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Engineering Biological Water Treatment for Simultaneous Water Purification and Plant Growth In Long Term Spaceflight

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Abstract

As of now, all manned space flights have either taken with them enough clean water to last the whole trip or a heavy and expensive water treatment system such as on the International Space Station. They work for now, but are extremely heavy and therefore, difficult to get into space. In future long-term manned flights, these current means of obtaining clean water in space will not be feasible. My team seeks to address this issue by designing a new form of water treatment that is affordable and effective: Biological filtration. Modern water treatment technologies which remove things other than sediments from water are very expensive and heavy. Plant based filtration solves this issue because it can remove the same contaminants, but has much less inertia because of its small mass, making it easier to transport in and through space. We are measuring how well plants in such a hydroponics system are able to remove contaminants from the water they are in. Specifically, we are using tomatoes and hardstem bulrushes in two hydroponics systems to determine how their presence affects the concentration of phosphorus in the water of their hydroponics systems.

Biological Pest Control and Water Treatment Implemented In a Hydroponics System

To many, using water is as fundamental to our life as breathing. It’s perfectly normal to dump gallons of water down the drain every time we shower without a second thought as to where it came from. However, as of now, about 2.5 billion people (about one third of the world population) do not have access to clean water (CDC.gov, 2016). Most of these cases aren’t because of a lack of water. They are because of a lack of affordable ways to clean said water. Although most of the water crises are concentrated in Sub-Saharan Africa and Southern and

Eastern Asia, this phenomenon isn't limited to developing societies: In Lancaster, Pennsylvania, the city collects $1.4 million in revenues per year, but complying with new EPA regulations (Safe Drinking Water Act) will cost an extra $2 million which is money the town simply does not have (AAAS, 2010).

The best way to solve this issue is by making advanced water treatment cheaper. One exciting way to do this is through hydroponics, but instead of manually adding desired nutrients into the water, one would use water with excess pollutants in it such as nitrogen and phosphorous. The resulting system would be able to grow food such as tomatoes using wastewater and clean the water it uses in the process. However, pests are an issue in almost every agricultural setting including this one, so pest control would be necessary. Currently, chemical pesticides are the most widely used solution to this. The only problem is that pesticides being used on the plants would contaminate the very water they were cleaning effectively negating the entire system. An alternative to chemical pesticides, though, is to use animals such as frogs which eat said pests.

Historical Overview

According to Kevin (2011) from Epic Gardening, the word hydroponics comes from the roots "hydro" which means water and "ponos" which means labor. It is simply the process of growing plants in a solution of water and nutrients without soil. The oldest instances of growing crops in water without soil taking place was in the legendary Hanging Gardens of Babylon and the Floating Gardens of China. However, modern hydroponics was first introduced by the man William Frederick Gericke who was looking for a more efficient way to grow plants. Like in most science, his idea was met with doubt, but he tested it and was able to grow 25 foot high tomato vines in only water and dissolved nutrients proving his colleagues wrong.

The main selling points for hydroponics as opposed to traditional soil farming are the water and fertilizer conservation capabilities and a higher level of control of the system. In a soil based farm, water is spread on the soil around the plants and the vast majority of that water seeps into the ground rather than actually being used by the plants, whereas in a hydroponics system, it can be recirculated until it’s used by the plants. The same goes for fertilizers, but the majority that does seep into the ground or runs off finds itself contaminating groundwater or adding excess nutrients in bodies of water. This leads to eutrophication which eventually removes enough oxygen from the water to create dead zones. Next, in a hydroponic system, plants are often in sealed containers which can be positioned off the ground to protect against non-flying pests; for example, slugs. Also, the grower is able to accurately control the nutrients that plants are receiving so that under the care of a responsible grower, they never have too much or too little of anything such as oxygen which can dry out or drown a plant in the wrong amounts (Kevin, 2011).

Around 4000 years ago, written records of water treatment started popping up. Depictions of boiling water, sand and gravel filtration, and straining have been found from ancient Greece and India. However, it was not what it is today. The main quantifier for water cleanliness was turbidity because almost nothing was known about microorganisms or chemical contaminants. The turn towards modern microscopic treatments began in 1627 when Sir Francis Bacon first attempted to desalinate seawater. He was unsuccessful, but others followed in his footsteps trying to remove microscopic contaminants and eventually, Antonie van Leeuwenhoek invented the microscope and discovered waterborne microorganisms. Fast forward just over 200 years and the first municipal water treatment plant was built in Scotland using slow sand filtration (a form of water filtration in which water is passed through sand to catch contaminants) in 1804. In the 1890s, America discovered that waterborne diseases like cholera and typhoid were much less common when they began implementing their own large-scale sand filters and water chlorination techniques. It wasn't until the 1940s when the idea arose that everyone in the developed world should have a right to safe drinking water and in 1972, the Clean Water Act was passed followed by the Safe Drinking Water Act in 1974 in the United States. It was around this time that clean water concerns started shifting from people to the environment. Industry and agriculture's use of dangerous chemicals rose and without immediate regulations to stop them, things like pesticide residue, lead, nitrogen, and phosphorous became an issue leaking into groundwater and nearby water bodies. These can harm wildlife directly or promote certain species, throwing off balance in ecosystems. (Enzler, 2017)

According to Oram (2014), the next step in water treatment may be using plants to absorb chemicals like nitrogen and phosphorous which can lead to eutrophication if allowed to enter water bodies or illnesses like methemoglobin (prevents hemoglobin from transporting oxygen in blood) or cancer when nitrogen interacts with certain chemicals in the body.

Current Trends and Practices

Until now, water filtration and agriculture have been far separate. Often, agriculture has been an enemy of water treatment as farmers use pesticides and fertilizers which then runoff into nearby bodies of water or leach into groundwater which can be toxic to the users of the water or cause eutrophication which removes oxygen from water creating dead zones.

Current water treatment has three main steps for its completion. The first of which is primary treatment. This step removes suspended solids in the water by means of filters which stop objects larger than a specific size from passing through and grit chambers in which water is left for denser-than-water objects to sink and settle at the bottom (EPA, 2017). After larger objects are removed, there is still an excess of biological material. The water is left to sit in large vats where the aerobic bacteria in it are let process the organic matter and exhales it which gives the characteristic stench of water treatment. This is called the sludge process (EPA, 2017) After this, there remains complete sterilization of water also known as tertiary treatment, usually done by adding chlorine. Although, chlorine is toxic to humans if not removed properly after the water is sanitized so there are alternatives which are more costly, but safer. These include exposing the water to ultraviolet light or adding ozone. While our current means of water filtration are advanced, they are not very effective at removing heavy metals or dissolved chemicals, both of which can be toxic if ingested. This is where biological filtration comes in. Plants like tomatoes can safely absorb nitrogen, phosphorus, and certain metals to help their growth while also cleaning up the water (EPA, 2017).

Controversies and Debates

If one were to control pests using frogs in a water treatment system, they would have several conundrums that would need to be worked out. Because it deals with living animals, the main obstacle to face is the ethics of using frogs. However, there are still some issues that arise with the biological filtration aspect because it is a fairly new technology.

Concerning frogs, they must be within a certain range of the system to maintain their function as a part of the system. This may cause the frogs to be confined to a smaller space than they need or not have all the vital aspects of their natural habitat. Also, because the frogs will be controlling pests for the plants filtering the water, they will again, need to be in relatively close proximity to it. If contaminants used in such a system which are toxic to the frogs, they would be in danger by being near it, exposing the frogs to potential harm.

Alongside concern for frogs, this design may be problematic for human consumers of the food. If nitrogen or phosphorus were to be filtered out with plants, they would merely absorb it and it would help them grow. However, past research has shown that when filtering heavy metals such as cadmium with rice results in a built up of the heavy metal in the plants (Lopez-Millan, et al, 2009). This would of course be toxic to any human being which proceeded to eat said plant. Because of this, a pre-biological filter would need to be implemented before the water reached the plants if the filtering plants were destined to be eaten.

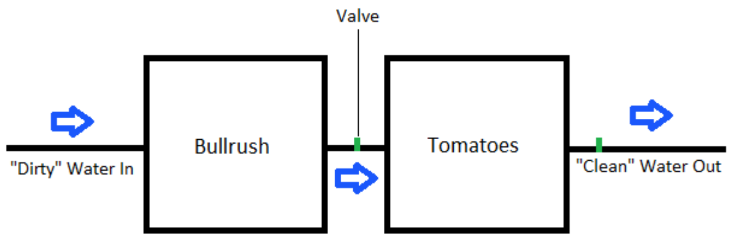
Conclusion

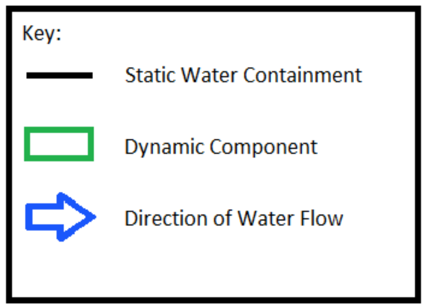
Although there are some kinks regarding the safety of the animals used in the experiment and the health of possible users of the food-growing aspect of hydroponics, current water treatment methods are lagging behind as contaminants like pesticides and fertilizers are leaking into water bodies and domestic usage water making a new dawn in water treatment necessary. According to the EPA, many current water treatment systems in place only reach tertiary treatment (sterilization usually with chlorine), but don't do much "physical-chemical separation." They've even suggested biological filtration as a means to attain total water cleanliness (EPA, 2017). Solving the issue of higher level water quality through hydroponics and controlling pests with animals while maintaining economic feasibility and environmental concern will prove to be quite difficult. However, as in any field the human urge to break new grounds will continue to pioneer the world of water treatment.

Materials and Methods

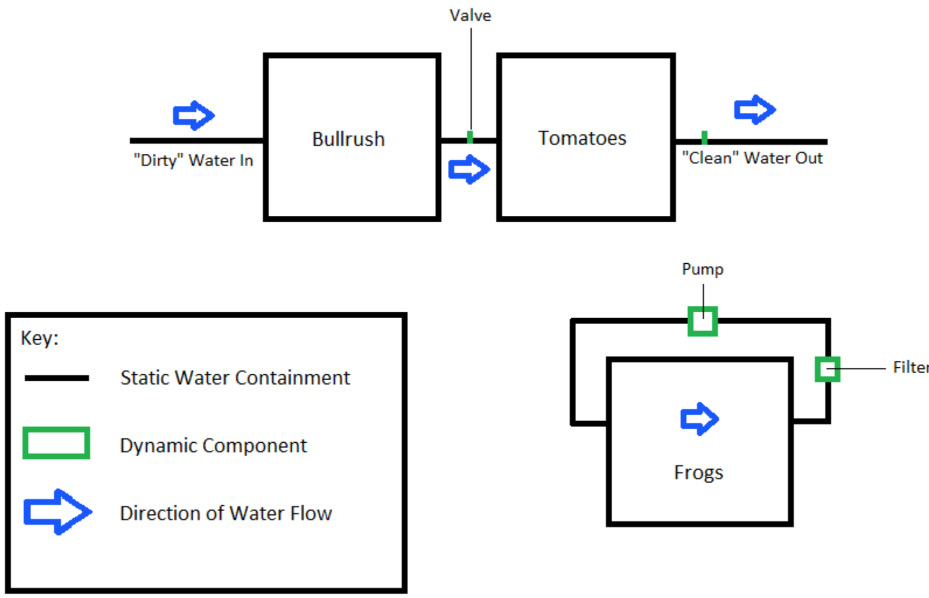
To begin with, we set up two plastic tubs which were 21.5x15x7 inches with chicken wire covering their tops. We then filled them up about three fourths of the way with water. In one tub, we set two medium-grown hardstem bulrushes into the chicken wire so their roots were submerged. In the other, we secured ten coffee filters into the chicken wire, then put recently sprouted tomato plants in each of the coffee filters. After the tomatoes grew large enough, their roots would secure themselves to the chicken wire. In the tomatoes' tub, we added 4 tablespoons of Jobe's Organics fertilizer containing 5% phosphorus which helps plants grow, but is less than ideal for normal human usage or runoff into water bodies where it causes eutrophication (Perlman, 2016). We did not need to add any fertilizer to the bulrushes' water because they were more matured plants when we acquired them. This means their root systems were strong and couldn't be separated from their immediate soil. Right after we added the fertilizer, we measured the phosphorus content of the water in both tubs using the Chemetrics K-8510D phosphate testing kit. We then continued to measure the phosphorus content of the water periodically after adding the fertilizer. This would show us how quickly and how much the phosphorus content of the water was being affected.

One of the advantages of using bulrushes to filter water is their ability to remove biological contaminants such as salmonella. My team will be able to create a system in which both plants' reservoirs are connected in series with pipes so the bulrushes filter bacteria and other biological contaminants before the water enters the tomato reservoir to filter the rest of the other contaminants such as phosphorus and nitrogen shown in the following diagram.



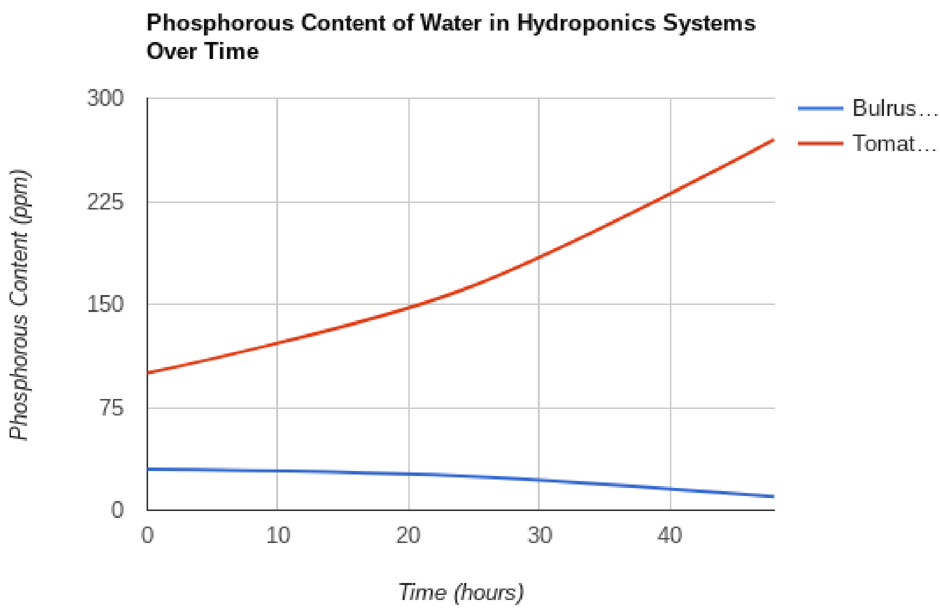


If this design were to be executed on a large scale in its intended use: more accessible water treatment, it would likely be outdoors. Because it uses plants, it would be subject to pests as any other outdoor plant. In such a system, using chemical pesticides is not an option because they would eliminate the purpose of filtering water. A new emerging pest control method is to use animals such as frogs which eat unwanted pests, effectively keeping them from destroying plants. It is my team's plan to implement this component into a full water treatment system which filters living and nonliving chemical contaminants from water using bulrushes and tomatoes, respectively that are pest controlled by frogs. Frogs are amphibians, meaning they live both in water and on land. Their water does need to be cleaned to a degree so, it requires a filter with a pump to move water through the filter. Eventually, this filter could be replaced with the previously described plant-based filtration system. Now, however, we are using a Bayite 12v DC pump and a water filter to achieve this. Throughout the whole system, water will be transported using ⅜ inch food grade vinyl tubing and its position will be controlled using OCS parts ⅜ inch valves in the manner shown below.



Results

After measuring the change in phosphate content in the water of both the hardstem bulrush and tomato tubs, we found unexpected data. As shown in the following graph, immediately after adding the fertilizer, the tomatoes' water had a phosphate concentration of about 100 ppm. Over a period of two days, it steadily rose to over 250 ppm. In the bulrushes' water, the phosphate concentration stayed between about 20 and 25 ppm over the course of a day, then dropped to about 15 ppm by the next day. This is contrary to what we thought would happen: both tubs' phosphate concentration would promptly decline after setting up the design.



Some qualitative observations to note are that when the fertilizer was added to the water, it appeared somewhat hydrophobic being that some clumped together near the roots of the tomatoes and the walls of the tub while the rest sank to the bottom. The bulrushes' water slowly turned brown as the soil clumped to their roots diffused into the surrounding water. Also, in regards to the tomatoes, as water was absorbed into the coffee filters holding the tomatoes, They got weak and six of the ten original tomatoes fell through into the water.

Discussion

Our data did not support my hypothesis as I expected phosphate content in both tubs to drop. This was quite different from what happened which was that the tomato water gained phosphate concentration and the bulrushes' only began to drop after a day. With respect to to the tomatoes, this is likely having to do with the hydrophobic nature of the fertilizer and the juvenility of the plants. When the fertilizer was added, it had a difficult time dissolving in the water, but was still there resulting in the relatively low, though existent amount of phosphorus.

Throughout the day, the phosphorus content was able to rise because the plants were so young and simply didn't need as many nutrients (such as phosphorus) from the water while the fertilizer continued to dissolve into the water, however, gradually. Considering the results of the bulrushes, it is likely that the dispersal of phosphorus from the soil clumps on the roots of the plants was adequately matched by the phosphorus absorption property of the medium-grown bulrushes until the soil finished releasing phosphorus. In more detail, over the course of a day, the soil from the bulrushes released the phosphorus it contained into the water. However, because the bulrushes were much larger, they had the capacity to absorb all that phosphorus as it is released unlike the juvenile tomatoes. This process kept the water at the same approximate phosphorus concentration until the soil was depleted and the bulrushes' phosphorus absorption property was able to absorb some of the remaining phosphorus in the water.

Considering other problems in the design, a main one was the previously mentioned tomatoes falling through their coffee filters. This is because the paper couldn't hold together when it got wet, allowing some of the tomatoes to drown. One way to counter this issue is to stack multiple filters in their holes so they have extra support once they get wet. However, doing this limits the flow of water between the tub and the tomatoes inside the coffee filters which may have an effect significant enough to prevent them from absorbing phosphorus and other contaminants from the water (their original purpose). Another way to prevent the tomatoes from falling through their coffee filters is to grow them in soil longer until they are large enough to secure their roots directly to the chicken wire as we did the bulrushes. Evidenced by the bulrushes themselves, this method has proved itself to work and should apply to the tomatoes. Given more time, this would be a wiser approach to take and is one worth pursuing in the future.

Conclusion

Overall, our findings were unexpected, but make sense after a closer look. Because of the gradual release of phosphorus into the water of both plants, it took longer than expected for the bulrushes to lower the phosphorus concentration. That coupled with the tomatoes juvenility caused them to not be able to lower the phosphorus concentration at all. In a real world setting in which such a system would be filtering contaminants that had already dissolved into the water, this would be an extremely insignificant problem and relates less to the design than it does the experimental method. We can learn that in the bulrushes' case, medium-grown plants have the ability to remove chemical contaminants from water. However, this stage of the design is merely a proof-of-concept to demonstrate said ability of plants and the design would need to be developed in order to increase their effectiveness to a desirable level.

Our design adds a great deal of contribution to its particular field. It not only shows the viability of plants for water treatment, but does it at a relatively low cost which is one of our main goals: to be able to bring affordable and sustainable water treatment to those who don't yet have it. This concept can also lead to more complex systems which filter out more contaminants for instance, salmonella as described earlier. With enough development, this technology can be robustly implemented in an affordable way to bring clean water to more people than ever before.

Another extremely appealing application of this research is in small, closed system living such as on long distance space flights or space stations. Astronauts would potentially be able to grow food from their own waste water and filter the water in the process, making for greatly sustainable and efficient food, water, and waste treatment methods. Learning how to create a system capable of doing all these things affordably and reliably will prove quite difficult, but is an important step in the field of water treatment and the progression of helping provide all of humanity with what we need for our future.

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