at the bottom. For the tube temperatures were recorded at the lowest point and at the inlet, and these temperatures were very close to each other. The two temperatures in the tube pasteurizer were usually similar. The air temperature inside each tent was also measured.

Detailed results for the bucket pasteurizer for July 21, 2014 are given below. The air temperature inside the collector is graphed, and it can be seen that this number responds quickly to passing clouds. For this day it was sunny in the morning and evening, but partly cloudy in the afternoon. This pattern is typical for this area in July.

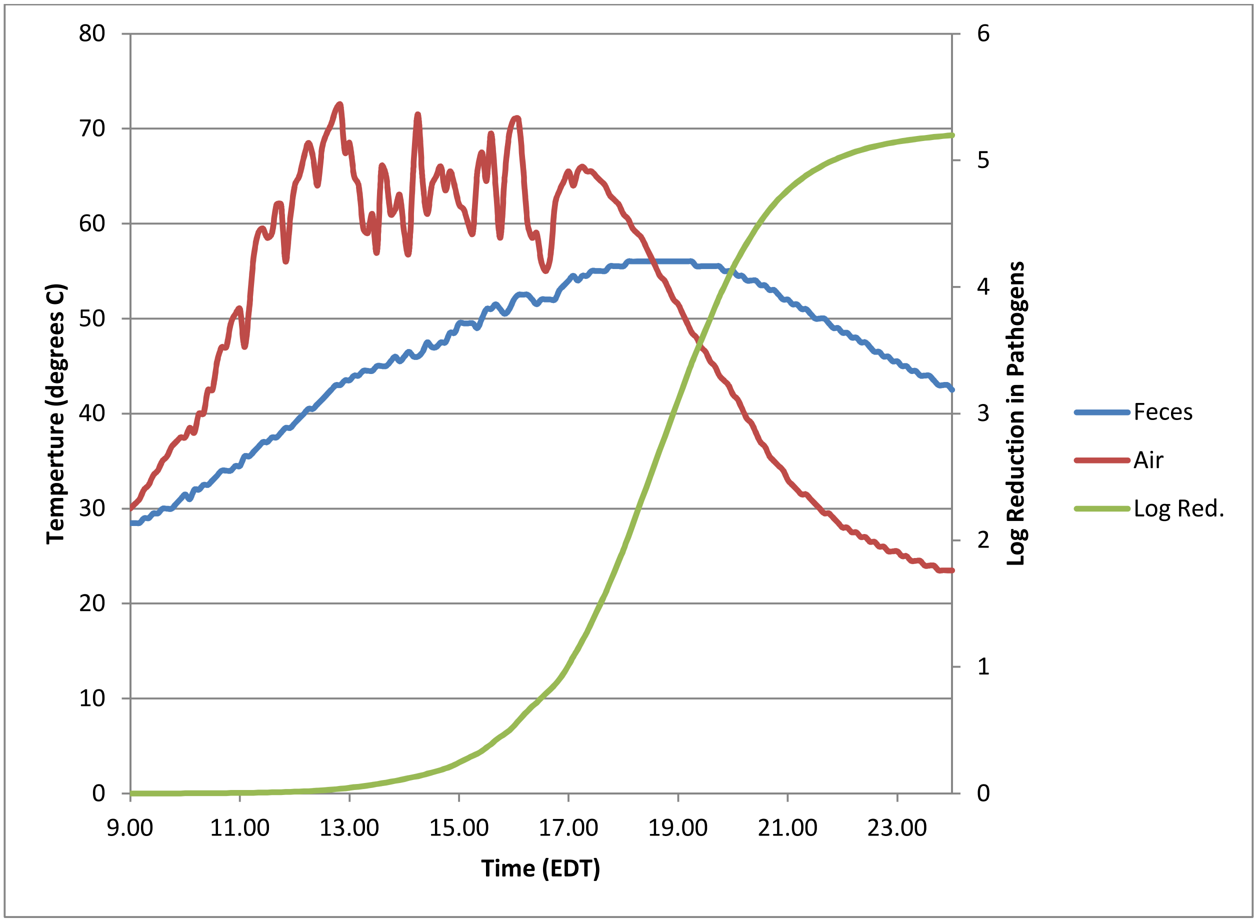

Figure 14: Results for July 21, 2014, bucket pasteurizer. Solar noon is about 13:20 local time.

The temperature of the feces at the bottom of the bucket (the coolest part) is shown, and this shows a peak of about 56° at about 18:30 local time, or about 17:00 solar time. The log reduction doesn't increase much until the temperature of the feces rises above 50°, then rises rapidly. By the end of the day it has not quite achieved a log reduction of 6, but is over 5. As a rule of thumb, for systems that gain temperature slowly and lose temperature slowly, having a peak temperature of about 57° is enough to get a 6 log reduction in one day. Getting two days of 3 log reduction would be equal to one day of 6 log reduction, as each day the pathogen count is reduced by 99.9%.

Figure 15 shows the results for the tube pasteurizer on August 28, 2014. Again, the air temperature responds quickly to passing clouds, and shows that the weather was sunny in the morning and partly cloudy in the afternoon. The sharp drop in air temperature at about 16:30 was caused by the shadow of trees to the west of the test site, and the sharp drop in feces temperature followed. The test site for this test was not at the farm, and thus the solar access was more restricted.

The log reduction only achieved a little more than 3 (one thousand fold reduction) as the feces cooled quickly after 16:30. The peak temperature achieved was 56°. On later days the system was moved to a sunnier location, but cool cloudy weather and the lower angle of the sun in the sky prevented better results.

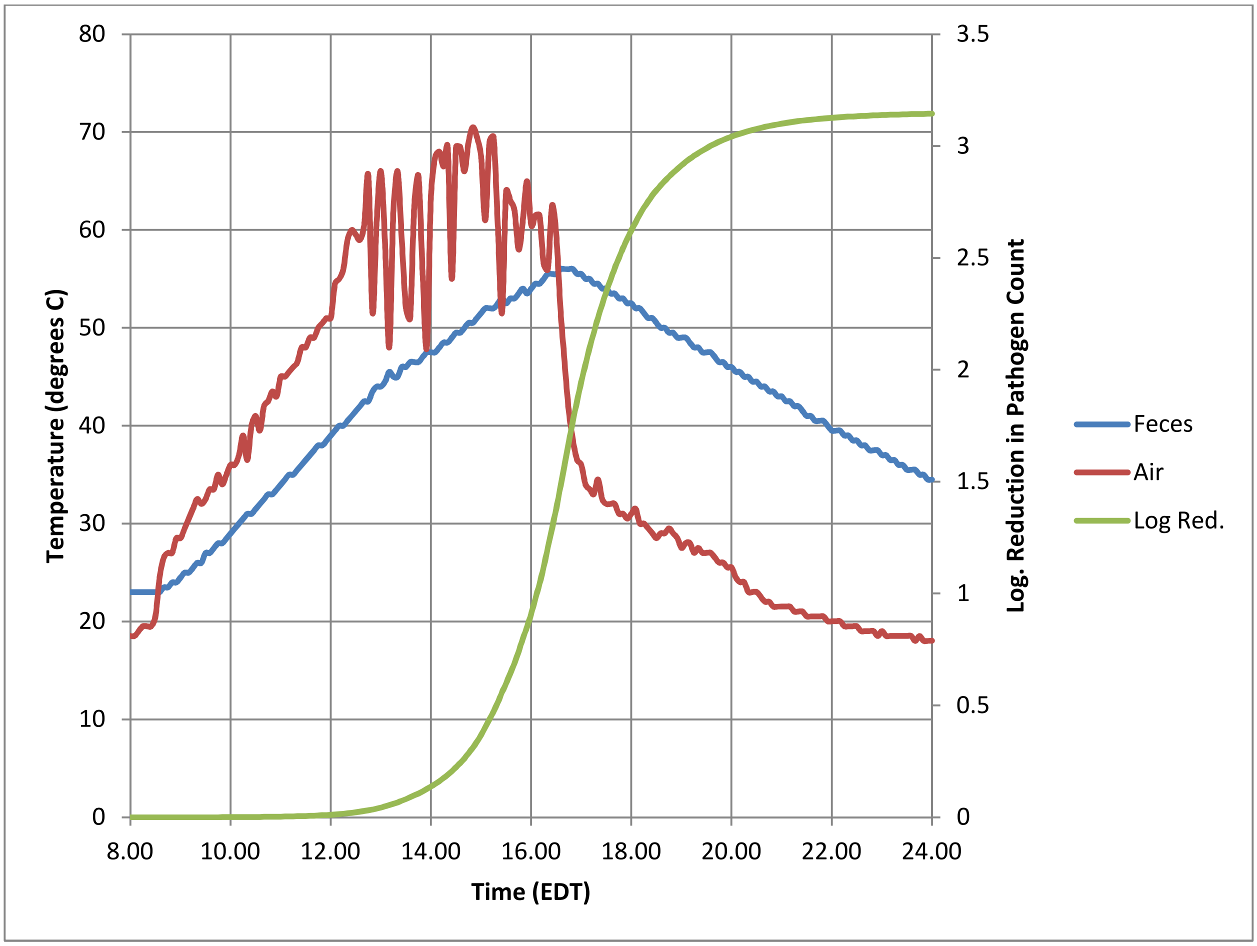

Figure 15: Results for the tube pasteurizer on August 28, 2014. The time is Eastern Daylight Saving Time, in this location solar noon occurs at about 13:20.

If one wanted some sort of confirmation that pasteurization was achieved, one might use a pasteurization indicator. A number of types of pasteurization indicators have been designed for the pasteurization of drinking water. One of these designs was by me, in 1992, and is described as part of Andreatta et al. (2013). The most popular types have a clear tube partially filled with a wax that melts at a temperature that indicates pasteurization and then drops to the bottom of the tube. The tube is reusable, but must be flipped over each time it is used. A different type of indicator involves shape memory metal alloys and has been tested to some extent. With these alloys, a wire is bent while below the transition temperature, then when it rises above the transition temperature it straightens.

For drinking water a wax with a melting temperature of 65°C would be selected, a temperature at which all pathogens are killed in a few minutes (Parry and Mortimer 1984). For pasteurization of feces, what would probably be done would be to study the entire system and determine for what peak temperature is pasteurization achieved, given how fast that type of system heats up and cools down. As mentioned previously, for the bucket pasteurizer this temperature is 57°C, for the tube pasteurizer it may be slightly higher given that the feces cools down quicker. Then, an indicator would be developed with that transition temperature. Most likely, the indicator for fecal pasteurization would be just outside the coolest part of the vessel, not in the feces.

Summarizing the results of solar pasteurization, it was demonstrated that pasteurization can be achieved with simple solar devices in reasonably good weather. Pasteurization was achieved on some days, but on most days it was not. Reasons for this include poor weather, non-optimized design until late in the summer, some mechanical difficulties early in the summer, and wet straw caused by placing the pasteurizer where water ran when it rained. Thus, these pasteurizers are a work in progress, showing potential but requiring some more work. In places with daily high temperatures above 30°C and mostly sunny skies, the pasteurizers should work very well.

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About the Author

I am qualified to work on sanitation because I am a hillbilly from eastern Ohio, where the word "shit" is used, on average, about 1.1 times per sentence. I also have three degrees in mechanical engineering. I work for an engineering consulting company, SEA, Ltd. in Columbus, Ohio, USA, and work on sanitation issues in my spare time, along with cooking and water pasteurization for the developing world. One can do a web search for my name and find various things I've done in cooking and water pasteurization.

I got interested in sanitation in 2013 after seeing a video about the sanitation conditions in Kibera. I was appalled at the situation, outraged that we went to the moon in 1969 but still couldn't empty a pit latrine, and embarrassed that my profession wasn't working on this. So I set out to do something about it….

The author, with some of the providers of the manure used in the testing.