Pure Zirconia Filters for In-situ Chlorine Generation for Water Disinfection

Professional Components of Relevance

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The numbers of the water crisis are staggering: 1.1 billion people on the globe lack access to clean water, 3.5 million die from water-related diseases annually, and all are preventable. A range of water treatments are available, but only a fraction can meet the needs of the developing world-- where the bulk of the water crisis takes place. In this case the desired water treatment system is point of use (due to the commonly decentralized infrastructure), easy to install and operate, inexpensive, and reliable. In-situ photochemically generated chlorine has the potential to fulfill these needs.

This research project will examine and improve on the use of ceramic oxides in the catalytic decomposition of hydrogen peroxide in the photochemical solution. The hydrogen peroxide is an undesirable byproduct that hinders the generation of chlorine. Pure, inexpensive zirconia will be freeze-casted into a filter with characteristic directionally-aligned and hierarchical pores. Anisotropic porous ceramic filters allow for the photochemical solution to be continuously scrubbed of hydrogen peroxide without the use of high maintenance powders and the true catalytic behavior to be observed. An effective zirconia filter can ultimately supply enough free chlorine to purify water in the far reaches of the third world.

A. Integration of Knowledge from Curriculum

Design, experiments and analysis are definitely required in both the production of the zirconia filter and its effect on the greater photochemical system. The curriculum has provided a sound methodology that directs the steps I will take in the laboratory. Design and experiments were necessary in producing the filters (creating the slurry recipe, manipulating the freeze casting process, selecting a sintering temperature) and will be readdressed during and after testing their effectiveness to decompose hydrogen peroxide. Current analysis includes looking at porosity and comparing it to the different variables of processing (powder to water ratio, freezing rate, sintering temperature). Further experiments could involve using different ceramic oxides. Further analysis could include characterization techniques (XRD, TGA, mechanical testing) that could set the stage for optimization.

The skill set and knowledge involved in this project range from the technical to the humanitarian. The following courses and experiences have provided me with both the preparation and motivation to understand and undertake the implications of this project.

- *Organic Chemistry:* this course helped clarify the overarching chemistry of the photoreactor device-- how quinones are used as photosensitizers, how chlorine radicals couple to yield free chlorine, and how the hydrogen peroxide byproduct can be produced and decomposed.
- *General Chemistry:* specifically, the laboratory work of this year-long series has been helpful. General laboratory techniques and analysis (including lab reports) was covered.
- *MSE Junior Integrated Labs:* like General Chemistry, this year-long series of labs has been helpful in honing laboratory techniques and reports. Specifically this has acquainted me with equipment available and needed in my project and also multiple databases for research. The unit on researching articles, writing a collaborative proposal and implementing that project has been of particular relevancy.
- *Bangalore Study Abroad Program:* a study of injustice and activism in many forms. Research and field trips with the Environmental Support Group lead to my initial interests in clean water projects for the developing worlds. This also gave me great insight into the necessity of considering societal and economic impacts as an engineer.
- *Keramos, Professional Ceramic Society:* this extracurricular focused on ceramics has allowed me to further expand my knowledge and comfort in casting ceramics.

- *Sustainability Studio:* this is a course from the Program on the Environment that focuses on sustainability on campus. My quarter focuses on the use of water on campus and has been a huge influence on my perception of the “water crisis” categorized into quantity, quality, storm water.
- *Technical Writing & Oral Presentation:* The two-quarter series has been helpful in honing my communication skills. Several activities have introduced me to various techniques for conveying information and practiced my abilities to present information clearly, concisely and accurately.
- *Fundamentals of Materials Science:* this course gave me a broad understanding of the relationship between materials and their properties that I use and will continue to use to analyze mechanical and chemical properties of the filters in order to optimize.
- *Materials Processing:* this course provides a range and pros and cons lists of different manufacturing and processing techniques to be kept in constant consideration. This will help determine the most appropriate way to manufacture filters.
- *IND E 250 Engineering Economics:* this course is relevant due to the cost constraints for a third world product. Financial analysis of expected costs and opportunity costs could help develop incentives for possible investors.
- *MSE 333 Characterization of Materials:* this course provided me with a toolkit of possible techniques for analysis. Knowledge of how different characterization techniques operate will help me decide what techniques best support the results I get.

B. Societal and Economic Aspects

The impact our work as engineers has on the worlds our technologies touch is extremely essential and sometimes overlooked. It is important to note the development of relevant and expected impacts at all stages of this project. These aspects are another measurement of success for the project in conjunction with the technological success of the filter.

Social Impact

I believe this to be one of the most important aspects of the projects. Because the design is catered towards developing countries there is social impact on a small and global scale. Our goal is to have communities without means of water disinfection adopt this technology and see positive results-- the technology is found to be easy to use, reliable, unobtrusive of the local environment, and induces an improvement in community health (eg. clean water access and sanitation increase, water-borne viruses and cases of diarrhea decrease). Desired impacts include: increased education of clean water and sanitation, an increase in employment and continued maintenance of the system. These improvements can evoke many other positive impacts-- the mortality rate and time to retrieve clean water can increase the overall production of a community. Eliminating a huge health risk can redirect time and focus to more productive and enjoyable enterprises. Those who were designated to fetch water can now contribute an income and are consequently employed and empowered.

On a global scale I hope to see this technology adopted by those who have the ability to disseminate and implement it to various locations-- particularly nonprofits or global health organizations established in the realm of clean water projects. Due to its versatility, this technology can help bridge the gap between humanitarian aid and the need of many developing communities.

Economic Considerations

The materials and processing must be economically feasible and “profitable” for the filter’s purpose. Because entire purification system is intended to work in-situ in developing countries the cost to make, distribute, install and operate the photoreactor must be minimal. If the system costs exceed the feasible options of organizations or communities in need, then they will look to the less effective, but more cost friendly options. Cost considerations will have a huge impact on the accessibility of this system. Consequently, we will look at what we can do to make the overall cost of the filter minimal (i.e. using zirconia as opposed to ceria, employing freeze-casting with a water solvent, etc.). In general, photochemical generation of chlorine is much less energy (and thus, less cost) intensive than the established electrolysis process.

Access to clean water can also have a profound, direct impact on the economy of the serviced community. Many hours are recovered that might have been spent retrieving water, preparing a fire and then boiling it. Many man (and woman and children) hours will be saved along with energy that can be redirected to cooking and warmth. The time and energy gained from not having to collect or purify water or from not having to recover from a waterborne illness or death would be used towards increasing productivity. Where extra income once was a side task, it would now be a main focus.

Currently, in some countries access to clean water is being privatized and sold at higher rates to the lower classes-- making it inaccessible to a large population. Providing a means of bypassing this already established system can have a huge effect on not only the economics but the politics of a developing community.

Ethical and Professional Issues

This project has unique ethical and professional issues because its target communities are those usually situated in areas with a decentralized or fragile relationship with the governing body. Many of these issues will arise in the marketing and implementation of this “humanitarian aid” system-- will it be sold as a profitable product? how will the system be operated and managed at the location? The same question from economic considerations applies here: how will this technology affect the “imbalanced” relationship of the community and governing body if an external entity is providing a necessity that was once “reserved” for the upper classes? The question of indirectly “undermining” the government should be addressed. Though the overarching sentiment of humanitarian aid appears to trump any individual issue, there remains many unseen, but possible, political implications of this “equalizing” technology.

Safety Considerations

The freeze-casting process is an especially safe technique, and should be on a larger scale. We will need to consider the safety and health risks of the entire system-- how inert or durable is the casing? will the installation technique (eg. use of epoxy) of the filter have an effect? is replacement of the filter necessary or dangerous? The risks of chlorine transportation along with much of the risks of electrolysis (such as the generation of hydrogen gas) are diminished with in-situ photochemical generation and point-of-use treatment. Because the photoreactor system will be on a small local scale safety risks might be more manageable, but will also require the education of responsible individuals.

Manufacturability & Scaling

The potential need or market for a point-of-use water treatment system is vast. Both rural and developing communities can benefit. Because the system is point-of-use and geared towards servicing a small community, locations might need the operation of several systems. For these reasons we must consider the scaling and manufacturability of the filters. In terms of the manufacturing process, water and zirconia are easily accessible and the freeze-casting process can very likely be automated. Yet there is the constraint of time; freezing rate is a huge influence of pore size and cannot be simply sped up for manufacturing. Further research into what combinations of variables yields sufficient results can aid in designing a process where time is decreased without sacrificing efficiency. In order to look at the effects of scaling we need to look at the design of the entire system and the efficiency (and strength) of the filter dependent on available surface area. If we can keep the system efficient at a larger scale we can accommodate a wider range of community sizes.

Communications

Because this project is in collaboration with a thesis project created within the Department of Civil and Environmental Engineering communication between us is crucial for a smooth integration of my ceramic filters into the photoreactor system. We make sure to establish a common understanding of each others' technologies in order to see how our own component fits. I have to consider the time constraints and the need for duplicating filter samples to supply both mine and their testing. It is also important to convey progress to one another. Although neither of our projects should be "dependent" on the other's it's necessary to keep lines of communications open to hear their feedback.

Reporting

Presentation and reports will be important especially if we plan on expanding or marketing this technology to the nonprofit or global health sector. My final written report will serve as a basis for multiple components: background information, motivation and context. These components are necessary in giving value to the results I report. Being able to convey my motivation and context are just as important as being able to analyze my results. The oral presentation of my work will be important in both evaluating my accomplished work and receiving feedback for future considerations. Sharing my project can also impact the work of future research in this field and catalyze the movement to finding an optimal material and design. Efficiently reporting my research via a written and oral component has the potential to propel my research beyond a senior project.