TECHNOLOGY

PRACTICAL POU SANITIZATION METHOD FOR DRINKING WATER USED IN DEVELOPING COUNTRIES

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The United Nations agencies estimate that 1.1 billion people, primarily in the developing world, drink unsafe water (1). Of that number, some 2.2 million people die each year from exposures to poor sanitation and contaminated water; the majority of them are infants and children less than five years of age (2-4). Not estimated are the less lethal illnesses triggered by parasites, diarrhea, and malnutrition due to the drinking of biologically contaminated water. Considering that a person must consume 2.5 quarts of clean water daily to maintain health, it seems that a simple, practical, inexpensive, easily available, sustainable device to sanitize drinking water at the point-of-use (POU) can rid mankind of this scourge. We have a vision for such a device, using the well-known activated alumina as a regenerable filtration medium.

Since all viruses, microorganisms, and parasites are organic matter strongly adsorbed on pure white fine granular activated alumina, sanitization of drinking water is possible by simple filtration through a bed of alumina. The practicality of such a device in the developing world is that visual staining of alumina by adsorbed organic matter in surface water provides a visual indication of when a bed is near exhaustion and regeneration is required. Further, by heating spent alumina in utensils over kitchen fire, following the evaporation of entrained water, the adsorbed organic impurities will first char, turning black followed by burning away of the carbon returning the alumina to a white color. Because of the chemical stability and mechanical toughness of activated alumina, a small supply of activated alumina can last through many cycles of use in this manner. The visual control of microbial removal by adsorption then charring and burning off should be of educational value.

Through this article, we put the conceptualization of this technology into the public domain with the hope that alumina producers, device manufacturers, governmental agencies, and non-profit organizations can perfect this application for distribution around the world. We provide here a review of point-of-use (POU) devices for developing countries for comparison, known properties of activated alumina, and our limited initial laboratory validation results for a technique by which a simple, affordable, and effective device for water sanitization can be made widely available.

POU Sanitization Devices

Three types of better-known POU devices are being offered and tested in developing countries. They are demand-operated slow sand filter, hypochlorite treatment, and a combination of hypochlorite, and a flocculent to facilitate disinfection along with precipitation of suspended particles.

Traditional slow-sand filters have been in use for more than 150 years. In response to the need for inexpensive small-scale water treatment for developing world communities, improvements to the effectiveness of this method led to a new finding. By promoting the growth of a layer of natural microorganisms on the surface layer of sand, and allowing it remain there by intermittent use and careful maintenance cleaning, the removal of microbes from the passing water is enhanced (5-7). When such sand filters are properly built and operated, microbial challenge tests have shown (6) that the biosand filter can remove 83+% of total heterotrophic bacteria, 100% of *Giadia* cysts, and 99.98% of *Cryptosporidium* oocysts.

Sodium hypochlorite solution (liquid bleach) and calcium hypochlorite powder have long histories as water disinfectants, and are now reaching into water systems serving communities and into household water treatments in the developing world (3,4, 8-11). Sodium hypochlorite-based system under the name of Safe Water System is being pilot-tested in 16 countries by the U.S. Center for Disease Control in partnership with the World and Pan American Health Organizations (10). Calcium hypochlorite tablets are widely distributed by humanitarian organizations like

TABLE A
Filtration of Lake Hodges Water through Activated Alumina

Sample	*Bed Volumes*	*Color*	*Clarity*	*Plate Count (cfu/mL)*
Control	*unfiltered*	*Light Yellow*	*turbid*	*27,600*
1	1	faint yellow	clear	4
2	7	colorless	clear	43
3	20	colorless	clear	623
4	40	colorless	clear	339
5	80	colorless	clear	>738

cfu/mL = colony forming units per milliliter.

TABLE B
Filtration of Discovery Lake Water through Activated Alumina

Sample	*Bed Volumes*	*Color*	*Clarity*	*Plate Count (cfu/mL)*
Control	*Unfiltered*	*Light Yellow*	*Turbid*	*4,140*
1	2	colorless	clear	6
2	40	colorless	clear	29
3	132	colorless	clear	51

cfu/mL = colony forming units per milliliter.

UNICEF (12) and Rotary International (13), and by the U.S. military to Iraq and Kuwait (12).

Since hypochlorite is less effective in highly turbid water (3, 14). For pathogens resistant to chlorine (3, 15), the idea was conceived of combining clarification by coagulation/flocculation of the turbid surface waters as practiced for municipal water purification with hypochlorite disinfection. A packet of combined powders under the name of PUR™ was introduced by Proctor & Gamble in the late 1990s (11), to both clarify/decolorize and sanitize water. The results of a randomized controlled trial over 20 weeks involving 6,650 people in 605 families in rural western Kenya was reported in 2005 (3). In the group using traditional cloth filtration water treatment, 28 deaths occurred in this 20-week study period. In the group using dilute chlorine bleach, 17 deaths occurred and in the group given sachets of flocculent-disinfectant, 14 deaths occurred. In this and a similar trial in Guatemala (4), reductions of incidence of diarrhea were in the range of 20% to 48%.

Properties of Alumina

Alumina (aluminum oxide [Al_2O_3]) is the most widely used oxide ceramic material in applications, including grinding media, abrasion resistant tiles, cutting tools, hip joints, and spark plugs. Bauxite ore is plentiful. Two to three tons of bauxite yields 1 ton of alumina, from which 50% by weight as aluminum metal is obtained electrolytically (16). Alumina is extracted from bauxite with a solution of sodium hydroxide, which solubilizes aluminum hydroxide (Gibbsite; $Al(OH)_3$), and aluminum oxyhydroxide (Bohmite and Diaspore; $AlO(OH)$) as sodium aluminate ($NaAl(OH)_4$). Crystalline aluminum trihydroxide (Gibbsite), called hydrate at this point, is then precipitated from the clarified extraction liquor.

The hydrate is a polymer of monomeric aluminum hydroxide that spontaneously polymerizes by dehydration reaction, forming ever-extending Al-O-AL bonds. Such is the floc formed when alum or sodium aluminate is used in coagulation/clarification treatment of water. When the hydrate is heated (calcined) to further complete the polymerization and dewatering process, the ultimate dehydrated polymeric form has the elemental composition of alumina (Al_2O_3). With carefully controlled temperatures between 180 to 600°C, activated alumina with large surface area is formed. The surface area gradually decreases as the temperature rises towards 1000°C (17). For the application described in this paper, it is important to note that the charring and burning away of adsorbed microbial and organic matter from activated alumina during regeneration occurs in the temperature range of 400 to 450°C (18).

Activated alumina is widely available and certified to remove trihalomethanes, arsenic, fluoride, selenium, beryllium, thallium, and sulfate (19-21). We could find no report in the literature of using activated alumina to remove microorganisms and colloidal organic particles in water treatment, even though it is well known that the large surface area of activated alumina carries a positive surface charge, and would strongly bind organic matter in water.

The author saw the advantages in this extension of the utility of activated alumina that lie in the feasibility of unlimited cycles of regeneration of spent alumina by pyrolysis and vaporization of adsorbed organic matter at easily attainable temperatures that do not deactivate the alumina (18). The extent of staining of a pure white filter bed, and regenerated pure white color after the charing then burning away of the adsorbed organic matter provide a visual indicator of exhaustion of the filter bed and completion of regeneration. The mechanical strength and hardness of alumina can conceivably sustain use through unlimited cycles of use and regeneration.

Validation Tests

We have found that colored stagnant water from Lake Hodges, Escondido, Calif., and nearby Discovery Lake, San Marcos, Calif., can be decolorized and sanitized by filtration through a pad of pure white activated alumina. Using heterotrophic plate count (HPC) of bacterial reduction as a surrogate and convenient measurement of reduction of organic colloidal particles, we have found 5 to 2 log reductions of bacteria over one to 80-bed-volumes of water filtered. After 80-bed-volumes, the pad of alumina was visually about two-thirds stained. The stained alumina readily reverted to pure white color when heated over a flame.

Following are the experimental details and test results:

1. Activated Alumina: Dynocel 600 28X48 granular from Porocel, Little Rock, Ark., surface area 366 square meters per gram (m^2/g).
2. Waters treated: 1. Lake Hodges, Escondido, Calif., 3 gallons of stagnant, turbid, tan-colored water was sampled on August 28, 2004, was treated the next day; 2. Discovery Lake, San Marcos, Calif., 3 gallons of clearer, less colored water was sampled on Sept. 12, 2004, and treated on Sept. 30, 2004.
3. HPC assays were performed by D-Tek Analytical Laboratories, San Diego, Calif., using Standard Method 9215-D. Sterile sample containers were provided by D-Tek Laboratories. Filtration equipment were sanitized in a drying oven at 110°C for 2 hours.
4. Filtration of Lake Hodges water: 100 g of activated alumina was packed in a 6 centimeter (cm) diameter x 6 cm high flat-bottom filter funnel lined with filter paper (Fisher P2), attached to a 250-milliliter (mL) filter flask to apply a gental

vacuum from a water aspirator. The pad of alumina had about 185 mL in volume with about 100 mL of free space. Thus, one bed-volume = 100 mL. The surface of the alumina pad was protected with a filter-paper disc. Following 5 samples were obtained for HPC assays. Description of the samples and assay results are in Table A. After 80-bed-volumes of water had passed through the filter pad, the alumina pad was visually only about two-thirds stained. HPC reduction was 2 to 5 logs. Larger organisms and color bodies are clearly more strongly adsorbed and retained.

5. Filtration of Discovery Lake water: 15 g of activated alumina was packed in a 1.8 cm x 30 cm fritted-glass chromatography column. The column of alumina had about 15 mL of bed-volume. Lake water was filled to a constant height in the column so that a flowrate of about 15 mL/minute was maintained. Four samples were obtained for HPC assays. Description of the samples and assay results are in Table B. After 132 bed-volumes of water had passed through the filter column, the alumina was visually only about half stained. HPC reduction was about 3 logs. Larger organisms and color bodies are clearly more strongly adsorbed and retained. It is apparent, as expected, a gravity drip system is more effective in filtration than higher filtration rates generated by vacuum suction from below (as in 4 above), or by positive pressure from above the filter pad.

Regeneration of spent alumina. Stained alumina from the above-described tests were taken in a crucible and heated over a flame. Following evaporation of water, charring on the alumina occurred, then the black color disappeared, returning the alumina to the original white color.

Although not actually performed, on basic principles, we can expect the trace amounts of inorganic ash residues from the pyrolysis of biological and natural organic matter to have little effect on the performance of the alumina or toxicity of the product water in subsequent cycles of use.

Conclusions

The simplicity, practicality, economy, and sustainability of such a POU device have been demonstrated in principle. Our vision and hope is that others can design, manufacture, and distribute devices based on this principle. It is critical that such devices be universally affordable and available.❑

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