Design and Development of a Portable Water Filtration System

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Abstract

A portable water filtration system has been designed and developed as a capstone design project. This system includes a compact, lightweight water pump that filters impurities to improve drinking water quality. The water passes through a carbon element filter, an ultraviolet light and a hollow membrane tube filter. This system can be used in developing countries where purified drinking water is scarce. The project used different phases of product design and development processes. Engineering analyses were performed to determine head loss, sterilization time, power consumption and stress due to impact. Most of the components were designed and developed using a 3D printer technology with ABS plastic materials. The filtration system will be tested using environmental protection agency guidelines for drinking water quality.

Introduction

Clean drinking water is a necessity for all human life. Typical hikers consume 1 liter of water per 5 miles. From this information, if a hiker completes a round trip of 15 miles in a day they must carry 3 liters of water. When camping, the hiker needs water through the night to recover and also will most likely need an additional 2 liters of water for cooking and cleaning. When camping and hiking a 15 mile round trip, the required water volume to be carried will be approximately 6 liters/ 6 kilograms of water per person. Many developing countries have a drinking water related contamination problem. The people in developing countries must rely on small water treatment plants close by or bottled water donated by a developed country in order to get the necessary amount of clean water. Unsafe water causes 2.2 million deaths worldwide, mainly in developing countries among young children under 5 years old.[10] Many of these people did not have any access, or limited access, to clean water. There is a need for small devices that are able to filter contaminated water. There are currently products on the market that partially take care of this need. None of these units however, are able to quickly obtain and fill empty water supplies.[15] The problem with the current products is that they are either too heavy, or too difficult to obtain large amounts of quality drinking water within a reasonable time span. The proposed device must be a small self-contained water pump that pushes the water through a filtration unit and fills up an external water bottle the consumer is now able to drink without any worry about contamination. The needed device will be tailored to a more competitive market of hiking and camping. This was decided because a device tailored to hiking and camping will also be quite suitable to conditions of third world countries. Designing the product around camping/ hiking will essentially allow the product to appeal to two different markets.

Background

In the spring of 2014, 38.05 million people had gone either hiking or backpacking within the last 12 months[12]. The graph also showed that there was an increase in hikers/ backpackers, from 2008 through 2014, the number of people that had hiked within the last 12 months increased by approximately 9 million people[12]. This data shows that the market for a portable filtration pump should also be rising. Another website showed that an organization called "The Water Project", claims that for $34 per person they can provide people in developing countries access to clean water. Many of these people live in rural areas where water sanitation equipment cannot be installed due to lack of external power sources.[13] A small portable pump per family in a rural area could do the same or better job than sending bottled water to the area. The bottled water is not a permanent means for the people to access clean water.

Literature Review

Investigating the Effectiveness of Ultraviolet (UV) Water Purification as Replacement of Chlorine Disinfection in Domestic Water Supply showed that using a microbial UV light can be used in mass water purification plants. This paper showed that the water does not need to be out in the open and should be enclosed in an FEV tube. This is allows for the water to be directed where needed and allows for the water to be exposed on all sides to the UV Light. [1]

Hollow membrane filters are already beading used in large scales around the world in order to purify the water. Membrane filters show they can remove almost all pathogens in the water and any debris larger than .01 microns. What a membrane system lacks in however is virus protection along with removing things like lead and arsenic from the water source.[2] Another downfall of a membrane filter is they can be clogged easy and require a pre filter in order to maintain a constant flowrate throughout the system.[3]

Home purification is becoming more prevalent around the United States. Consumers in the US are choosing alternatives to their municipal water systems. Many dislike the chlorine taste in their water. One solution that has become big business is bottled water. Consumers assume this water is better quality. However across the nation, it turns out, bottled water is the same quality as the municipal supply. Bottled water can also contain plastics that may have leeched from the bottle. The other option is a home filter. Many consumer products exist such as a carbon system or a full reverse osmosis. These systems help take the chlorine out of the municipal supply, but can remove other minerals in the water that the body needs.[4]

Silver is a known antibacterial agent. Silver coils are inserted into closed systems in order to make sure no bacterial or algae growth appears in the system. One way this can be incorporating into filter systems is to infuse silver into microspheres that can be used in a system that relies on the water flowing through several layers of material. Those layers include gravel, carbon, and ceramics to remove more pollutants as the water moves downward through the system (Polymeric Microspheres Containing Silver Nanoparticles). Other than silver several antimicrobial materials can be infused into polymer beads. These materials may include copper alloys, fluorocarbons, carbon nanotubes, and more.[6,9,10,11]

Methods

Methodology behind the design and development of the Portable Filtration system began with Design Parameters. Parameters of the design was to include, ease of use, weight, size, rate of flow, capacity of flow, and FDA Approval. It was difficult to define ease of use as this parameter is one that is relative to the user. The end goal from this was to have as few buttons and operations required for usage as possible. The mass of the system was spec'd to be 2 kg or less to simulate the mass of two liters of water that would be held in a typical hikers back pack. The Size of the Unit was specified to be the size of 1 liter of water in order for there to be a size savings in the backpack compared to that of a bottle of water. This size however, was increased through the actual design phase as it was deemed less important to other factors such as flow capacity and flow rate. The Rate of flow was decided to be 1 liter per minute of flow. This was decided as it was one of the reasons the unit would be beneficial. There are other products on the market that can achieve the same result as this design, however, the market niche for this product would be that the flow rate is much larger than that of the other units which were examined closer to .1 liter per minute. Flow capacity of the design was decided at 7.4 liters (2 Gallons). This flow capacity was determined as because of the average daily needs of a recreational hiker hiking throughout the entire day. FDA approval was the most important factor for this product, because the water being dispensed from this filter is meant to be safe drinking water. The design had to be around removing the impurities in the water at a rate acceptable as is defined by the FDA or it would not be able to be sold in the United States and would not be fit for human consumption.

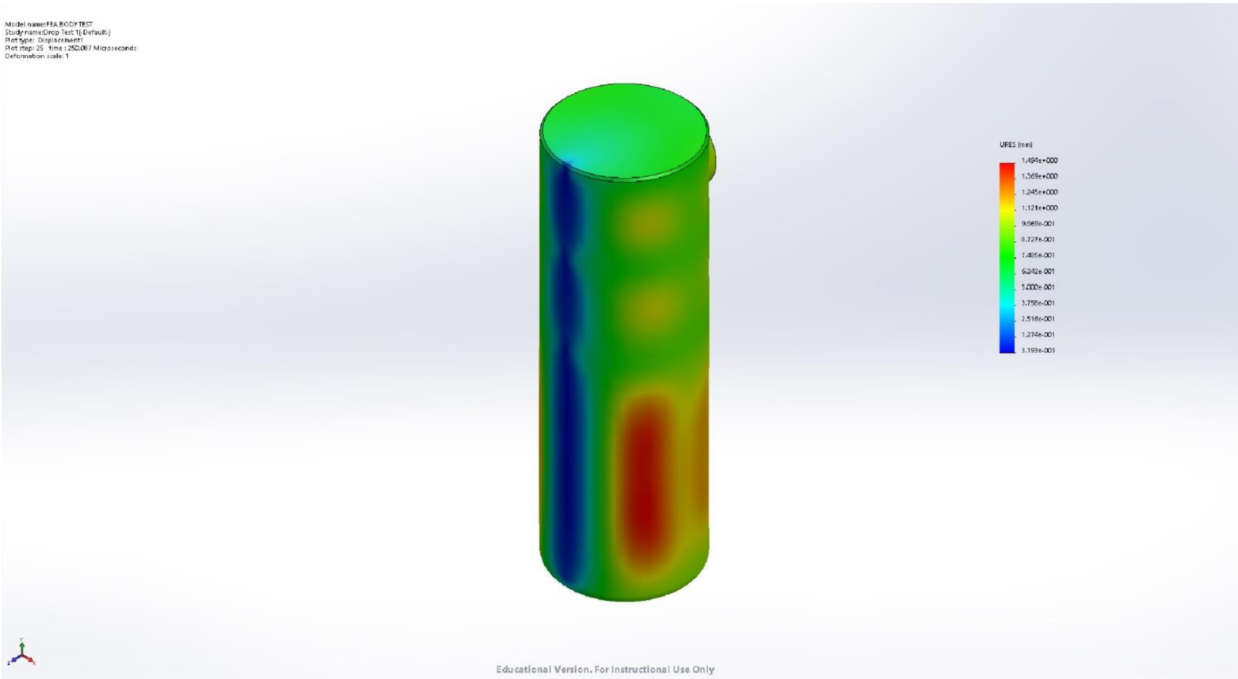
A house of quality (HOQ) was constructed based on these clearly defined parameters and were rated on customer importance. The idea behind the design was then rated from these criteria and compared to two other competing products, the Life Straw, and the Filtration bag. Based on all of these ideas and tools, a Product Development Specification (PDS) was created to define and document all of the traits that a competitive product design must encompass. This PDS was then used to create three separate feasible concepts. All three feasible concepts were set to be able to deliver all of the traits defined in the PDS in different ways. Tools such as Analytical Hierarchy Processes, and Pugh Charts were used to develop a comparison scale at which to analyze the three feasible concepts, and decide on the concept that would achieve all of the most important traits fully while still achieving the rest of the traits to a degree. It was during this phase that the size and mass of the product were affected as they were rated as less priority compared to that of the flow rate, flow capacity, and filtration traits. These three traits were defined as the most important ones. A full analysis of the selected concept was done to fully define the size, mass, flow requirements, and energy requirements, as well as body strength of the system. The completion of this analysis allowed for the final development of the design of the product. Final Design reviews were completed for the product which allowed for funding for the prototype building of the system.

All in house built components of the system were created first while the standard components were purchased through outside suppliers. The Prototype was successfully created after altering some points of the design. The final step in the Design was to test the prototype. The Testing Procedure for the prototype was clearly laid out in a methodical manner so as to isolate the variable being tested by the prototype. Clear parameters were put into place to define the limits for every test for pass or fail. Some aspects of tests did not allow for clear pass and fail. These certain testing aspects had a defined grey period to allow for partial pass and partial fail.

Design tools/Processes

A multitude of tools and processes were used during the design process of the portable water filtration system. Some of the most commonly referenced tools and processes were for the creation of the actual design concept. These tools included the HOQ, Failure Mode and Effect Analysis (FMEA), AHP Charts, Pugh Charts, Function structure, and decision matrices. The most common of all of these tools and processes was the HOQ. The HOQ was the most used tool as it is the tool that the design was created from. The AHP charts, Pugh charts, and decision matrices, were all created based on the information given in the HOQ. The HOQ also strongly influenced the PDS which was used in the creation of the three feasible concepts for the system. The FMEA was an important tool to use in order to define certain aspects of the design that needed to be in place in order for the safe and effective working of the system. AHP charts, Pugh charts, and decision matrices were created and used for deciding which concept was the best of the three without introducing any bias or inconsistencies.

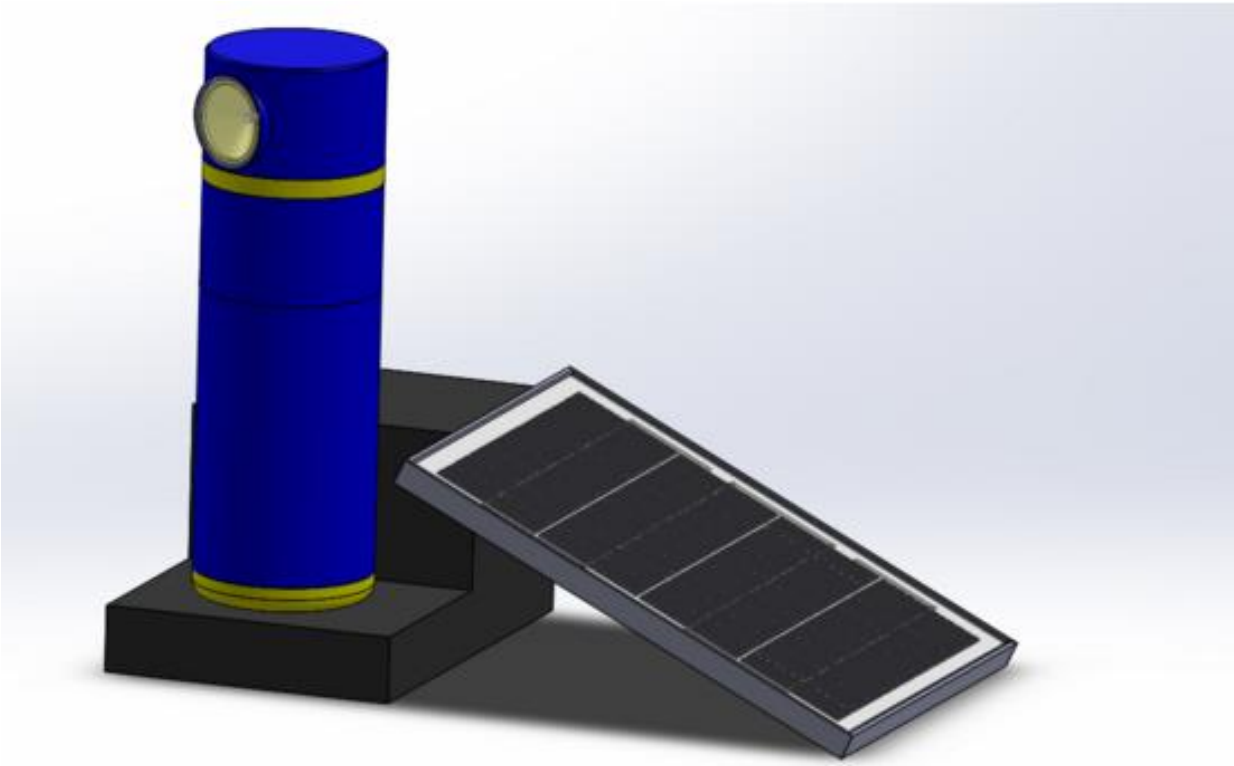
Another section of Design tools and processes that were used would be the computer programs and the rapid prototyping tools used for the final analysis, design, and prototyping of the system. The tools used that fit this criteria are, CAD programs, FEA analysis Programs, CFD analysis programs, and the universities rapid prototyping plastic 3D printing machine. The FEA analysis program used for this project was created by inventor. This program allowed for the Von-Mises stress calculation of the body of the filtration system from a fall of 5 ft. onto a slab of concrete. This analysis ensured that the thickness of the body of the system was sufficient when manufactured using ABS plastic as the material (see figure 1). The CFD analysis program was also created by Inventor. The use of this program generated data allowing for the estimation of the head loss of the carbon element filter and hollow membrane tube filter being utilized in the design. Accurate analysis of these systems was pivotal for selecting the correctly rated water pump to be used for this design. The 3D printers at the University allowed for the rapid prototyping of all components in the system there were to be made of plastic. This list was substantial and included the main body and carbon element filer housing.



(Figure 1 FEA Analysis from a 5ft Drop)

Results

The design results as show in Figure 2. Results of the analysis and design process ended up with some information that would require design changes in the end route. At the beginning of the concept phase, when the size of the bottle was specified, the hypothesis was that the needed size of the pump would be approximately five liters per minute. After the analysis of the hollow membrane filter and carbon element filter, whose respective rated head losses were much greater than previously estimated, we found that we needed a much larger pump. This larger pump impacted the diameter of the housing greatly as it was almost 100 millimeters lager square than the pump that was hypothesized for usage. The mass of the pump also greatly influenced the overall mass of the pump to over the two kilogram standard that was previously defined. With only those setbacks however, it was found that the system surpassed the FDA requirements, flow capacity, and flow rate were all deemed as being the most important aspects of the design, the product was still considered successful.



(Figure 2 Rendering of Design)

Conclusion

Just like in many other product designs, tradeoffs were required for this system in order to make it for the price point that was required. In the end, the volume and mass of the portable water filtration system was traded off as less important than the flow rate, flow capacity, and FDA requirements. Through the design reviews with the class Professor and machining technicians at the school, it was deemed that there was no way of meeting all of the requirements without drastically increasing the price of the product. This tradeoff was the major cause for consideration in the design to decide the best way to make everything work as closely as possible. The resulting design was therefore not quite identical to the original design submitted before prototyping, however, was as close as possible while still remaining economical.

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