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ANALYSIS AND COMPARISON OF SUSTAINABLE WATER FILTERS

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Analysis and Comparison of Sustainable Water Filters

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ABSTRACT

In 2001 the United Nations declared clean water a "basic human right," and set a goal to halve the number of people without access to clean water and sanitation by the year 2015. There are currently thousands of types of water filters on the market with the ability to purify water contaminated in many different ways. However, most of these filtering methods are too expensive and don't meet the specific needs of many unindustrialized nations of the global south. Such organizations as the United Nations and World Health Organization are currently pushing the water filter industry to develop sustainable solutions to empower many unindustrialized nations with the ability to filter their own water. These sustainable technologies are innovative, simple, and incorporate combinations of basic science and local materials to create usable and efficient filters. It is the goal of this report to investigate the different sustainable water filter technologies, determine a set of guidelines for creating sustainable filters, and then give suggestions about the specific technologies that will help best meet the UN goal.

Keywords: sustainable, water filter, global south, United Nations, World Health Organization.

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EXECUTIVE SUMMARY

This report sets guidelines for developing sustainable water filter technology, compares five current sustainable water filters according to these guidelines, and then gives recommendations for the use of these filters. The recommendations provided are designed to help best meet the goals set be the United Nations (UN). The UN's primary goal, according to their 2001 press release, is to halve the world's population without access to sanitary water by 2015. To reach this goal more than 500 million people will need to gain access to sanitary water, the majority living in the global south.

The global south is the politically correct term referring to unindustrialized or third world nations (most of which are located in the southern hemisphere). These nations lack the economic, technological, and natural resources to develop and pay for advanced water filtering processes. Sustainable methods overcome such barriers by using simple science, readily available materials, and common manufacturing practices to make products. Being able to use sustainable manufacturing allows nations of the global south the ability to produce their own filters and purify their own water, as opposed to relying on foreign aid. Being self-sufficient gives countries more options, including the promotion of economic and cultural prosperity. However, sustainable filters are only one step towards complete sanitation of water sources.

After analyzing the five sustainable filters, it is evident that much more work needs to be done. None of the filters sufficiently filtered out viruses or chemicals, and only one filter was effective at reducing the consumption of hard metals. If the UN is to effectively reach its goal, all contaminants must be eliminated. On a positive note, viruses, chemicals, and hard metals account for a small percentage of the deaths related to consumption of unsanitary water. It is bacteria that present the greatest water-borne threat to human health in the global south. Fortunately, four of the five water filters researched eliminated more than 95% of bacteria.

If sustainable filter technologies similar to the ones studied in this report are to be successful, education and empowerment must be the driving factors behind the filter production. If a community is given the opportunity to learn for themselves about the importance of water conservation and filtration they will be more likely to implement such practices into their daily lifestyles. This is the same for developing filters. If a local potter makes a ceramic filter, the community is more likely to trust him or her than a filter given to them from a foreign government. Giving a community the independence and economic opportunities that will come through the development of filters is essential. It is also necessary to do so in a manner that does not interfere with local cultures or the environment. Even though the gap in technological advancement between industrialized nations and the global south is increasing, these nations will not be stretched beyond their limits if they are not dependent on outside sources for their own well being. Sustainable filters are a means of limiting this dependence, and will serve to improve global health until better solutions are developed.

INTRODUCTION

The United Nations (UN) and the World Health Organization (WHO) have both stated in numerous publications that they believe future wars will not be fought over oil, but rather over access to sanitary water. Sanitary drinking water is defined by the WHO as water that does "not represent any significant risk to health over a lifetime of consumption." With over one billion people drinking unsanitary water and 2.2 million dying worldwide every year because they lack basic hygiene, it is imperative that action is taken to reduce these numbers (WHO/UNICEF, 2004). In 2002 the UN declared clean water a "basic human right," and set a goal to halve the number of people without access to clean water and sanitation by the year 2015 (ENS, 2001). Many countries are on track to meet this goal; however a large portion of the **global south** (developing countries primarily in the southern hemisphere) does not have the filtering resources necessary to make the 2015 deadline.

There are thousands of types of water filters that have the capability to purify contaminated water. However, most filters are too expensive for the nations with the greatest need for **potable** water. Figure 1 shows improved drinking water coverage according to wealth quintiles. According to Figure 1 the poorest nations trail the richest nations with 40% less improved water source coverage in 2002. The regions with the worst coverage are located in sub-Saharan Africa and Oceania (Figure 2). Technologically advanced filters have no real application in countries without the capability to sustain them, which is why more basic filtering methods are needed to truly have an impact on the global clean water shortage. Such organizations as the UN and WHO are currently pushing the water filter industry to develop **sustainable** solutions to empower many rural nations with the ability to filter their own water in cheaper, more environmentally friendly ways. These sustainable technologies are innovative, simple, and incorporate combinations of basic science and local materials to create usable and efficient filters. It is the objective of this report to suggest a set of guidelines for creating sustainable filters, investigate five different sustainable water filter technologies, and then give suggestions on how to best help meet the UN goal.

PART I: GUIDELINES FOR CREATING SUSTAINABLE WATER FILTERS

Sustainable, or appropriate, technology is defined as, "Technology that can be made at an affordable price by ordinary people using local materials to do useful work in ways that do the least possible harm to both human society and the environment," (W. Cunningham, M. Cunningham, Saigo, 1999). It is possible to identify guidelines for classifying a sustainable technology from both this definition, and information from some of the ethical standards that are beginning to emerge in this area. One publication that provided insight into the ethical standards for developing these guidelines was The Journal of Sustainable Design. The Journal of Sustainable Design publishes many articles highlighting the most recent developments in the area of sustainable product design and research.

After reviewing many journal articles and doing intensive research, it became evident that there are no documented standards classifying sustainable filters based upon quantitative specifications. Instead, there is a gray area in which engineering judgment is used to determine the level to which a filter actually is sustainable. The following guidelines are suggested based on an evaluation of the sustainable technology definition, the ethical standards, and information from sustainable development of non-filter technologies. It is important to keep in mind that these steps are to be used in addition to traditional engineering standards and ethics.

Guidelines

1. Limit non-renewable energy consumption

Little to no consumption of non-renewable energy should occur during the production or use of a water filter that is to be classified as sustainable. "Sustainable development will subsequently remain a dream or fiction if we do not rationalize our use of raw materials," (Kretzschmar, 1994). According to Kretzschmar, the most important part of this "rationalization of raw materials" is limiting the use of fossil fuels and non-renewable energy. It is common knowledge that there is a finite supply of non-renewable energy, especially fossil fuels such as oil and coal. There are also severe local and global impacts on human health and the environment when fossil fuels are combusted to produce energy. Global warming and birth defects are just two of the countless risks associated with pollution created by the production of non-renewable energy. By creating sustainable products the dependence on non-renewable resources will be reduced. If there are no non-renewable energy options available to a manufacturer, it is recommended that the "rational use of energy" guidelines are followed.

> "Rational use of energy or RUE means: save energy where and when possible; increase the efficiency of the processes; improve the quality of the energy vector or fuel; use energy under its most appropriate form; and recuperate energy from waste streams in order to optimize the net energy input per unit end product and minimize, at the same time, its environmental impact," (Kretzschmar, 1994).

If non-renewable energy is used in the production of a sustainable product, sufficient RUE methods should be included to balance out any possible negative effects on the environment or human health. In general, a water filter product can only be considered completely sustainable if production uses only renewable energy, or the non-renewable energy impact is completely balanced by positive contributions using RUE methodology.

2. Lessen environmental impact

The environment should not be negatively impacted during the production or use of a sustainable water filter. This includes limiting pollution, building facilities that do not destroy natural habitats, and not interfering with any other natural processes. Basic engineering ethics should be used to assess the environmental impact caused by the production and use of a water filter, and proven science should determine whether or not a product is meeting all environmental standards. It should also be noted that once harmful contaminants are filtered from a water supply using a sustainable filter, contaminants should not be reintroduced into the ecosystem. This may involve training or instructions included with the purchase of a sustainable water filter.

3. Select appropriate materials

Materials should be selected that are readily available, easy to manufacture, and adhere to steps 1 and 2. Material selection is a crucial step in developing a successful sustainable filter. Materials should be readily available, renewable, recyclable, and re-useable when possible. It is important to continue developing new ways to use common materials, especially when developing sustainable technology for the third world. As science progresses the global south is falling farther and farther behind in an industrial sense. If these countries are to become more independent, local materials must be used more efficiently and in a sustainable way. Also, the importation of more technologically advanced materials will only serve to hinder a third world countries industrial and economic growth as well as fuel further dependence on foreign goods.

4. Choose safe and efficient manufacturing processes

Manufacturing processes should not pose harm to individuals, be as simple as possible, and adhere to steps 1-3. Typically, conventional manufacturing processes do not effectively eliminate environmental impact, and are not nearly efficient enough to be considered sustainable. New methods should be developed to make manufacturing as sustainable as possible. **LEAN** and **Just-in-time manufacturing** are two methods of improving the efficiency of manufacturing processes. It should also be noted that material selection and energy consumption are directly related to manufacturing, making the effectiveness of each dependent on one another.

5. Assess cultural impact

Steps 1-4 should not disregard cultural principles, practices, or customs. If a product is not socially acceptable, people will not want to use or own it. If individuals are forced into using a culturally unacceptable product, the product may begin to slowly deteriorate cultural identity. Many product developers consider the indirect effects of a product on various populations, but not the direct implications. There is a big difference between designing a product that makes use of **green principles** and a product that meets green principles and still maintains cultural acceptance. Culture and identity need to be sustained just as much as the environment.

Adhering to the five guidelines is essential to create a sustainable product, and directly reduce the toll product manufacturing has on the Earth. Although it is impossible to manufacture a *completely sustainable* product, these guidelines provide a way of making products as sustainable as possible. Please keep these guidelines in mind as the report investigates five different sustainable water filter technologies in part two.

PART 2: INVESTIGATION OF SUSTAINABLE WATER FILTER TECHNOLOGIES

After developing guidelines for classifying a filter as sustainable or not, five water filters were chosen that closely matched these guidelines. The water filters chosen were:

1. Silver impregnated ceramic filter
2. Sediment filter with iron oxide
3. Plastic mesh micro-filters
4. Activated carbon filter
5. Solar cooker

All five of these filters were researched, and evaluated based upon the following criteria:

- Manufacturing time/cost
- Material availability
- Efficiency of removing contaminants
    - Bacteria
    - Viruses
    - Chemicals
    - Hard metals
- Cultural impact
- Filter Specifications
    - Pore size
    - Flow rate
    - Physical size

This report will now highlight this research with an individual analysis of each water filter, followed by a cross-comparison of the collected data.

1. Silver impregnated ceramic filter

The silver impregnated ceramic filter was invented by a Guatemalan potter, and has since been studied and analyzed by top ranking research institutions. The Massachusetts Institute of Technology has tested and praised the ceramic filter as "a valid tool to decrease the contamination level of water consumed by households in rural areas" (MIT, 2002). The ceramic filter has been 99.9% successful at removing bacteria under laboratory testing conditions. This statistic is quite impressive for such a simple, yet ingenious **point-of-use** filter.

The ceramic water filter takes advantage of **burnout materials,** such as sawdust, to create tiny pores in a clay pot. The process of creating a ceramic filter begins by uniformly mixing exact proportions of clay and finely ground burnout materials. The choice of burnout material is usually dependant on what is readily available in the area of production. The most ideal burnout material is sawdust produced by the processing of hardwoods. Hardwood sawdust will not bloat as much as sawdust from softer woods, resulting in smaller more uniform pores and fewer defects in the filter (Rivera, 2004). Once the burnout material and clay are mixed, they can be formed into the desired filter shape. The most common shapes are the pot or candle (Figure 3). There is no specific shape requirement for the filter, however it is necessary that the clay is uniform and does not contain air bubbles or other imperfections. Several manufacturing groups producing similar filters in Nicaragua use a car jack and mold to press the filter into the desired shape. Once the shape is formed it is fired in a flattop updraft kiln. This particular type of kiln is small, conserves energy, and burns extremely hot. The filters are usually fired at **cone** O12 (~1600 F), however the necessary kiln temperature will vary depending on the type of clay used (Rivera, 2004). An experienced potter should be queried during the manufacturing and development process to aid in the determination of the correct kiln temperature. After the pot is fired, the burnout materials dissipate and the clay hardens (Figure 4).

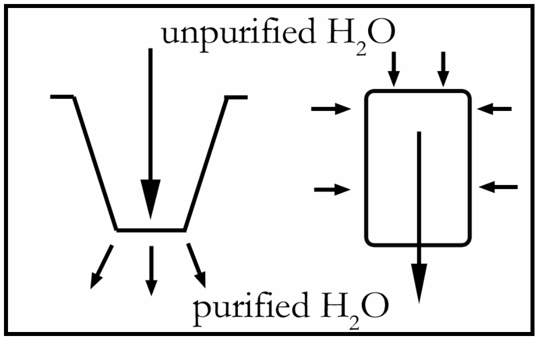


Figure 3: Diagram comparing pot (left) to candle (right) ceramic filter shapes.

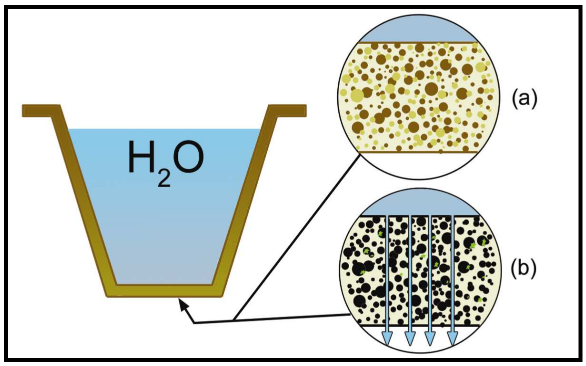


Figure 4: (a) Burnout particles are suspended in clay prior to firing. (b) Once fired, the burnout materials dissipate and tiny pores remain. These tiny pores capture bacteria while letting water pass.

The ceramic filter is usually soaked for 24 hrs in water to enhance the curing process. Once cured and completely dried, the filter is tested to ensure the proper flow rate. A flow rate of 1.5-2 liters per hour is required. If a flow rate greater than two liters is achieved, the pore size is too large. This is not desirable because harmful contaminants will exit the filter. If a flow rate of less than 1.5 liters per hour is calculated, then the filter will not meet the basic water purification needs of most families. Once a filter passes the flow rate test it is then painted on the inside (where contaminated water will be placed) with colloidal silver.

Colloidal silver is a common disinfectant, and is readily available in most countries of the global south. Colloidal silver is a silver ion, and is created by passing an electrical charge through solid silver suspended in a H_2O solution. Passing the current through the silver creates the silver "colloid" with one less electron. "[Colloidal] silver binds to the cell membrane of bacteria. Sensitive cells then increase in size and cytoplasmic contents, and cell membrane and outer cell layers all present abnormalities. These abnormalities result in cell **lysis** and death," (Danielle, 2001). Adding the silvers antibacterial properties to the filter ensures the 99.9% removal of most common types of water borne bacteria. This added effect is positive, however ingestion of too much silver can cause severe health risks related to **argyria** (silver poisoning). These risks have limited the use of colloidal silver in the United States. However, the side effects have been studied in depth and do not pose any significant risk to users of the ceramic filter. It fact, studies have proved "that all water concentrations of silver after filtration in the Potters for Peace [ceramic] filter were well below both the USEPA and WHO standard" (Lantagne, 2001).

Advantages

The silver impregnated ceramic filter can be made almost anywhere in the world. The only requirements to make the filter are that clay, sawdust, and colloidal silver are available along with the ability to fire a kiln. With the addition of colloidal silver, ceramic filters are 99.9% effective at removing bacteria. The ceramic filter is also point-of-use and can be distributed to remote communities, making it one of the most effective and culturally acceptable sustainable filters on the market.

Disadvantages

The fuel consumption and pollution of the kiln is the greatest disadvantage involved with the production of the ceramic filter. It should also be noted that the filter does not sufficiently filter out viruses, harmful chemicals, or hard metals. Eliminating these contaminants will eventually need to be addressed, along with the fact that the efficiency of the filter is reduced to removing only 60-70% of bacteria when actually used by rural families. This is a direct result of improper use and/or cleaning of the filter.

Recommendations

To address the fuel consumption concern, it is recommended that renewable energy sources are used to fire kilns when producing this filter. One solution that is becoming very popular in the global south is fuel briquetting. This is the process of compressing compost, manure, grass, and other agricultural byproducts into donut shaped briquettes. Using the briquettes instead of wood or coal decreases deforestation and makes this filter more sustainable. The kiln will still produce smoke, but the fact that trees will no longer be cut down helps to balance this out negative effect with a positive. Briquettes also burn hotter, longer, and more efficiently than wood or coal. The higher heat index of briquettes ensures that the kiln temperature will not be negatively affected. The final recommendation is that there is continued implementation of instructional stickers (Figure 5) and water conservation education.

2. Sediment filter with iron oxide

Sediment filters are quite common and have been around for centuries. Most sediment filters are not point-of-use, but rather filter large amounts of water for an entire community. A sediment filter takes advantage of multiple layers of sediment to naturally filter contaminants from water. The top sediment layer consists of larger sized rocks (large matter is captured in these layers to prevent clogging), followed by smaller rocks, then sand and very finely ground sediment (Figure 5). Contaminants are trapped in the tiny pores between the sediment and clean water exits the bottom of the filter. This purification method is similar to the method in which well or spring water is purified by traveling through layers of sediment on the earth's surface. And just as a deeper well will yield cleaner water, a larger sediment filter will produce purer water.

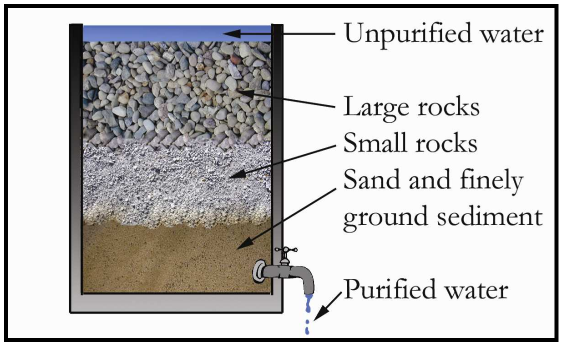


Figure 5: Schematic of a typical sediment filter.

The sediment filter is sufficient at filtering bacteria, and thanks to a new discovery hard metals are now also being removed using sediment filters. The application of iron nails throughout a sediment filter makes it very effective at removing substances such as arsenic. When iron nails are added to a sediment filter, iron oxide (rust) is eventually formed. The balanced chemical reaction for the creation of iron oxide is $4Fe + 3O_2 = 2Fe_2O_3$, and the ionic half equation is Fe (s) = Fe_2+ (aq) + 2e- (basic chemistry). This is an oxidizing process, which means that iron is losing electrons. This loss of electrons makes the iron very attractive to other hard metals. It is this attraction that makes the addition of iron to the sediment filter so important. Harmful hard metals such as arsenic bond to the negatively charged iron, and the water exiting the system is free of hard metals.

The addition of nails and other iron or aluminum material to sediment filters works well. A commonly encountered problem with this process is evenly distributing the nails. Methods to improve distribution of oxidized metals are currently being studied at the University of Wisconsin – Madison, where research is being done using nanotechnology. In this research, grains of sand or charcoal are covered with tiny aluminum or iron oxide particles. These can then be evenly distributed as an entire layer in a sediment filter in order to retain a greater amount of harmful hard metals. This is a very new research and there is has not been any released results on the effectiveness of this approach.

Advantages

The main advantage of the sediment filter is that it uses natural filtration and readily available materials. The added benefit of removing both hard metals and bacteria make the sediment filter a popular choice for many centralized communities.

Disadvantages

One of the problems with a sediment filter is that there is a low degree of scientific control. Sediment can form pockets or form large pores. The use of higher capacity sediment filters reduces the scientific error, but the increased size also makes manufacturing much more difficult. Having large sediment filters that are not point-of-use add the issue distribution. If a community is centralized, distribution is usually not difficult, but if a community is spread out it is more difficult to distribute water from a centralized location. On-site or point-of-use purification increases the likelihood that individuals will use purified water, and is a reason the large sediment filter has limited applications in rural communities.

Recommendations

The sediment filter removes hard metals and bacteria using somewhat primitive technology. With the advancement of nanotechnology it is possible that the same scientific principles used in the sediment filter could be applied to many different applications and with greater efficiency. It is the recommendation of this report that further research is done concerning nanotechnology, and that sediment filters be used in centralized communities. The effectiveness of sediment filters is not as great as the other filters in this report and maintaining the large basins is quite costly. These factors make the sediment filter a last resort option .

3. Plastic mesh micro-filters

The plastic-mesh micro-filter is currently used in many industrial filter applications including the production of carbonated beverages or other liquid food products. This is an exciting technology that has not reached its true potential. Plastic mesh micro-filters can be produced from many common polymers, usually polyethylene. Pore sizes as small as 0.5 microns can be consistently produced using tiny needles or lasers to perforate hundreds of individual layers of this fabric like material. Unlike the ceramic filter, which also has ~1 micron pores, the plastic mesh micro-filter has flow rates up to 10 times faster (15-50 liters/hr), and has a relatively lower degree of scientific error. This makes the mesh filters extremely reliable, and very effective. The problems with the filter are that it requires advanced processing techniques, uses petroleum based plastic material, and is not very sustainable. Also, the filter is so good that it often clogs and requires frequent cleaning.

With these problems in mind, research can be conducted to help improve these filters and make them more sustainable. With the widespread distribution of plastics, it is becoming easier to obtain the necessary resources for the plastic mesh filter. Plastics are also extremely cheap, and these filters can be produced for ~$0.01/sq. in. If a cheap, recyclable solution can be mass-produced – the positive global effect would outweigh the negative aspects concerning the products sustainability. The plastic mesh micro-filter is particularly applicable to communities dealing with natural disaster. These communities do not have time to set up a ceramic filter making operation or build a sediment filter. The filters are extremely lightweight and much cheaper than shipping in bottles of purified water. It is possible to design a filter that would snap over the end of a faucet and cost only pennies. These filters would help save money and empower individuals to obtain their own water without relying on the next shipment to arrive in relief situations.

The final development concerning the plastic mesh micro-filter is the surge in use of bioplastics. Bioplastics are created from agricultural crops instead of from petroleum. These biodegradable plastics are more sustainable, and have potential to fit in the filter market. The only problem with bioplastics is that they decompose over time, which causes pores to enlarge and water to become contaminated. If the decomposition of bioplastics can be reduced in filtering applications, this will make the plastic mesh micro-filter a much more sustainable option.

Advantages

The plastic mesh micro filter is cheap, recyclable, and the pore sizes are easily controlled. Having a such a controlled product creates higher reliability and allows for 99.9% elimination of contaminants larger than the manufactured pore size.

Disadvantages

The plastic mesh micro-filter is currently not sustainable, nor can it be manufactured in most unindustrialized nations. Not being able to locally produce the product makes it less culturally acceptable, and less likely that individuals will properly use it. It is also important to keep in mind that much of this data is based on current research or industrial applications, and flow rates will change drastically when they are not used in combination with a pumping system.

Recommendations

If the filter can be made more recyclable and easier to manufacture, it will be much more suitable as a sustainable technology. Being able to locally produce such a filter would have extremely positive results. Until then, it is the recommendation of this report that the mesh filter be used only in emergency situations.

4. Activated carbon filter

Activated carbon filter media is relatively common, and is found in Brita or PUR filters. The activation of carbon occurs when charcoal or matter rich in carbon (i.e. coconut husks, bones, plants) is treated with oxygen (How Stuff Works, 2005). According to Dr. V. Hauer, an activated carbon researcher, "activation can be achieved by passing water vapor ($C + H_2O \rightarrow CO + H_2$), air ($C + 0.5O_2 \rightarrow CO$) or carbon dioxide-bearing gases ($C + CO_2 \rightarrow 2CO$) through a carbon substance at 700-900˚C." This opens up the pores between carbon atoms that are highly attractive to many organic and some inorganic compounds. As water is forced through an activated carbon filter certain compounds adhere to the gaps. Eventually the gaps become full and the filter will need to be replaced. Substances that adhere to the gaps include chlorine, organic arsenic, and

Advantages

The activated carbon filter makes water taste good and eliminates chlorine and various organic compounds.

Disadvantages

This filter does not filter out nearly enough contaminants, and cannot be considered as primary filter. "AC [activated carbon] filtration should only be used on water that has been tested and found to be bacteria free or effectively treated for pathogenic bacteria," (How Stuff Works, 2005).

Statements similar to this one were found from numerous sources, leading to the conclusion that activated carbon is simply unacceptable at removing bacteriological and viral contaminants.
Recommendations

It is the recommendation of this report that activated carbon is used only as a secondary filter, or in areas where chlorine contamination is present. If ingestion of high amounts of chlorine occurs, individuals can become ill or die. In situations where chlorine is being added to water in an unregulated manner, the use of an activated carbon filter is highly recommended to prevent health complications.

5. Solar Pasteurizer

The solar pasteurizer is technically not a filter. This report chose to analyze the solar pasteurizer because it is a device proven to eliminate bacteria from water. The pastuerizer is a combination of reflective materials that focus sunlight, a dark container that absorbs sunlight, and insulating materials to prevent heat loss. There are many ways to construct a solar pasteurizer (conical shape, box shape), but no matter how it is construction it is essential that there are tight seals and appropriate materials are selected. Once a pasteurizer has been constructed, it is placed in the sunlight until the water reached 65˚C. At this temperature bacteria will die, and the water will be purified. Users of solar pasteurizers will need a thermometer or wax indicator to determine when water is ready for consumptions. When a wax indicator reaches 65˚C it shrinks, becomes unbalanced, and flips over in the water. This signals the completion of the pasteurization process. The wax filter re-expands when it cools and can be used over indefinitely. The wax indicator is preferred over a thermometer because it is cheaper, more sustainable, and does not contain mercury.

Advantages

Once constructed a solar pasteurizer requires nothing more than a sunny day in order to eliminate bacteria.

Disadvantages

If there is no sunlight, it is impossible to heat the water to 65˚C. The solar pasteurizer also does not remove chemicals, hard metals, or very many viruses.

Recommendations

The solar pasteurizer is a very good at removing bacteria if the conditions are right. In areas close to the equator having a solar pasteurizer could effectively produces enough purified water for an entire family. The pasteurizer can even be used to heat food and beverages. However, if regiors are prone to long rainy seasons or other factors that would inhibit a solar pasteurizer, it is recommended that alternative options be available to purify water.

Table 1 – Quantitative Comparison of Water Filter Specifications

Filter	Pore size (microns)	Bacteria removal (%)	Hard metal removal (%)	Virus removal (%)	Capacity (liters/hr)
Silver impregnated ceramic	0.6-3	99%	50%	20%	1.5-2
Sediment Filter with Iron	1-100	95%	90%	20%	10-500
Plastic Mesh Micro-Filter	0.5,1,2	99.9%	50%	30%	10-50
Activated Carbon Filter	1-10	50%	50%	10%	150
Solar Pasteurizer	NA	99%	0%	30%	4

Table 2 – Cultural Impact of Water Filters

Filter	Locally Made	Manufacturing Time	Manufacturing Cost (US$)	Material Availability	Environmental Impact
Silver impregnated ceramic	YES	36 hrs.	4	GOOD	Deforestation
Sediment Filter with Iron	YES	1 week	100-1,000	GOOD	Ore mining
Plastic Mesh Micro-Filter	NO	1 hr.	0.01/sq. in.	POOR	Petroleum based
Activated Carbon Filter	NO	1 hr.	15-50	POOR	Use of charcoal
Solar Pasteurizer	YES	2 hrs.	10-30	GOOD	None

Information in Tables 1 and 2 is estimated based on all of the references provided.

PART III: RECOMMENDATIONS TO THE UNITED NATIONS

In order to meet United Nations goal to halve the number of individuals without access to clean water by 2015, more than 500 million people will need to receive aid. This is a formidable task, and will require a combination of different sustainable and non-sustainable technologies to bridge the gap between industrialized and unindustrialized nations. The UN and WHO are already monitoring the progress of many nations in meeting this goal. From the UNICEF/WHO assessment of improved water and sanitation coverage, it is evident that poorer nations are struggling to a greater degree than wealthy nations to improve the quality of their drinking water (Figure 2). This was expected and is disheartening, but the fact that there has been great improvement worldwide over the past ten years gives hope to the cause (Figure 2).

Following the analysis of the five water filters, it was evident that none of them completely eliminated all contaminants from water, and none of them were able to remove viruses or chemical agents. This is not ideal, however there is hope for progress. Viruses and chemicals cause far fewer health problems as a result of drinking unpurified water when compared to bacteriological agents.

Over 4% of all deaths worldwide are caused by diarrhea (WHO/UNICEF, 2005). These deaths are most commonly attributed to gastrointestinal infections (2.2 million deaths/year), cholera, E.coli, and dysentery; all caused by bacteriological pathogens (WHO/UNICEF, 2004). This is why the first and most important step to take in the battle against unsanitary water consumption is the elimination of all bacteria. As resources and technology advance, the addition of measures to reduce viruses, chemicals, and hard metals can be implemented. The following sections highlight the recommendations to better eliminate the four most common contaminants - bacteria, hard metals, viruses, and chemicals.

Bacteria Removal

All of the water filters analyzed eliminated over 95% of the bacteria in a water supply with the exception of the charcoal filter.

"The most medically important waterborne diseases caused by bacteria include typhoid (Salmonella typhi), paratyphoid (Salmonella paratyphi-A), bacillary dysentery (Shigella spp.), campylobacter enteritis (Campylobacter jejuni) salmonellosis and enteric fever (Salmonella spp.), leptospirosis (Leptospira) and cholera (Vibrio cholerae)."

These bacteria are responsible for the majority of deaths associated with drinking unpurified water (WHO/UNICEF, 2004), and are the reason this report has chosen bacteria to be the most important contaminant to eliminate. Activated charcoal's inability to fully remove bacteria, and the fact that it is a fossil fuel, leads to the conclusion that activated charcoal filters should not be used as a primary filtering process. Of the four filters that were able to remove bacteria, the plastic mesh micro-filter performs the best over time. This is a direct result of advanced manufacturing involved in the production of plastic mesh micro-filters. The ceramic filter, sediment filter, and solar pasteurizer perform just as well as the plastic mesh micro-filter in "laboratory conditions." However, when these filters are used in practice individuals are not properly using or cleaning them. It is also very common for households to even ignore using their filters. For instance, the overall effectiveness of the ceramic filter has been shown to have dipped to 60-70% when used in common households in Nicaragua (Lantagne, 2001). These findings lead to the recommendation that a stronger emphasis be placed on the education of filter owners. The proper use of filters as well as the necessary cleaning methods should be highly stressed, and more informative instructions with text and pictures describing the processes must be included with each filter. If individuals in the global south understand the "bigger picture," they will be more likely to conserve water and properly use the filtering methods available to them. Continued funding of Non-profit Government Organizations will aid in developing appropriate and sustainable technologies, and if this is combined with proper education, the UN's progress towards reaching their goal will exponentially increase.

Hard Metal Removal

The only filter that was able to remove hard metals was the sediment filter with iron nails. Without advanced manufacturing or industrialized filtering methods, hard metals are very difficult to eliminate. The creative solution of adding nails, which become attractive to hard metals after oxidation, is truly ingenious. If nanotechnology can be further developed filters could then be lined with a coating of iron or aluminum particles, which will then attract hard metals in a less crude and more efficient manner. There are a lot of variables in this research, and nanotechnology could end up creating more harm then good. It is the recommendation of this paper that further investigation of this research continue, but the use of nanotechnology should not be implemented until the health and environmental risks are completely known. Another, less technologically advanced, method of removing hard metals is the use of settling basins. In a settling basin gravity forces hard metals to the bottom of a tank, and then water slowly leaves from the top of the tank, thus leaving behind the settled hard metals. This process is slower, but could be used where iron is not available and hard metals pose a significant risk.

Virus Removal

"There are over 100 viruses from 13 families that are capable of transmission in drinking water," according to the Environmental Protection agency (EPA, 2005). This is quite scary considering that none of the filters studied sufficiently removed viruses from sample water. Viruses are as small as 0.004 microns, which is nearly impossible to remove through filtration. To remove viruses it is necessary to disinfect water by boiling or treating it with chemicals. In areas where viral infections are common, it is not recommended that any of these filtering methods be used without the addition of boiling or using chlorine to further disinfect the water. However, if water-borne viruses are not prevalent theses filtering methods are can be used until more effective means are available. In several areas that do have large numbers of cases of water-borne viruses chlorine has been distributed in small bottles to members of the community. This chlorine is added to water in what could be potentially lethal quantities if not used properly. If this option is to be pursued further it is the recommendation of this report that activated carbon is also distributed along with the chlorine. Activated carbon does not filter viruses, but one of it's redeeming qualities is it's strong attraction to chlorine. Using the chlorine to disinfect the water, and then the carbon filter to remove excess amounts of the possibly lethal chemical are a possible alternative to remove viruses when no other options are available.

Chemical Removal

None of the filters, with the exception of activated carbon removing chlorine, effectively eliminate any chemicals. There are no real recommendations for the application of sustainable filters to remove chemicals. The only advice that can be given is that water is periodically tested for harmful chemicals, and if they are detected consumption of water from that source should cease immediately. These problems can be curbed with stricter waster disposal regulations and containment of industrial run-off.

CONCLUSION

The technological gap is growing wider between industrialized nations and the global south. With this widening gap comes a greater responsibility of first world nations to develop sustainable and appropriate technologies to meet the immediate needs of struggling nations without depleting or damaging earthly resources. There are over 1 billion individuals drinking unsanitary water, and the medical implications resulting from the lack of this basic human right are horrific. The study of these five basic water filters demonstrated the ingenuity that is possible, but also the flaws in using such simple and non-advanced technology. Combining these technologies could result in a very efficient filter, but the ability to complete such a task would not be possible in most areas of the world. It was the fusion of simple science with local resources that led to the invention of many of the sustainable filters currently in use. A similar process is necessary to determine where certain filters should be produced. If there is clay and sawdust available then make ceramic filters, or if water is gathered from a centralized source then make a sediment filter. There are so many different variables involved that it is impossible to choose what type of filter is best for all applications.

Sustainable filters are not a permanent solution. They do not filter all contaminants and are merely one step in the right direction concerning human health, without moving backwards environmentally. If sustainable filter technologies similar to the ones studied in this report are to be successful, education and empowerment must be the driving factors behind the filter production. If a community is given the opportunity to learn for themselves about the importance of water conservation and filtration they will be more likely to implement such practices into their daily lifestyles. This is the same for developing filters. If a local potter makes a ceramic filter, the community is more likely to trust him/her than a filter given to them from a foreign government. Giving a community the independence and economic opportunities that will come through the development of filters is essential. It is also necessary to do so in a manner that does not interfere with local cultures or the environment. Even though the gap in technological advancement between industrialized nations and the global south is increasing, these nations will not be stretched beyond their limits if they are not dependent on outside sources for their own well being. Sustainable filters are a means of limiting this dependence, and will serve to improve global health until better solutions are developed.

APPENDIX

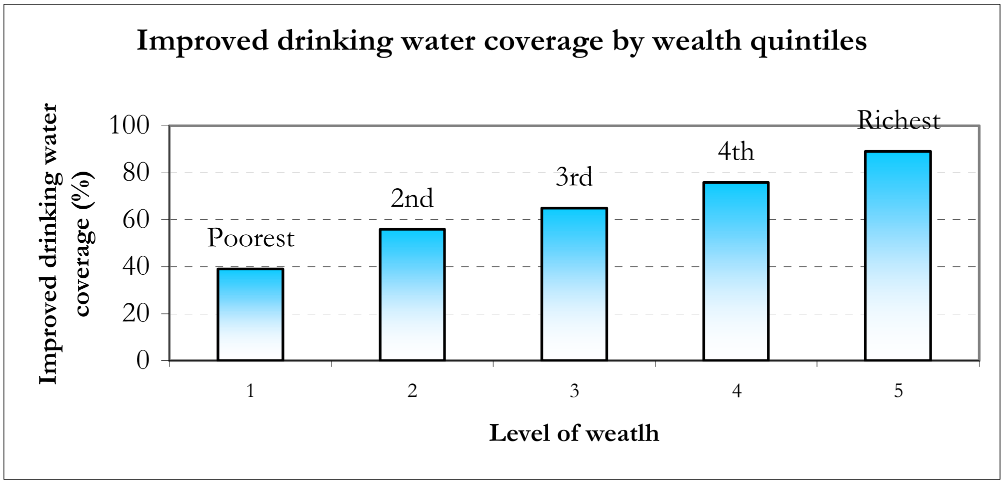
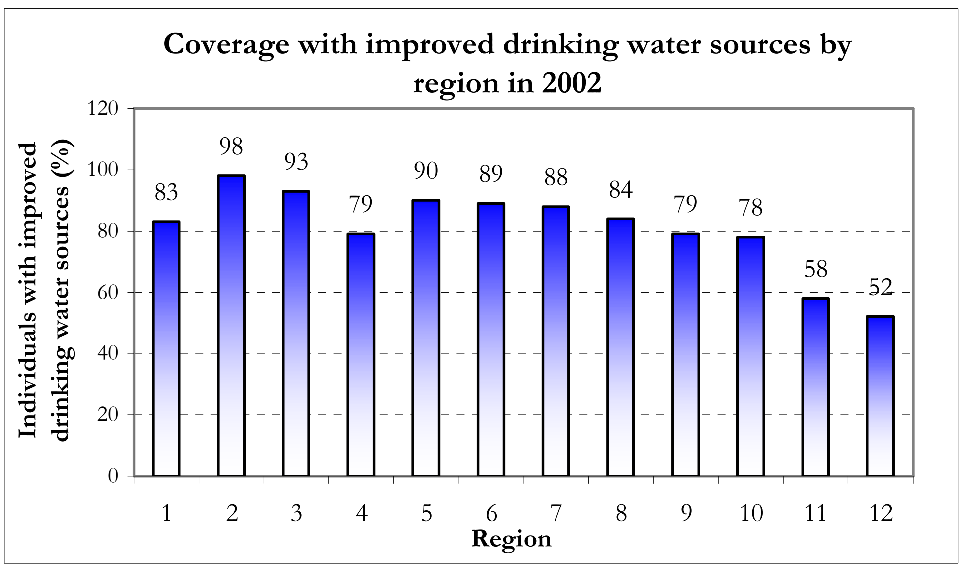


Figure 1: Improved drinking water coverage by wealth quintiles (WHO/UNICEF, 2004)



Region ID and
% increase 1990-2002
1 = World +6%
2 = Developed regions -2%
3 = Eurasia +1%
4 = Developing regions +8%
5 = Northern Africa +2%
6 = Latin America
& Carribean +6%
7 = Western Asia +5%
8 = South Asia +13%
9 = South-Eastern Asia +6%
10 = Eastern Asia +6%
11 = Sub-Saharan Africa +9%
12 = Oceania +1%

Figure 2: Coverage with improved drinking water sources by region in 2002 (WHO/UNICEF, 2004).

Figure 6: Instructional sticker for operation and cleaning of the Potters for Peace ceramic filter (www.potpaz.org).

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GLOSSARY

Argyria: Sickness caused by excess of silver in the bloodstream.

Cone: A pyrometric unit of measure for the temperature within a kiln. Cone O12 is approximately 1600 F.

End of pipe solutions: Solutions that take into account only the outcome, and are not concerned with the process or preventative measures.

Global South: Term for countries in Africa, Asia and Latin America. Generally thought of as the group of impoverished countries that are mostly in the Southern Hemisphere. A preferred term for "Third World" or "developing" countries. (Webster, 2005)

Green principles: Environmentally friendly principles.

Just-in-time production:

According to Manufacturing Engineering and Technology, "The just in time production concept was implemented in Japan to eliminate waste of materials, machines, capital, manpower, and inventory throughout the manufacturing system. The JIT concept has the following goals:

- Receive supplies just in time to be used.
- Produce parts just in time to be made into subassemblies.
- Produce subassemblies just in time to be assembled into finished products.
- Produce and deliver finished products just in time to be sold." (Kalpakjian, Schmid, 2001).

LEAN manufacturing: "The major assessment of each if the activities of a company: the efficiency and effectiveness of its various operations, the possible dispensability of some of its operations and managers, the efficiency of its machinery and equipment in the operation, and the number of personnel involved in each particular operation. It continues with a thorough analysis of each activity, including those due to productive and to nonproductive labor," (Kalpakjian, Schmid, 2001).

Lysis: A process of disintegrating or dissolution (as of cells) (Webster, 2005).

Point-of-use: In the case of filters, it is a filter that can be used on location by attaching to a faucet, sitting next to a sink etc.

Potable: Middle English, from Late Latin *potabilis,* from Latin *potare* to drink; akin to Latin *bibere* to drink, Greek *pinein***:** suitable for drinking (Webster, 2005).

Sustainable: Of, relating to, or being a method of harvesting or using a resource so that the resource is not depleted or permanently damaged (Webster, 2005).