High Speed Water Sterilization System for Developing Countries

HydraVita

Team Members: Tal Bar-Or, Gaurav Gupta, Juan Jacobus, Ritwik Lodhiya and Ishan Sehgal | **Advisor:** Dr. Andrew Jackson | **Additional Funding:** Penn Year of Water

Penn Engineering

Abstract

HydraVita is a high-speed water sterilization system designed for use in developing countries. To our knowledge, this is the first sterilization system to implement a silver nanowire/carbon nanotube-coated cotton filter (AgNW/CNT filter). The device's main capabilities are inactivating bacteria and reducing the turbidity levels of water. In order to accomplish these objectives, HydraVita incorporates two main components: a turbidity-mesh cartridge that eliminates organic impurities and a AgNW/CNT filter cartridge that kills bacteria. In order to power the filter, the system is equipped with two 12V rechargeable batteries and a solar panel. This allows HydraVita to be used in remote locations with no connection to the power grid. Furthermore, the system is designed for modularity so that it can be easily disassembled for cleaning and maintenance in the field. The input and output water reservoirs are outfitted with standard NPT valves that give operational flexibility to the user, as it can be directly connected to a hose, water tank, or piping system. HydraVita's novelty stems from its high-speed functionality, low manufacturing cost, modularity, and ease of maintenance.

AgNW/CNT Filter Technology

The AgNW/CNT filter technology was developed at the Yi Cui Lab at Stanford University and first published in the Nano Letters journal in August 2010. The research conducted made use of regular cotton sheets, coated with silver nanowire (AgNW) and carbon nanotube (CNT) solutions. It was observed that when water is passed through these filters and exposed to a 20V potential difference, it is possible to inactivate over 98% of the bacteria in it. Instead of trapping the bacteria as most other filters do, the AgNW/CNT filter lets the pathogens flow through but renders them harmless to humans in the process.

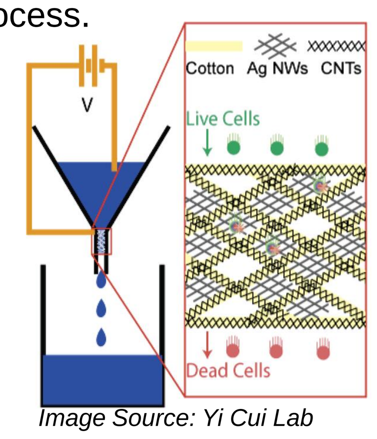


Image Source: Yi Cui Lab

The counter-electrode is the positive terminal which provides the reference voltage for the AgNW/CNT filter's induced potential. Water completes the electric circuit and allows charge flow towards the electrode which is in turn connected to the filter. Due to the highly conductive properties of silver, the filter attains the same electric potential as the electrode.

Electroporation – Electric fields larger than 100 kV/cm are known to break down cell membranes and decrease the viability of the cell.

Antimicrobial properties of silver – Silver is a bactericide that has the ability to inactivate bacteria in otherwise biocompatible substrates.

Changes to solution chemistry – Electric current flow causes pH changes and produces chemicals like chlorine which have a sterilizing effect on water.

Although this nano-technology application was discovered at Stanford before we began our Senior Design Project, it had only been tested in a very small and controlled laboratory setting. The tests were conducted on single, small filters (112 times smaller than ours). To our knowledge, we are the first group to design and build a fully integrated mechanical prototype that incorporates this technology.

Specifications

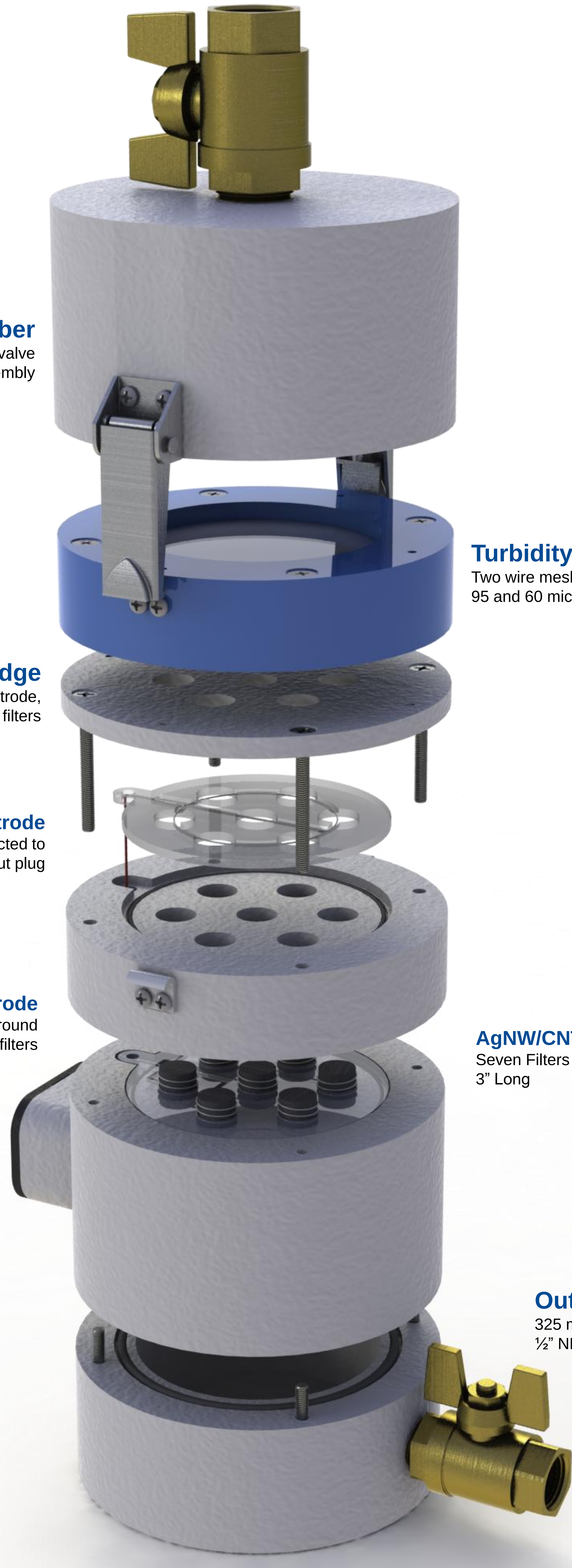
- 81% bacteria inactivation
- Filters up to 18 liters an hour
- Can supply water for up to 29 people per day
- Requires 160 mW (at an average of 7mA draw)

Advantages

Low Cost – The actual amount of silver nanowires and carbon nanotubes contained in their respective solutions are very small and therefore inexpensive. Cotton is a cheap material that incorporates the necessary properties needed for the filter to work: high porosity, as well as chemical and mechanical robustness. Furthermore the system requires only a few miliamperes to operate.

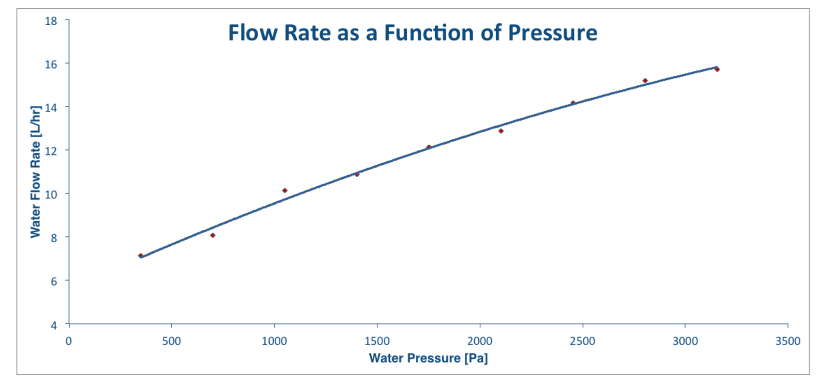
High Flow Rate – The AgNW/CNT filter kills bacteria as it passes through the filter, instead of physically trapping it like traditional water filters. This allows for a much higher flow rate than that of conventional water sterilization methods.

Modular – The system's modular design facilitates its use in remote areas. Unskilled individuals are able to easily disassemble the main components in order to perform routine cleaning and resolve minor maintenance issues.



Flow Rate Test Results

HydraVita operates as a gravity-fed system, therefore the water output flow rate depends almost entirely on the pressure at the input reservoir. The tests we conducted showed a roughly linear relationship between the two variables.

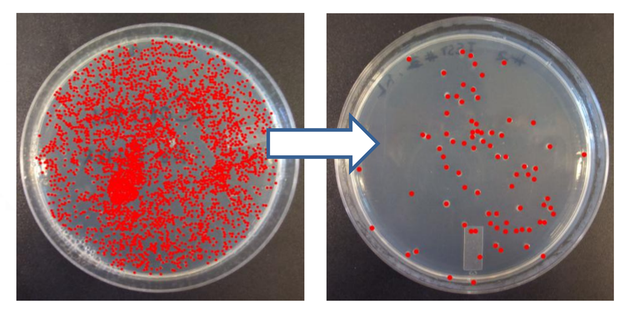


The flow rate can be altered by varying the packing density of the rolled cotton filters. However, after a certain density threshold value, the bacteria inactivation effectiveness decreases dramatically. The experiments we conducted revealed that a 9 inch wide sheet of cotton forms the optimal packing density when rolled along its width to a 0.6" diameter filter. At lengths below 9 inches the porosity of the filters becomes too high and significant amounts of bacteria pass through without being affected by the electroporation process.

Bacteria Test Results

Small Scale Prototype

- 1 Filter
- 0.15" Diameter, 1.5" Long
- 20 Volts, 12 mA

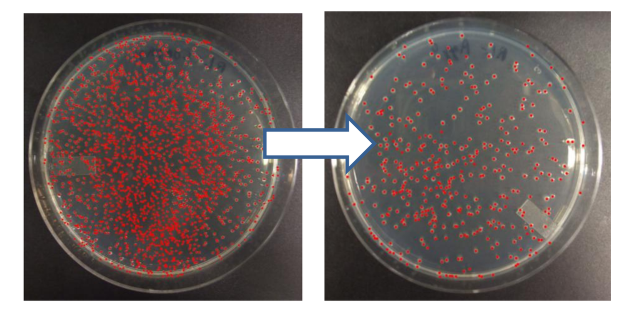


3,020 Colonies   81 Colonies

97% Inactivation

Full Scale Prototype

- 7 Filters
- 0.6" Diameter, 3" Long
- 24 Volts, 2 mA



2,130 Colonies   402 Colonies

81% Inactivation

Power Supply

The HydraVita system is powered by two 12V, 7.2Ah lead acid batteries that are recharged with a 24V, 20W high-efficiency solar panel. The batteries can power the system for up to 42 days without sunlight, assuming an average current draw of 7mA. The system is also equipped with an integrated battery level indicator and a voltmeter in order to ease the operation and maintenance processes.

Future Plans

Extend path length and increase number of AgNW/CNT filters in order to augment probability of bacteria inactivation and to boost water flow rate.

Perform more extensive biological tests in order to determine the AgNW/CNT filter's effectiveness in killing other types of bacteria, viruses, and protozoa.

Re-design the current electrode and counter-electrode setup in order to reduce the probability of poor electrical connections and minimize potential leakage points.

Perform a more in-depth material selection analysis in order to obtain a cost/worth relationship that will allow us to select the optimal material for manufacturing.

Re-design main filter housing and associated components to be manufactured by a more efficient process.