Water Purification using Carbon Nanotubes

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ABSTRACT

Seldon Technologies has developed a carbon nanotube (CNT) based filtration media (Nanomesh™) that takes advantage of the inherent properties of CNTs (high strength, high surface area, electrical conductivity, etc.). Because CNTs represent the ultimate limit in a fiber's diameter, the material achieves highly efficient filtration with a minimum of a pressure drop. This equates to lower power consumption to achieve the desired product (in this case, clean water).

Over the past six years, Seldon has demonstrated the feasibility of using its material to clean water, air and fuels. In 2007 Seldon was issued a patent [1] for the filtration of fluids using CNTs. Additionally Seldon has demonstrated that it is possible to produce large quantities of Nanomesh™ on papermaking machines largely using off-the-shelf processing equipment.

Keywords: carbon nanotubes, filtration, water purification

1 INTRODUCTION

Over 1 billion people lack access to adequately clean water. Additionally, an estimated 2.5 million people die each year from diarrheal diseases and millions more are chronically ill due to a lack of portable water. In the United States and throughout the world, the number of identified contaminants in the water supply is increasing, the water distribution infrastructure is aging, and the costs of upgrading and repairing it are beyond the capability of many municipalities. Hence, there is a growing concern that the water being delivered to people's houses contains harmful impurities.

According to the World Health Organization, decentralized (i.e., point of use) water purification devices will be essential in the future for delivering clean water to a large number of people. This points to a solution that is robust, easy to use and versatile in its configurations. Individual filter elements are a very effective means of bringing clean water to a large number of people without the construction of large purification plants.

It is understood that due to the hydrodynamics of flow around fibers, the efficiency of depth filters improves as the diameter of the fibers making up the filter element decreases. This is due primarily to two effects: 1) smaller fibers possess larger surface area and can therefore capture and hold more contaminants; and 2) smaller fibers disrupt the fluid stream to a lesser degree – the particles get less "advance warning" that they are about to strike the capturing fiber. However, if the fibers are too small in diameter they may lack sufficient strength to avoid breakage under the stress induced by fluid flow. CNTs however, possess exceptional mechanical strength (tensile strength ~100 GPa, modulus ~1000 GPa) [2] making breakage nearly impossible. Additionally, due to their very small diameters (on the order of the mean free path of air molecules), carbon nanotubes present a relatively low resistance to the flow of fluids. This, combined with their high surface area, means that highly-efficient, bio-contaminant removals are possible with a thin filtration media possessing a relatively low pressure drop.

For the past four years, Seldon Technologies has primarily focused on developing CNT-based water filtration media. Seldon's water filter material removes bacteria, viruses, spores, cysts, total organic carbons and inorganic contaminants from water using adsorption and sieving. Additionally, the pressure drop across the filter is much less than what is typically seen with nanofiltration and reverse osmosis systems (1 – 2 bar compared to 3 – 20 bar for nanofiltration and 5 – 120 bar for RO [3]) and a 2"x 9" cartridge is capable of working for well over 1,000 gallons of influent. This level of filtration is accomplished passively without the use of chemicals.

2 SELDON'S TECHNOLOGY

2.1 Background

Common illness-causing organisms other than viruses are 1 - 5 microns long and can typically be removed by size-exclusion filtration. However, the removal of viruses (on the order of 20 nanometers) by size exclusion is impractical as it would present a very high-resistance to flow and could not be used in small filtration systems. Seldon's approach uses chemically activated carbon nanotubes as an adsorptive surface for the attraction of viruses and other microorganisms. The very small size of CNTs creates an enormous removal capacity in the Nanomesh™ filtration media which equates to the ability to purify large volumes of water.

2.2 Work to Date

The bulk of Seldon's development work has focused on testing the technology's effectiveness in removing

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bioburden (i.e. bacteria, viruses, etc.) from water. Seldon's 2" x 9" water filters now reliably remove bacteria and virus from more than 1,000 gallons of water and some tests show that filters can purify up to 3,000 gallons of water.

Seldon has successfully completed third party testing of its Nanomesh™ filter at the University of New Hampshire's Water Treatment Technology Assistance Center. Using specific protocols from NSF P231, UNH demonstrated that while there was a very high biological challenge upstream of the filter, none of the contaminants made it through the filter. The third party test of Seldon's Nanomesh™ filter was terminated at 600 gallons. At Seldon, duplicating the third party's test conditions as closely as possible, the filter testing continued to operate up to 1,000 gallons.

Internal and third party testing has verified that Seldon's material is capable of reducing or removing all of the contaminants listed in Table 1. While further testing is required to determine the capacity of Seldon's material for removing the chemical contaminants listed in the table, the initial results suggest that the media could be suitable for large scale remediation efforts.

As Seldon's water purification technology reaches maturity, a number of product lines will be launched within the year. Table 2 summarizes the initial round of products Seldon is releasing.

2.3 Large Scale Production

Since May 2007 Seldon has conducted ten large scale production runs of its water filtration material (this includes producing both Nanomesh™ and pre-filtration material). It has been an on-going process at Seldon's facility in Vermont to evaluate this material's biological removal performance. While not all of the material produced on a large scale has shown a high level of performance (filtration of 3000^{+} gallons), the material does perform relatively well and shows a higher level of consistency than batch processes used previously. As a result of this work, Seldon has demonstrated it is possible to produce large quantities of a product incorporating a nanoscale material on a papermaking machine (see Figure 1). Additionally, the production of Nanomesh™ is accomplished without the use of solvents, which are often used to disperse carbon nanotubes.

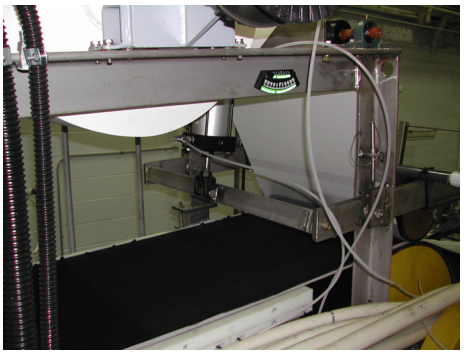

Figure 1: Wet lay deposition of Seldon's Nanomesh™ water filtration media.

3 WATER FILTRATION IN THE FIELD

Seldon has initiated the "*Pure Water – Saving Lives*" program to facilitate getting water purification technology into the hands of the people who need it the most. Seldon's filtration technology meets the four most important criteria for universal application: ease of use, adequate flow rate, appearance and taste. Because Seldon's filtration technology does not rely on chemicals or power to function, it can be used in some of the least developed areas of the world.

In 2006 a team from the Tuck School of Business at Dartmouth College collaborated with Seldon to study the problem of arsenic contamination in the ground water found in Bangladesh and the West Bengal region of India. It is estimated that 35 million to 75 million people of Bangladesh's population of 125 million are at risk of drinking arsenic contaminated water [4]. According to the Tuck study, which compared a variety of purification

Bacteria	Acrylonitrile	Copper	Paraquat	Phenol
Cryptosporidium	Antimony	Dioxin	Perchlorate	Radium
Giardia Lamblia	Arsenic	Herbicides	Pesticides	Thallium
Endotoxins	Benzene Compounds	Iodine	Phenol	TOC's
Chlorine Taste & Odor	Cadmium	Lead	Radium	Trichloroethylene
Turbidity	Carbon Tetrachloride	MTBE	Selenium	Uranium
Viruses	Chromium	Mercury	Perchlorate	Vinyl Chlorides
Acrolein	Chloroform	Nitrates	Pesticides	VOC's

Table 1: Summary of the contaminants that can be removed using Seldon's Nanomesh™ filtration media.

Product	Description
Nanomesh™ terminal filter	Designed to remove bacteria, virus and a wide range of chemical contaminants
Nanomesh™ pre-filter	Designed to extend the life of the terminal Nanomesh™ filter by removing particulates and adsorbing organic contaminants
WaterBox™	Portable dual cartridge water filtration system with an electric pump and optional manual pump, Suitable for small groups of people
WaterStraw™	Personal emergency water filtration device capable of filtering 10 liters of water
WaterStick™	Personal water filtration device capable of filtering 300 liters of water and can be plugged into some types of water carrying backpacks
WaterTap™	Dual cartridge system that can be installed in a person's house under the sink

Table 2: Summary of products to be released by Seldon Technologies during 2008.

technologies, the ability of Seldon's material remove arsenic as well as bacteria and viruses renders it a more durable, more versatile product. Additionally, Seldon's filter excels because it complements the existing tubewell infrastructure.

Throughout 2007, a Dian Fossey Gorilla Fund International field project located in Bisate, Rwanda used prototypes of Seldon's water purification products. The purified water is being used in a medical clinic and in a private home. Users from the NGO have provided valuable feedback to Seldon on how the units operate in the field. Additionally, all users have regularly commented on how good water tastes when filtered through Seldon's system as compared to other water purification methods.

Also in the past year, a high profile NGO acquired a WaterBox™ for testing in one of their emergency vehicles in sub-Saharan Africa. Seldon is awaiting feedback from this group.

Most recently another group of Tuck students has collaborated with Seldon to investigate the possibility of creating micro-enterprises selling clean water in Ghana. The Tuck Team is conducting a study in the town of Pokuase, to determine if this type of micro-enterprise water scheme might be adapted and if so how. Part of the study will be examining the effectiveness or limitations of Seldon's technology in this setting, researching information from the customer perspective and identifying financing opportunities for entrepreneurs, or target customers.

6 ABOUT SELDON TECHNOLOGIES

Founded in 2002, Seldon Technologies has received $15 M in government sponsored funding from AFRL, DARPA and NASA. Additionally, Seldon has entered into collaborative research agreements worth $2.4 M with corporate sponsors. In addition to its patent for the purification of fluids using carbon nanotubes, Seldon has 11 patents pending. The company currently employees 35 people in eastern Vermont.

REFERENCES

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