Access to clean water is a daily challenge for 1.8 billion people in the developing world. The United Nations has set a goal of ensuring safe drinking water for all by 2030.

Filtering safe drinking water through granulated ceramics

Modular filters based on silver-coated ceramic granules provide sustainable, affordable access to clean water when water treatment infrastructure is lacking.

By Reid Harvey, Mike Chu, and John Hess

The world is thirsty for safe drinking water. But too many do not have access, especially in developing regions. Silver-treated ceramic granule filters offer an affordable, sustainable option for purifying water in households, and even on municipal scales.

Introduction

Worldwide, the predominant problem with drinking water is a prevalence of pathogen contamination. According to a United Nations fact sheet,[1] 80 percent of wastewater reenters the environment untreated. An estimated 1.8 billion people use water sources contaminated with pathogens from untreated urban wastewater, agricultural runoff, and other contaminated water sources, which expose them to increased risk of water-borne pathogens such as cholera, dysentery, typhoid, and polio. The problem is most pronounced in countries at the lower end of the economic spectrum that tend to lack wastewater management infrastructure such as sewer systems and water treatment plants.

Systematic challenges

Municipal water treatment involves the use of chemicals, coagulation, flocculation, and filtering through sand, along with such exotic approaches as ultraviolet and reverse osmosis. Implementing these types of water treatment systems in the developing world could work technically, but is difficult to sustain and is limited by problems with delivering water. In addition, municipal treatment can be too expensive for poor communities to implement.

On the household scale, inexpensive water treatment usually involves the use of chlorine, which requires a level of education for testing and dosing that presents a barrier to those who may never have been to school. Boiling contaminated water is an alternative. Even so, of the various household alternatives, only boiling is one purification method that has achieved scale.[2] However, those whose daily income is below poverty levels cannot afford fuel for boiling.

Other forms of acquiring clean water include solar distillation (setting a bottle of water in the sun for six hours) or rainwater catchment. However, these, too, are not sustainable nor user-friendly. Additionally, rainwater catchment depends on the bounty of the sky.

In much of the developing world, water is collected by women as part of their household duties. In their collection of water, these women may walk or stand in line for hours every day. Water collected this way is most often pathogen-contaminated, and, worldwide, well over a thousand small children die every day because of their drinking water.[3] Small children with immature immune systems get diarrhea, which leads to dysentery and death. Parents may not recognize the warning signs in time to give children life-saving oral rehydration therapy.

United Nations priority

The United Nations identified 17 Sustainable Development Goals (SDGs) comprising a roadmap "to achieve a better and more sustainable future for all" by 2030.[3] Clean Water and Sanitation—Goal 6—is both a consumer product and a human right. According to the UN, sanitation and drinking water improvements have led to "over 90% of the world's population now [having] access to improved sources of drinking water." However, the UN calls for increased investment in freshwater management and local-level sanitation systems, especially in at-risk regions of Sub-Saharan Africa, Central Asia, Southern Asia, Eastern Asia, and Southeastern Asia.

Solutions proposed for the developing world tend to focus on conventional municipal water treatment, often on a smallish scale. Unfortunately, many such development efforts have failed in the past owing to little provision by the donor for maintenance after the first couple of years.

Point-of-use water treatment

The need for point-of-use water treatment in the developing world for rural areas is obvious. However, point-of-use water treatment in urban areas, where the delivery infrastructure from municipal treatment tends to be damaged or non-existent, is also needed to avoid delivering water that gets recontaminated on its way to communities.

Modular, portable solutions that do not rely on other plant facilities and infrastructure—such as reliable electricity service—may offer an effective pathway to providing clean, safe water for millions of people. Chemical-free water purification systems also are desirable, as chemicals introduce a supply chain dependency and require physical plants or other infrastructure to implement. Low cost and ease of maintenance are urgent priorities.

Heavy metals exert a toxic effect on pathogens that generally renders them harmless. Unfortunately, consuming

United Nations Sustainable Development Goals[3]

1. No poverty
2. Zero hunger
3. Good health and well-being
4. Quality education
5. Gender equality
6. Clean water and sanitation
7. Affordable and clean energy
8. Decent work and economic growth
9. Industry, innovation, and infrastructure
10. Reduced inequalities
11. Sustainable cities and communities
12. Responsible consumption and production
13. Climate action
14. Life below water
15. Life on land
16. Peace, justice, and strong institutions
17. Partnerships for the goals

United Nations targets for achieving Goal 6: Clean water and sanitation

1. By 2030, achieve universal and equitable access to safe and affordable drinking water for all
2. By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations
3. By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally
4. By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
5. By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate
6. By 2020, protect treatment, recycling, and reuse technologies
7. Support and strengthen the participation of local communities in improving water and sanitation management

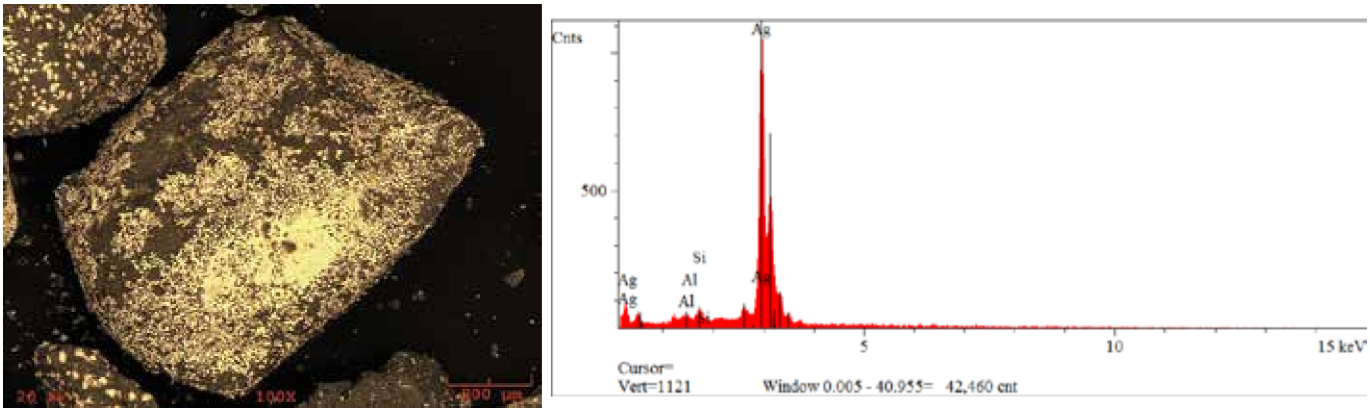

Figure 1. (a) Scanning electron micrograph showing bright regions of silver deposits on ceramic granules. (b) Energy dispersive spectroscopy X-ray spectrum confirms localized silver deposits on an aluminosilicate clay particle.

even small amounts of heavy metals can harm people. Silver, however, has no deleterious health effect for those ingesting minute amounts, and it has long been exploited for its antimicrobial properties, even in ancient times. Since the 1970s nanoscale silver has been used as the active antimicrobial ingredient in drinking water purification systems.[4] Because of the prevalence of silver-containing water purification systems, the EPA[5] set a standard for leached silver levels not to exceed 0.1 milligrams per liter (100 micrograms per liter).

For at least 10 years researchers have worked on impregnating porous clay-based ceramic filters with colloidal silver as simple water purification systems using local clay resources and not requiring infrastructure such as electricity. These silver-ceramic filters have been shown to be effective water purifiers. Oyanedel-Craver and Smith[6] made cylindrical filters from clay-rich soil, water, grog, and flour and applied silver by either dipping or painting. They measured filters exposed to water contaminated with Escherichia coli (E. coli) and found they removed 97.8 to 100 percent of the pathogen.

Filter effectiveness requires pathogens to encounter the silver to experience its lethal influence. Thus, a filter using silver-treated granules will expose large surface areas of silver, and the granular media introduces more pathways for contaminated water to wash past silver.

The lead author (Harvey) first developed a water filter media during a 2003 visit to Kathmandu, Nepal, in response to an urgent need for water, sanitation, and hygiene (WASH). Working with a local pottery along with a local NGO and UNICEF systems, monolithic candle filters of common earthenware red clay went into thousands of low income homes and into large-sized filter systems for 800 schools of rural districts. The use of red clay suggested the reproducibility of the model, and a subsequent such project was implemented in Kenya.

TAM Ceramics (Niagra Falls, N.Y.), long a manufacturer of high-purity ceramic granular media, has licensed the technology from the lead author (Harvey) and is optimizing a water filter media with silver-coated ceramic gran-

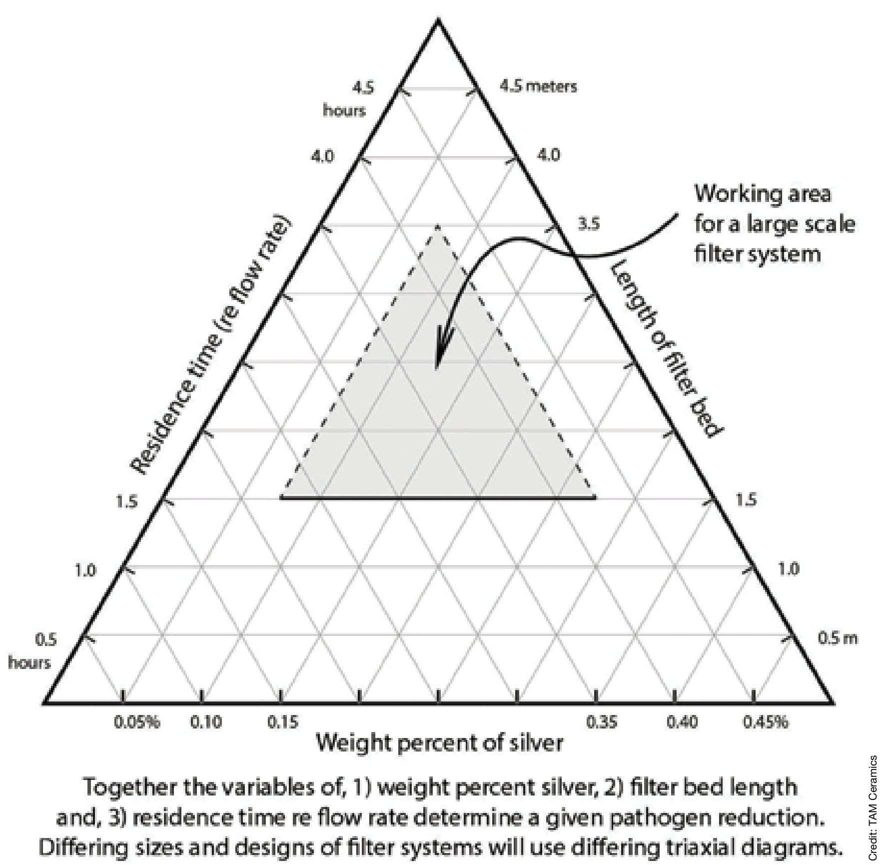

Figure 2. Triaxial diagrams aid optimization of filter system design by demonstrating relationship between amount of silver, filter bed length, and flow rate. The area shaded grey represents the region of optimal filter design. Diagrams will vary based on filter system size and design.

Figure 3. A granulated media water filter suitable for households costs $3 to $6.

ules. As pathogens flow through the granulated filter bed they are deactivated through the oligodynamic effect from repeated contact with the silver.

For the granulated filter media, the inventive step in development was simply to crush and granulate a silver treated candle filter. This granulated media was then put into sections of thin-walled PVC pipe, ending up with a remarkably low-cost system of household water treatment. This approach is as innovative today as it was in 2003 Kathmandu, considering the dearth of sustainable technologies. Mere clay is indeed the way.

To functionalize the filter media, fired ceramic granules are treated with a silver solution followed by a second firing to bond the silver (Figure 1a). X-ray energ dispersive spectroscopy confirmed the presence of silver on the granules (Figure 1b).

We tune granule particle size distribution to the customer's filter design and application, within sensible limits. In general, coarser particles give a fast flow rate, while finer particles give a slower flow rate and longer residence time. Triaxial diagrams, such as Figure 2, help with establishing optimal conditions with respect to particular filter containment, size, and design.

The filter itself, shown in Figure 3, is not very large. A community-sized system containing four 8-inch PVC "candles" filled with silver-coated ceramic media produces up to 100 gallons of clean water per hour. A household-sized filter produces up to two liters of clean water per hour and costs $3 to $6. These systems should last about 10 years.

Testing effectiveness

The number of pathogen–silver contacts is determined by the amount of silver, the length of the granulated filter bed, and the residence time of the pathogens. Pathogen reduction varies with the amount of silver used in treatment, between 99.90 percent and 99.99999 percent (log 3 to log 7 effectiveness). While filter media providing log 3 pathogen reduction would be appropriate for such applications as hand washing, filter media yielding log 7 pathogen reduction should be acceptable in clinics or hospitals.

Water with 99.9999 percent (log 6) pathogen reduction is considered suitable for drinking. However, in worst case scenarios, a log 3 reduction or even less is arguably an acceptable, pragmatic threshold that could work for greater numbers of vulnerable populations.

TAM continuously works with certified laboratories to refine test set-up and procedures. Testing for E. coli reduction assures that the filter media does its job getting people safe drinking water. Small children are especially vulnerable to E. coli, never having had a chance to develop immunities. Filter granules have been shown to reduce E. coli between log 3 and log 7. The filter lifetime will be no less than 10 years, but can be greater if requested.

Municipal water utility treatment traps pathogens with slow sand, which allows about one percent to get through. A subsequent step with chlorine or a look-alike disinfectant destroys the one percent of pathogens that slip through slow sand filtration. In contrast, for prospective municipal-scale applications, TAM's filter media has the advantage of combining filtration and disinfection into a single step.

A scalable future

TAM's granulated ceramic filter systems are genuinely sustainable in addition to being suitable for filters of any size—a first. For the developing world, since 2003 there has been an emphasis on household water treatment, on a point-of-use basis. Now, however, large-scale filter systems offer an altogether new paradigm for delivering safe water to entire communities. Clean, safe water can be made available for everyone simply by the force of gravity. These filters offer clean water at accessible prices, too. A household-scale filter costs $3 to $6.

Is water a human right, a consumer product, or both? Despite intense debate, the question remains unresolved. However, TAM Ceramics suggests that sustainability be a qualification to help answer the question of rights versus cost.

Systems based on filter media are sustainable and low cost. The cost of the filter media will be as low as possible when granules are manufactured in close proximity to the market, a step that will happen once the market has been established. In addition, these filters are more user friendly than competing water purification systems.

Ceramists are uniquely positioned in their capacity at getting people safe drinking water and clean air around cook stoves, as well as industry from the grassroots. There is arguably no other approach to manufacturing that makes possible so much fundamental industrial development. Of the 17 Sustainable Development Goals, nearly all are addressed squarely by the capabilities of ceramists—it all starts with safe drinking water and environmental health.

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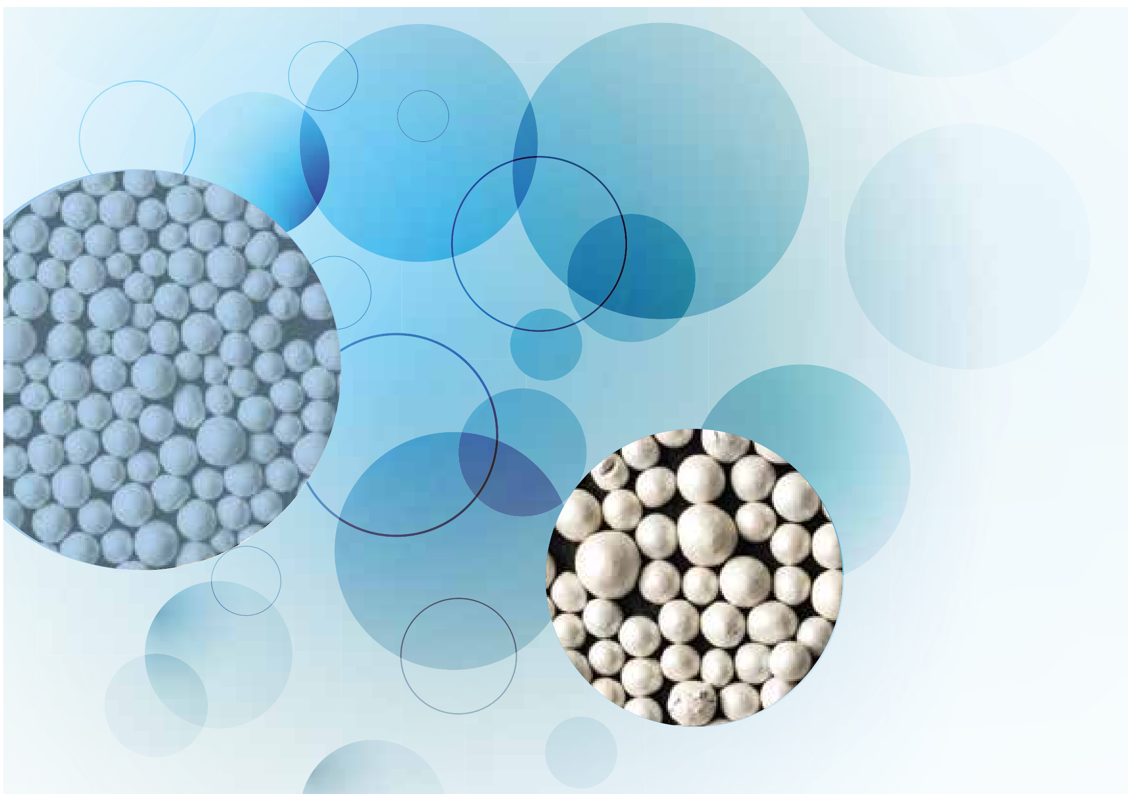

Credit: Golisano Institute for Sustainability at the Rochester Institute of Technology

Glasses, ceramics, and metals are critical to a clean energy and mobility transition

Understanding the intensity and criticality of materials used in clean energy production, low emission transportation, and lighting helps engineers design solutions for a more sustainable world.

By Alexandra Leader and Gabrielle Gaustad

The continued growth and development of our economies comes with significant attendant environmental impacts. Across the globe, raw material usage for both energy generation and manufacturing alike has increased exponentially, and the growth is likely unsustainable. Hurricanes, massive forest fires, and unprecedented flooding have become increasingly recurrent phenomena in the past few years, likely caused and/or exasperated by the impacts of climate change. Anthropogenic greenhouse gas emissions, generated by the sectors shown in Figure 1a, are proven contributors to climate change. Fortunately, the minerals, metals, glass, and ceramics industries embraced these challenges as opportunities to drive groundbreaking work in their fields. For example, they developed clean energy technologies to address electricity and heat production, building, industry, transportation, and other energy categories, tackling a total of 76 percent of the total global greenhouse gas emitting sectors.[1] These technologies, however, also require material consumption; understanding their use and supply is key to ensuring overall sustainability.