# Foam Filtration AguaClara Research Team

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**Abstract**

The Foam Filtration team developed a two-stage emergency water filter. The filter was presented at the 2012 National Sustainable Design Expo in Washington, D.C. as part of the P3 competition for sustainability. While at the expo, rough data was collected on the performance of the pilot scale filter as a proof of concept. The competition also involved submitting a grant proposal highlighting all past research on foam filtration and presenting a plan for future research and eventual implementation.

## Literature Review

Following previous experimental trials with foam as a filter medium, results indicated that filter performance was adequate only in systems that utilized the addition of a coagulant to the influent water. Using Sobsey's evaluation criteria for point-of-use (POU) water treatment systems, devices requiring coagulation are rated lowest on the effectiveness scale [Sobsey]. This is because the system would not only require the operator to be familiar with multiple steps, but the need for coagulant would also increase material cost and create a need for maintenance. These findings indicate that a foam filtration device would not prove to be a disruptive technology and would be impractical for a POU system due to the need for added chemicals.

Thus, focus has shifted from a foam filter as a POU system to an emergency response unit that could provide safe drinking water for a larger number of individuals during a crisis. In emergency situations, including natural and man-made disasters, re-establishing a safe water supply is of the utmost importance [Dorea]. In such situations, reliable and clean water is necessary to reduce the risks associate with waterborne diseases, and to aid in the maintenance of proper hygiene in order to prevent communicable disease outbreaks [Clarke and Steele]. More specifically, adequate water treatment can prevent waterborne disease outbreaks, including epidemics of diarrhea and cholera, in refugee camps and other disaster relief events. Diarrhea, cholera, and other waterborne diseases are often the leading killer of individuals in refugee camps. Diarrheal diseases in the past have been the cause of an estimated 40% of deaths among individuals in refugee camps, where 80% of these cases have occurred in children under two years of age [Doocy and Burnham]. In extreme cases, diarrheal diseases can cause 85-90% of deaths in refugee camps, as was seen in the 1994 crisis in Rwanda [Toole and Waldman][Doocy and Burnham]. In natural disasters, such as floods, earthquakes, and tsunamis, compromised water supplies can lead to an increased disease burden as well as increased mortality. In the end, the most effective measure in preventing waterborne diseases like cholera in an emergency situation is to quickly and efficiently provide a source of clean water free of pathogenic agents. Thus, there is a great need for a low-cost emergency drinking water treatment system that can be easily operated immediately following a disaster.

Previous trials have shown that a polyurethane foam filtration system in combination with a coagulant can provide clean, low turbidity water. The design of an emergency treatment unit has a variety of constraints that differ from the previous POU design. The updated system is designed to meet the UNHCR's (United Nations High Commissioner for Refugees) water recommendations for refugee situations, which includes providing 15 liters of "reasonably safe" water per day per individual [UNHCR]. Additionally, studies have shown that filter performance can be improved through the use of a multi-stage system of roughing and finishing filtration. Nkwonta and Ochieng remark that roughing filtration has proven to be reliable and effective in removal of solids, turbidity, and coliform bacteria [Nkwonta and Ochieng]. Roughing filters can act as a physical filter for solid particles in water, and can partially reduce the amount of pathogens in drinking water. When used in combination with a finishing filter, the roughing filter system can prove very effective in providing safe drinking water.

Another design consideration involves the need for rapid response in an emergency. Often, a disaster can result in a disruption of infrastructure and public services, which can be even more pronounced in lower income countries without reliable infrastructure to begin with. Thus, a system that can be easily and efficiently transported is invaluable in such situations. Previously implemented systems have shown success with a design that can be transported in and operated from the bed of a truck [Garsadi]. Additionally, if any power is needed, it can be provided by the truck engine. Design considerations, consequently, include size and power restrictions that are limited by a truck's capacity.

The system ultimately must meet a variety of criteria in order to prove to be a disruptive technology. According to the Centre for Environmental Health Engineering at the University of Surrey, adequate treatment apparatuses not only provide adequate quantities of quality drinking water when and where it is needed, by the system must be affordable for relief organizations and cost effective to maintain [Clarke and Steele]. In light of these guidelines, the design of a roughing and finishing foam filter system, in combination with a coagulant dosing system and size constraints, should be relatively easy to maintain and meet the aforementioned standards.

Ultimately, adequate water treatment for safe, disease-free water is a fundamental global need. According to the World Health Organization, 1.73 million deaths each year can be attributed to poor sanitation and water treatment [WHO]. Because of this dire need, the World Health Organization has included improved water treatment and access to clean water in the fifteen Millennium Development Goals. In developing nations that have been subject to a recent disaster, clean water can be even more difficult to deliver to those most in need. Thus, a robust, disruptive technology would prove invaluable in disaster relief.

# Background and Design

## Potential Applications of Foam Filtration

The AguaClara Foam Filtration Team is currently investigating the use of reticulated polyurethane foam as a medium for water filtration. In Spring 2011, the foam team demonstrated that foam can effectively treat turbid water with the addition of a coagulant; influent waters at 10 NTU were treated to an effluent of less than 0.3 NTU, meeting EPA drinking water standards. Foam filtration was originally investigated for application in an AguaClara plant, but it was deemed an inappropriate technology due to the difficulty of mechanized foam media cleaning at the municipal scale. Cleaning and operating would be much easier for a POU unit, so this too was investigated as an application of polyurethane foam water filtration. Depth filtration trials showed that the POU unit would require the use of a coagulant such as alum or PACl to effectively reduce the turbidity of water below the EPA standard. As shown in Figure 1, even at a low influent turbidity of 5 NTU and a low approach velocity, the filter was unable to achieve effluent turbidity meeting EPA standards without coagulant.

The necessity of a chemical feed makes this device slightly more complex than POU devices that are currently used in households, so other applications were considered. Foam filtration would be appropriate for use in emergency situations, when relatively large numbers of people need quick access to clean drinking water. Additionally, community water kiosks, which are already incorporated into rural lifestyles in many developing countries, would be a useful application of this technology. In the case of emergencies or kiosk designs, one or two operators could be employed to perform regular chemical dosing and maintenance.

## Emergency Filtration Unit

Different pore sizes were tested for use as a roughing filter with variable influent turbidity during the Fall 2011 semester. Also, the depth of the filter bed was changed to determine the most efficient depth for roughing and finishing filtration. Foam with 30 pores per inch (ppi) was proposed as a roughing filter because of its relatively large pore size and high solids load capacity. Data collected from 30 ppi performance at three different foam depths show that increasing foam depth increases performance. As can be seen in Figure 2, a foam depth of 15 inches produced the best efficiency in intial trials. Our final foam design includes a 30 inch roughing filter, to maximize filter performance while

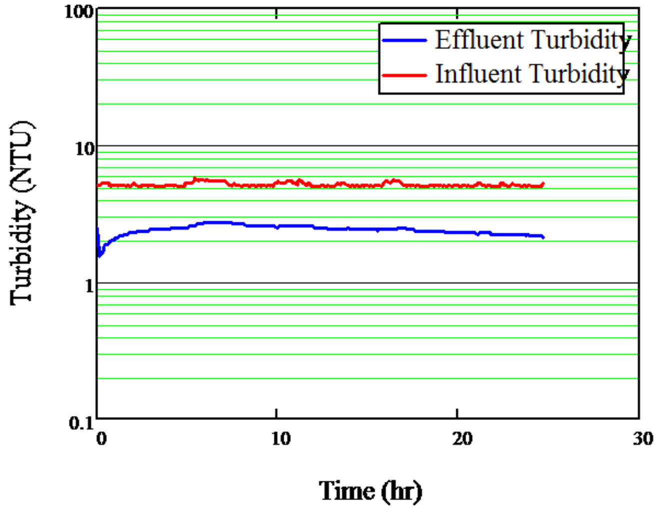


Figure 1: Performance of 90 ppi foam with an approach velocity of 1 mm/s with no alum feed and a 5 NTU influent

still taking mobility and transportability into consideration.

Head loss across the bed was also measured for the 30 ppi foam, but it was determined to be negligible for any filter depth. The same foam was tested with three different influent turbidities and corresponding coagulant concentrations. Figure 3 shows that although the filter performed better with lower influent turbidity, the 15 inch deep 30 ppi filter performed well enough to be an effective roughing filter. Paired with a finishing filter, it would able to produce potable water which meetsand meet EPA turbidity standards.

The original design for the emergency/kiosk filtration system consisted of two roughing filters in parallel and one finishing filter, so that the water may flow through one roughing filter while the other is being cleaned. This would allow a nearly constant flow of water through the system, which would be imperative in an emergency situation. Upon testing of our pilot-scale device, we determined that cleaning was simple and fast enough that a second roughing filter would not be necessary. A cleaning apparatus (Figure 4) has been designed for the system which consists of a long pole and a head with holes drilled in it to allow flow of water. The “plunger” will be used to compress the foam much like one would compress a common dish sponge for cleaning, releasing dirty particles from the foam (Figure 5). When the exit tube is lowered below the water level, the water will flow out of the filter. The foam will remain submerged throughout the process to keep it saturated and prevent the development of air pockets and preferential flow patterns. These would lead to far less effective filter performance.

Based on these designs, we have constructed a full-size filter apparatus. The

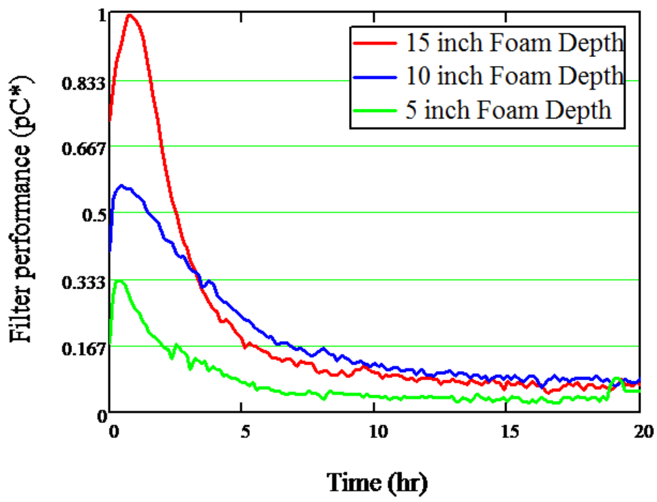


Figure 2: Filter performance at varying foam depths.

full-scale filter unit is small enough to fit on the back of a truck bed and is easily operable with minimal training for effective use in an emergency situation or community kiosk. The roughing filter is 30 ppi foam, 30 inches long, with a 4 inch diameter, and the finishing filter is 90 ppi foam, half the length of the roughing filter. The plumbing connecting the roughing filter to the finishing filter is a simple flexible tube.

# Methods

## Foam Filter Apparatus

The foam filtration team has finished constructing a prototype of a two-stage foam filter. We have also received foam and have added it to the prototype. See Figure 6 for our current prototype design.

The updated prototype makes use of an aluminum frame on which the two filters are mounted side by side. The filters' heights can easily be adjusted up and down if needed to adjust for head loss in the plumbing. The two filters are connected by flexible tubing, which also allows for easy adjustment. When the device is running, turbid water will flow into the top of the roughing filter, down through the 30 ppi foam, and out through an orifice at the bottom of the filter. It will then travel via flexible tubing to the top of the finishing filter and down the 90 ppi foam through another orifice at the bottom of the pipe.

For the purposes of the EPA National Sustainable Design Expo, our design included a supercritical flow pipe after the finishing filter (See Figure 7). The top of this pipe is level with the top of the finishing filter, ensuring the filter remains

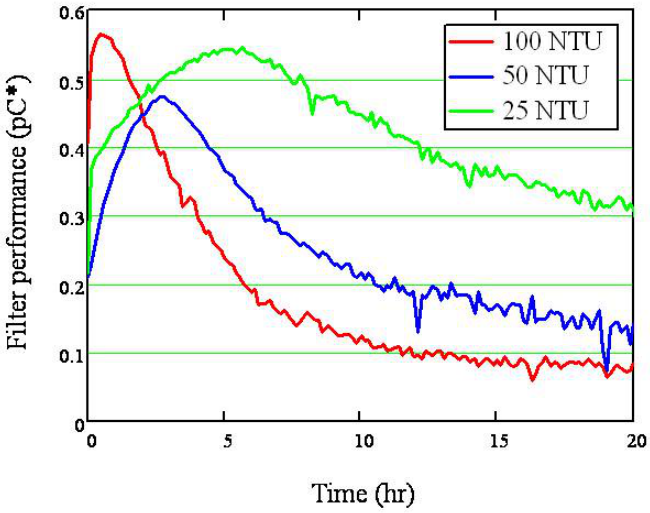


Figure 3: Filter Performance of 30 ppi foam with an approach velocity of 6 mm/s, an alum feed with varying influent turbidity of 100, 50, and 25 NTU

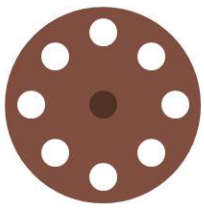

Figure 4: Top view of the plunger head, with holes which allow water to flow up through the filter when the foam is compressed

saturated and never fully drains. If the filter drains and is not continually submerged, air pockets could form in the foam and hinder performance.

From the supercritical flow pipe, the effluent water is dosed with chlorine with a constant head tank dosing system and subsequently flows into a reservoir. At the expo, in order to avoid bringing in large volumes of water, water was recirculated from the reservoir using a submersible pump. The treated effluent water exited the supercritical flow tube into a clean water reservoir (a large beaker). The clean water then overflowed from the beaker into a larger tank that served as the inlet reservoir. In this tank, clay was added to the water and the dirty influent water moved via the submersible pump to the roughing filter. Before entering the roughing filter, coagulant was dosed with a constant head tank. The demonstration prototype also included a small linear flow orifice meter (LFOM) to illustrate the linear dosing system that will eventually be im-

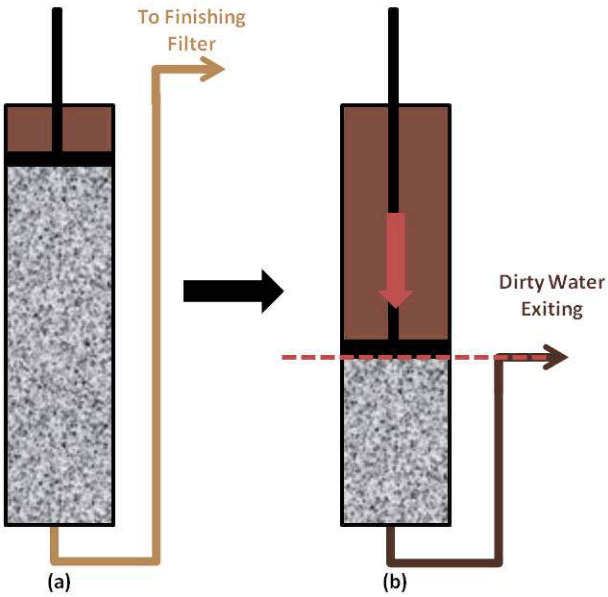


Figure 5: The cleaning process consists of compressing the foam to release particles, and allowing the dirty water to flow from the filter

plemented in the final design. When combined with a chemical dose controller (CDC) developed by AguaClara, the LFOM and constant head tank will automatically adjust the coagulant dose with a changing influent flow rate ensuring a constant coagulant dose in the filtration column.

The foam is re-expanded after cleaning compression by a length of Kevlar cord that passes through a 1/4 inch diameter PVC tube in the top of the filter. The PVC tube is in place to ensure that the forces applied to the Kevlar cord do not in any way damage or tear the foam. The Kevlar cord is then attached to a handle composed of a length of tubing for ease of use. The resulting system easily re-expands the foam while the foam is still submerged in the filtration column.

## Experimental Design and Data Acquisition

Now that the prototype has been fully constructed, including the foam, we will begin testing with 100 NTU influent water at a filtration velocity of 6 mm/s in the columns. For the purposes of our experiment, we will modify our design by adding turbidimeters after each stage of filtration. These turbidimeters will determine the efficiency of each stage of filtration so we can ensure the final output meets the EPA drinking water standard. Figure 8 shows the setup of the prototype for testing purposes. Along with our filtration trials, we will test the effectiveness of the proposed cleaning method. At the EPA expo, all

Figure 6: Prototype Design

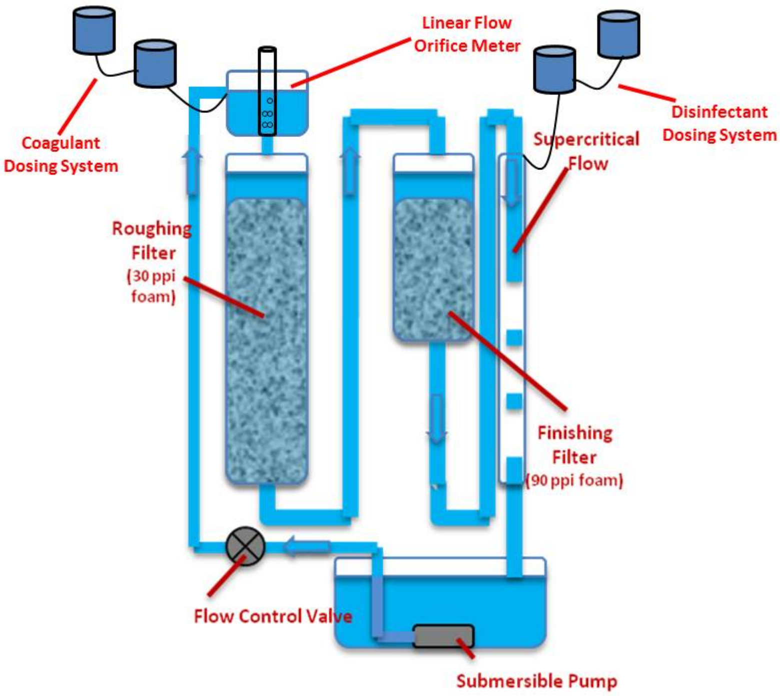


Figure 7: Prototype Schematic

data will be collected using a handheld turbidimeter rather than the via the experimental laboratory setup.

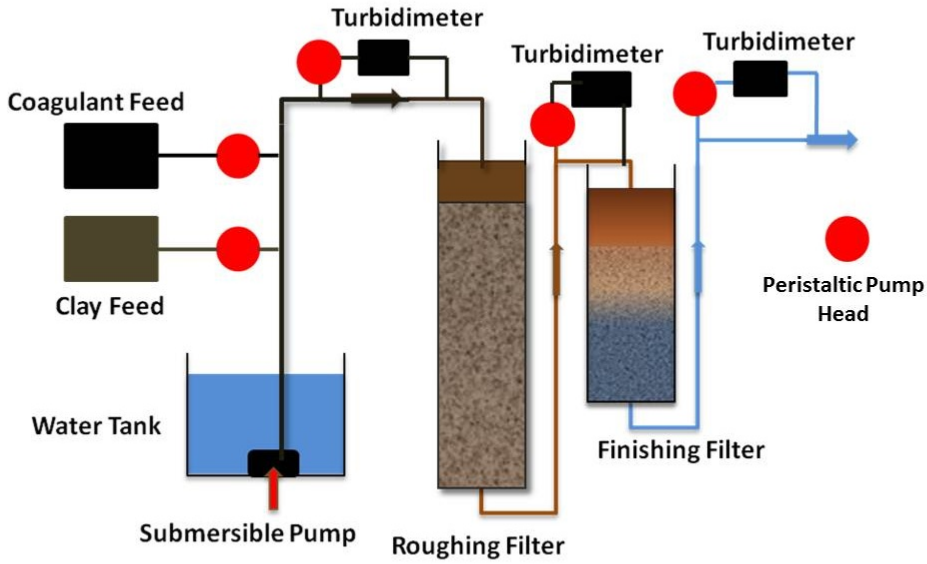


Figure 8: Schematic of the prototype during testing

## Data and Analysis

All quantitative data obtained for analysis of the complete foam filtration apparatus with roughing and finishing filters operating in series was obtained during continuous running of the device at the P3 expo in Washington, D.C. The longest continuous use of the filter without a cleaning cycle was approximately 4 hours. Neither the roughing filter nor the finishing filter dropped below an acceptable efficiency during this time, but instead the cleaning was for demonstration purposes and to test the efficacy of the cleaning process. During the four hours of testing, the influent turbidity was kept relatively constant but did vary, with an approximate mean of 120 NTU. The most turbid influent water was approximately 275 NTU, and this water was filtered to approximately 0.5 NTU after traveling through the both stages of filtration, giving an overall pC* of 2.74. Generally, when the influent turbidity fell below 180 NTU, the effluent turbidity was below the 0.3 NTU EPA standard.

The cleaning process, though demonstrated before it was necessary from a filter performance point of view, effectively removed particles from the foam and returned the filters to efficient operation. The foam columns were easily compressed and released an extremely large amount of dirt, but the turbidity of this water was not measured with the handheld turbidimeter because it could not be relied upon to accurately measure the turbidity of such highly turbid water. Once compressed, approximately one gallon of clean water was pumped through the system to force the dirt particles through the foam. After the gallon had been flushed through the filter, it could be visibly seen that not all the dirt had been removed from the foam, but the water was visibly more clean. The decompression of the foam using string was effective and led to no failure of the filter or damaging of the foam. As expected, because the foam was slightly larger than the PVC pipe in which it was contained, it pressed against the walls with enough pressure to seal the string to the side and avoid creating a preferential flow path for influent water and dirt particles.

The coagulant doser was calibrated correctly and needed to be refilled approximately every 70 minutes but did dose the necessary 8.3 mg/L of PACl into the filter. During points of operation, the dose was decreased, but the filter continued to operate at efficiency levels similar to those mentioned above.

## Conclusions

The data obtained at the expo may have been inaccurate for a variety of reasons. One of these is that turbidities were measured with a handheld turbidimeter that had not been fully calibrated, and which may have given inaccurate readings due to settling in the sample that was tested. The influent turbidity was also not constant because the water was not continually being mixed, and therefore the influent was not necessarily as turbid as the measured value at all times. Also, coagulant was being recirculated, and the flow rate was slightly lower than 2.5 L/s, both of which are factors that could have contributed to artificially improved filter performance and reduced effluent turbidity.

Despite these inaccuracies, continuous running of the filter at the expo proved that it is effective at the full scale, and it was capable of treating influent turbidities higher than had been previously concluded in the lab. One conclusion that can be made from this performance is that the roughing filter was also acting as a flocculator, causing particles to collide within its pores. This additional flocculation would lead to more effective performance than simply the additive performance of filters in series.

Running of the prototype also confirmed that the foam is able to be cleaned and return to its original effectiveness, as it was cleaned multiple times and showed no decrease in performance. Cleaning the filter visually revealed the amount of clay that was retained by the foam columns, and it also showed that the plunging method is able to release the particles exactly as was expected. In order to demonstrate the cleaning process more often, the filter was cleaned more frequently than every eight hours as proposed, so the performance had not yet been affected at the time of the cleaning. One conclusion drawn from cleaning the filter is that the method would be much more efficient if there were a valve on the side of the filter to allow the dirty water to flow out, instead of having to flow the water through the compressed foam. At the expo, the cleaning process required approximately one gallon of rinse water. It was cleaned approximately every four hours, in which time it would have produced about 300 gallons. This ratio could be improved by allowing the filter to run longer before cleaning, as well as by adding the proposed cleanout valve.

## Future Work

Future semesters should focus of three areas of improving the Foam Filtration project. The first area is to scientifically determine the performance of the prototype filter developed this semester in a controlled laboratory setting. Within this testing, the first aspect is to develop a Process Controller file to continuously monitor turbidity in the prototype in three key locations: entering the roughing filter, entering the finishing filter, and leaving the finishing filter. These turbidities will indicate the performance of the roughing filtration column, the finishing filtration column, and the performance of the system as a whole. The performance of the cleaning method will also have to be tested in a controlled setting again to determine exactly how much water is required to flush each filter, how many particles remain in the filter after cleaning or how long the filter needs to ripen before it returns to peak efficiency, and if the cleaning method could be improved by adding a drain valve part way up the filtration column to release the dirty water above the compressed foam rather than attempting to flush the dirty water through the compressed foam. Finally, the operational characteristics of the filter performance will have to be determined, such as the length of time the filter can run before it needs cleaning and empirical proof that the filter does not lose performance with repeated cleaning.

Another area for future work is to determine the various physical characteristics of the filter design itself. The first step would be to determine the headloss between each column, considering the design of the plumbing system, to precisely lay out the relative heights required for each filtration column. Another important physical characteristic to determine would be the life expectancy of the prototype, specifically the foam itself. This is of particular importance to warm and humid areas such as Honduras where plastics degrade faster in the harsh climate. The effluent and foam should also be tested to ensure there is no leeching of chemicals from the foam into the effluent.

Finally, the most important area of future work is to develop a "foam filter owner's manual" with the PR team that details all aspects of owning and operating a foam filter device. This manual will have to detail all aspects of the filter from a detailed parts list and construction guide to a cleaning and operation manual for running the filter. The manual will have to be professional in appearance, easy to understand, and would be ideally available in a number of languages. A brief annotated version of the manual should be a top priority for any future work because there have already been requests from third parties for instructions to build and operate their own filter. This manual should also include reccomendations on where to find reticulated polyurethane foam especially in resource poor communities, so additional research should be done to locate additional sources of foam.

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