Material Analysis & Design Considerations Towards an Economic Water Filtration Prototype for Developing Countries

A thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Science degree in Physics from the College of William and Mary

by

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The purpose of this research project is to explore water filtration techniques and respective physical parameters to analyze their potential for implementation into an effective, affordable, and portable water filtration device for use in developing countries. The need for new water purification methods might seem unwarranted in a developed country with ample purification technologies, but on a global scale the need is severe. Furthermore, this need is sure to increase as climate change results in increasing temperatures. Currently, "a quarter of the world's people don't have sufficient access to clean drinking water, and more people die every year from waterborne illnesses – such as cholera and typhoid fever - than from all forms of violence combined". (Lappe) Unfortunately, the consequences of an insufficient water supply extend beyond personal health, as it is capable of generating violent social unrest in the most affected areas. For example, a severe drought resulting in a shortage of water for drinking and farming purposes has been identified as one of the main catalysts for the current Syrian conflict. (Staff)

Many research papers have been written on the antimicrobial properties of nanoparticle silver in water filtration, yet two particular papers provide the foundation for the potential technologies explored in this research project. Both papers explore the antimicrobial properties achieved by attaching nanoparticle silver to two different materials, cotton cloth and flexible polyurethane foam (FPU). (Thomas, Prashant) These materials are low-cost relative to alternative water-filtration techniques, and possess great potential for cost-effective, widespread deployment in developing regions.

Water filtration via these methods provides another valuable advantage. They eliminate the need for electrical power, and can be configured to effectively filter water using simply pressure generated by gravity.

A further benefit to each of these techniques is their environmental impact. All necessary chemical ingredients for synthesis of the two structures are non-toxic and biodegradable, eliminating the need for harmful chemicals. Additionally, synthesis takes place at room temperature. This allows the filters, which will require wide distribution throughout sparsely populated rural areas, to be synthesized locally, rather than in a distant laboratory, greatly reducing shipping expenses and increasing availability or quick replacement.

The purpose of this research project is to closely examine the properties of cotton fabric and FPU, obtain quantitative physical parameters, and evaluate their potential for integration into a final water filtration unit that fulfills necessary constraints.

Design Considerations

Size

The target market consists of populations who reside in developing regions and travel greater than 1km round-trip to collect water. According to WHO Water-Quality Guidelines, this market has a "Very High" public health risk from poor hygiene, since basic water consumption and hygiene practices are likely compromised. ("Guidelines") To encourage adoption of the filter, it will be designed to have a capacity of approximately 5 gallons, approximately equal to the current amount of water typically collected. Furthermore, at 5 gallons, the weight of the filter at capacity is approximately 42 lbs., a weight that is assumed manageable for most people, including children, to bear around their torso.

Shape

For transporting water, 5-gallon containers are typically balanced on the head in the traditional fashion. This container will exert approximately 975 kPa of pressure on the cervical spine (neck vertebrae). When exerted over long distances, this pressure can have detrimental effects on a person's health. Severe spinal and back pains have been documented throughout developing countries as a result of transporting water via this method. (Geere) To counter this effect, a flexible tube design has been adopted, allowing the user to comfortably support the weight of the water on the torso, eliminating any stress on the neck. Additionally, as a mother is unlikely to leave small children home alone

Figure 1: Zambian lady carrying water & baby.

while collecting water, the final design will enable small children to balance on the water filter in the traditional fashion. Finally, this design enables the user hands-free transportation, which is invaluable as violent assaults are common during the water collection process.

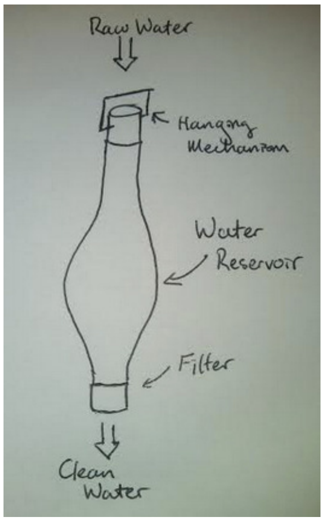


Figure 2: A) Schematic for overall unit design B) Concept for filtration unit in use

Function

There are essentially two options for water filtration in relation to the time the filtration occurs, either point of source or point of use. Point of use filtration is identified as the superior method for implementation in developing countries. (Wright) This is due to overcrowded, unsanitary pumps, poor maintenance and broken technologies that can undermine the performance of point of source filtration apparatuses. Furthermore, the necessity to keep the purified water isolated during the return voyage is a difficult challenge and often ignored. For these reasons, this device will be designed as a point of use filtration mechanism, so that the filtration process occurs immediately before the water is needed for its intended purpose.

Cost

A most important constraint of the filter design is the final price. It is essential, to facilitate adoption, that the price is as affordable as possible. Typical water filters cost upwards of $50; however, plenty of alternative water purification methods exist that are equally as effective yet cost drastically less.

The antimicrobial properties of nanoparticle silver have long been known as powerful agents for water purification. “Silver nanoparticles cause structural changes in the bacterial membrane constituents and thus damage the bacterial membrane leading to uncontrolled transport through the membrane and finally cell death. . . . In addition, . . . have proposed that Ag^{+} ions, released from silver nanoparticles can interact with phosphorous moieties in DNA resulting in inactivation of DNA replication, and inhibit enzyme functions.” (Thomas) Therefore, our filter will utilize the power of this inexpensive particle to guarantee sanitization.

Experimental Design

Cloth

The purpose of the first set of experiments is to understand the properties of simple cotton cloth, and apply these properties to a filter design. Through timing the passage of water through cotton layers, we can get a clearer understanding of how the cloth reacts to the passage of water, and observe any fundamental changes of its inherent properties.

Simply running raw water through folded over cotton has been proven to drastically reduce turbidity, and can even reduce bacterial presence up to 99%. (Tammisetti) Yet, this method is not sufficient to guarantee removal of harmful bacteria and viral pathogens throughout multiple successive trials.

Researchers at Trinity College in Dublin have surveyed the potential of silver nanoparticle loaded cotton for water filtration. They attached the antimicrobial nanoparticles through green synthesis via the primary agent chitosan, and were able to observe antimicrobial activity. (Thomas) However this activity was only demonstrated by placing the cloth in E. coli loaded broth, as opposed to passing the water through the cloth.

The first set of experiments will consist of immediately successive trials through single, double, and triple layers of cloth. However, this will not be sufficient since our filter is intended for extended, everyday use. We want to understand the cloth's performance over an extended period, and see if there are any differences between the experiments. Therefore, a second set of experiments will consist of a smaller number of trials, performed with 24-hour intervals.

FPU

Although slightly more expensive than cotton, the difference is small enough that flexible polyurethane foam is an excellent candidate for our low-cost filter. Researchers at the Indian Institute of Technology (Madras) have developed a chemical process to bind nanoparticle silver to flexible polyurethane foam. (Prashant) After passing water with input loads of E. coli at 1×10^3 and 1×10^5 CFU/mL through the silver enhanced FPU, they observed no bacterium in the output water. Another exciting result from their research is that no loss of nanoparticles from the foam's surface was observed due to the passage of water through the foam. This implies that any properties observed using normal flexible polyurethane are inherently maintained (although they might differ by a factor) after silver nanoparticles are attached. The purpose of these trials is to understand the passage of water through flexible polyurethane foam, and obtain quantitative parameters to evaluate possible integration into the final filter. Trials will be conducted while varying the thickness and structure of the flexible polyurethane layer to understand its inherent properties.

Structural Components of Filter

Fashioning apparatuses to test the properties of cotton and flexible polyurethane was initially a significant obstacle. Frequent department store visits were made, and a Dremel was lost in the process of transforming generic equipment into a specialized apparatus. It became apparent after multiple erroneous trials that this strategy was insufficient to design experiments that wouldn't jeopardize the integrity of collected data. Water would leak, structural consistency was not maintained throughout trials, and it was sometimes impossible to verify that the water was proceeding throughout the various levels as intended. Therefore, we utilized 3D design and printing to produce specialized plastic components to increase the efficiency and performance of the trials and produce sound experimental data.

Three different components were produced to examine the properties of the materials, and test the effectiveness of their implementation.

1. Simple Layer Configuration- For testing single or multiple layers of cloth.

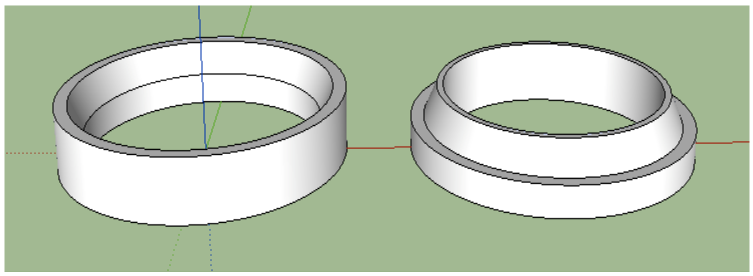
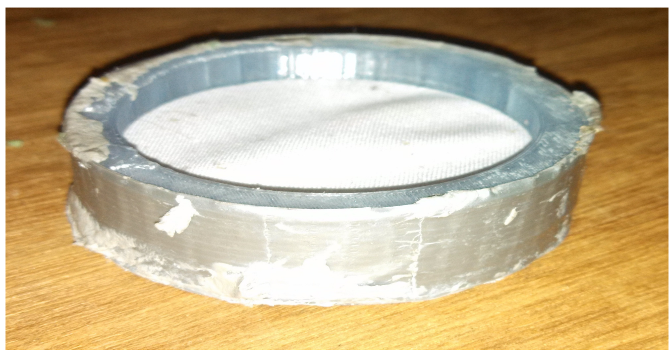


Figure 3 : Computer Automated Design (CAD) (above) & Experimental Apparatus (below)



2. Spherical Configuration-For testing various cloth & polyurethane combinations.

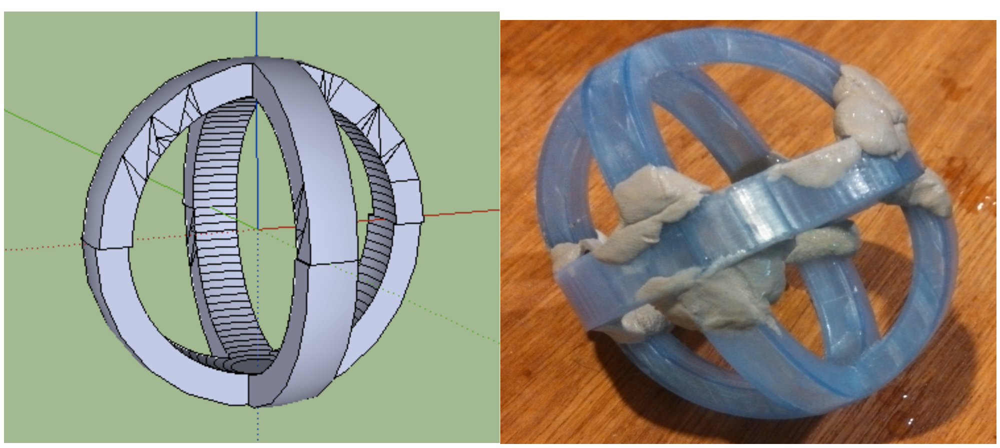


Figure 4: CAD (left) & Experimental Apparatus Fastened With Standard Plumber's Putty (right)

3. Cylindrical Configuration- For testing various cloth & polyurethane combinations. The two components are interlocked to increase the contact time of water with cotton fabric. Their design forces the water upwards and downwards throughout concentric cylindrical volumes. The most advantageous aspect of this design is that it can be reconfigured as needed to ensure sufficient contact time for water purification. For example, if greater contact time is required, the holes between concentric cylinders or the size of the cylinders themselves can be adjusted to achieve the desired flow rate of water through the system.

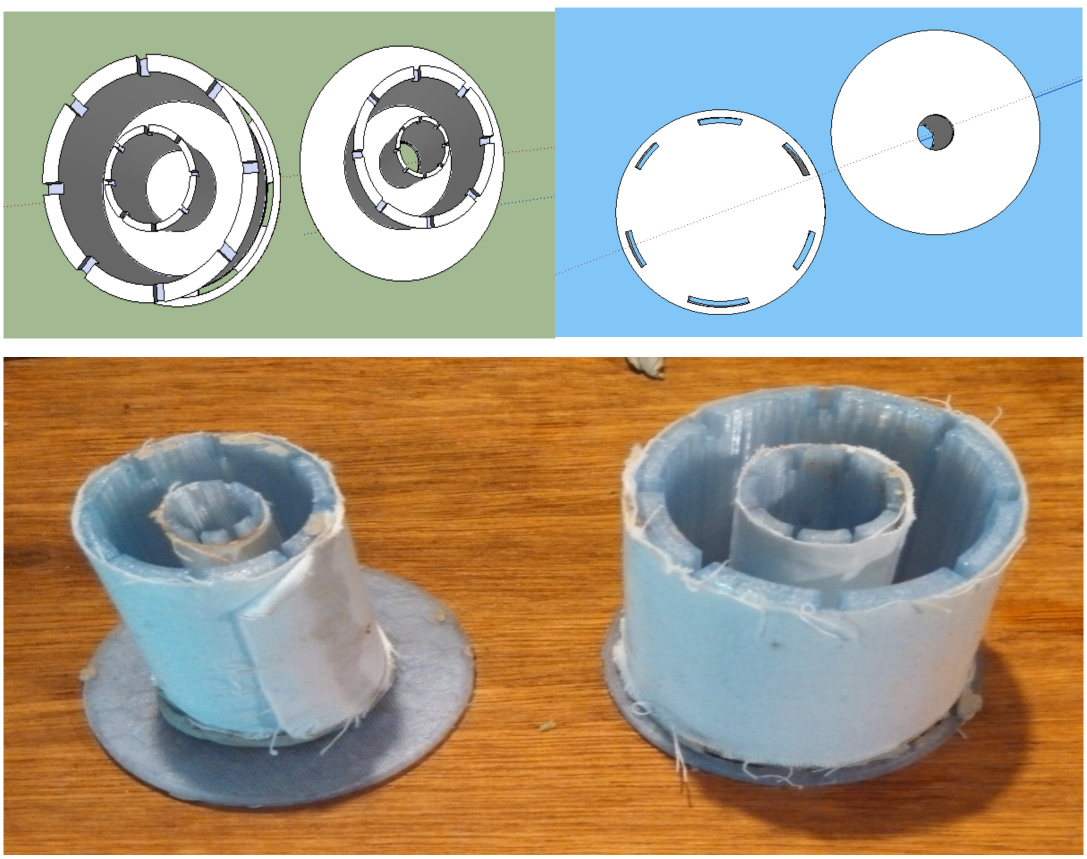


Figure 5: CAD From 2 Angles (top) & Experimental Apparatus with Cloth Attached (bottom)

Experimental Procedure

Cotton Trials

-Material: White, cotton sheets with 200-thread count.

-A small circular cross section of cloth was placed between rubber layers with a 3/16” hole in the middle, on end of 1 ½” PVC tube.

-Plumbing putty used to seal edges and guarantee passage through intended area.

-Each trial was performed with 1L of tap water.

-Time measurements were made in a graduated cylinder collecting the falling water at successive intervals of 100mL.

FPU Trials

-Material: Cylindrical sections of FPU (1.3 lb/ft^3) were cut with scissors, and volume attained by wrapping in plastic wrap and placing in water.

Name	Volume	Height	Diameter
1 Layer	200 cm^3	2.5 cm	10 cm
2x Layers	400 cm^3	5.0 cm	10 cm
3x Layers	600 cm^3	7.5 cm	10 cm
2x Single Piece	450 cm^3	5.25 cm	10 cm
3x Single Piece	750 cm^3	8.25 cm	10 cm
Sphere	250 cm^3	8 cm	8 cm

-Using a 3” (d) clear acrylic cylinder, the FPU was fixed between a 3” (d) plastic disc which had an opening of ¼”, and a ring of plumbing putty to keep the FPU static.

- For every trial 1 L of tap water was run through the FPU.

-A first trial was run to saturate the FPU, and the 1L volume was restored after saturation, and maintained throughout the succeeding trials.

- Time measurements were made in a graduated cylinder collecting the falling water at successive intervals of 100mL.

Sources of Error

Although satisfactory experimental set-ups were established, that did not eliminate potential sources for error. The largest and most profound cause of faulty data was a result of human error made while timing the volume of water collected in the graduated cylinder. Running water through the cloth layers resulted in a relatively smooth, single stream, making it easier to time the flow rate accurately. However, water through the flexible polyurethane foam was not as calm. The water emerged out of the bottom surface of the foam in multiple rivulets, causing splashing and an uncertainty of the precise water level as it rose in the graduated cylinder. Any source of human error from timing the water levels could be improved by using a high-speed camera to record footage, allowing for more accurate data.

Another possible source for error is finding the pressure using the average height of water between measurements. This could be improved by measuring the water levels at increments smaller than 100mL, which would be possible with a more detailed graduated cylinder and the use of a high-speed camera.

Y-intercepts throughout the data are not 0, as you would expect. This is due to the process of pouring the water into the upper reservoir, and the discontinuities in pressure created, as opposed to releasing the entire volume at once through a valve. This issue should be corrected in the next set of experimental apparatus.

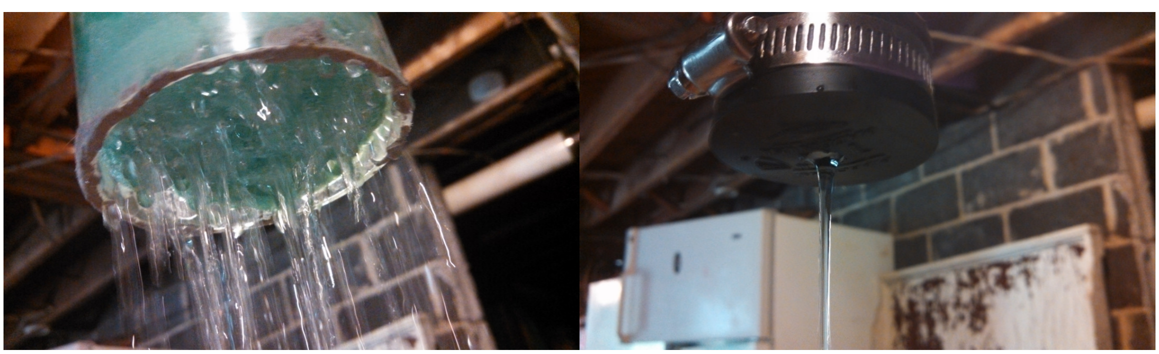


Figure 6: Water Passing Through FPU (left) & Cotton Layer (right)

Sample calculations for water through one layer of cloth

-Raw data collected involved timing the rising levels of water in the graduated cylinder in 100 mL increments. Results from these measurements are visualized in the Time v. Net Flow graphs. Figure 7 A.

-Incremental flow rate and the average pressure calculated and visualized in Flow Rate v. Pressure graphs. Figure 7 B. Proportionality constants are calculated from a linear fit, and

-Flow Rate = dV/dt [dV = 100mL] / [dt = difference in time between measurements]

-Pressure: (Plotted pressure = average pressure between two measurements)

P = **ρ g h**

ρ = 1.0 gm/cm^3

g = 9.8 m/s^2

h = Determined by subtracting volume of water in graduated cylinder from original volume (1L)

-Incremental flow rate was plotted against overall trial number. Each horizontal line accounts for the change in incremental flow rate between the same measurements. For example, the bottommost line represents the flow rate of water through the layer between 200mL and 300mL as measured by the graduated cylinder, when the pressure is the least. Then, successive measurements are represented by increasing horizontal lines for all intervals through 700mL and 800mL. Figure 7 C.

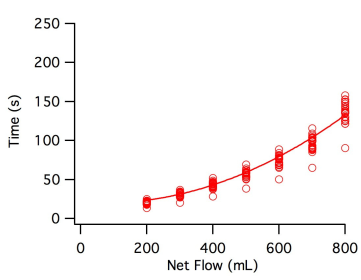


Figure 7 A

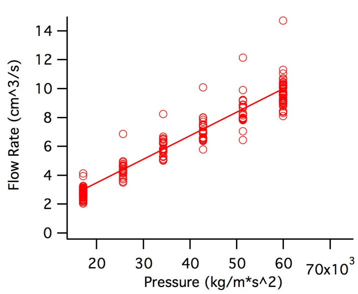


Figure 7 B

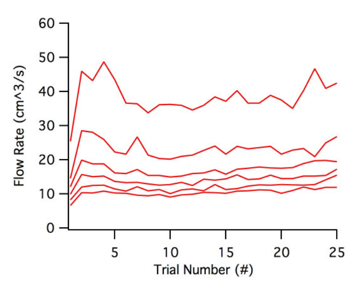


Figure 7 C

Data Results

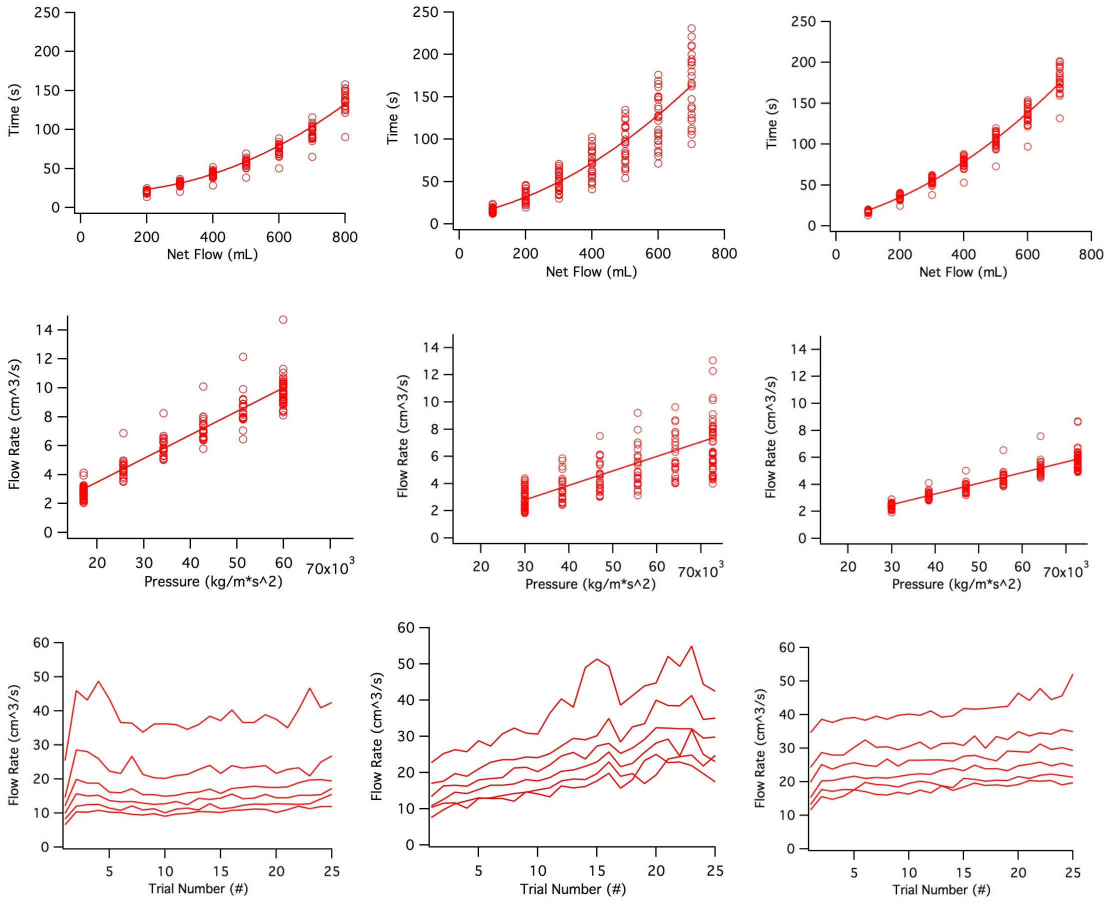
Cloth

1 Layer | 2 Layer | 3 Layer

Time v. Net Flow

Flow Rate v. Pressure

Flow Rate v. Trial #



Time v. Net Flow

Model Function: f(x)=a*x^2+b*x+c

Layers	A	B	C	RMSE
1	.0002405	-.0585	24.73	8.196
2	.0002053	.0307	3.77	22.12
3	.0002216	.03878	2.52	9.30

Flow Rate v. Pressure

Model Function: f(x) = a*x + b

Layers	A=1/(Effective Resistance)	B	Correlation	RMSE
1	.000164	-.6145	.9390	.8822
2	9.147 E -05	.1236	.6893	1.413
3	7.774 E -05	.1520	.9123	.5134

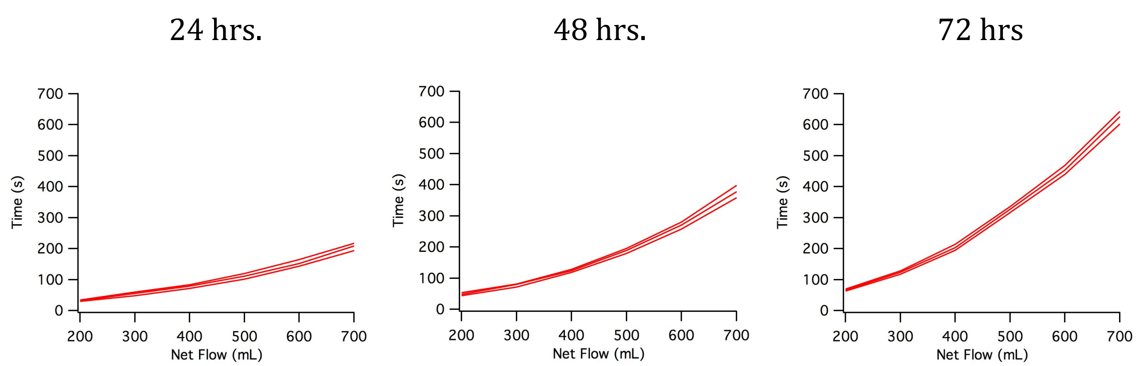
Flow Rate v. Trial Number

Correlation

	Correlation	RMSE
1 Layer	.939	.8822
2 Layers	.6893	1.413
3 Layers	.9126	.5087

1 Layer Cloth Over 24 Hour Intervals

Time v. Net Flow



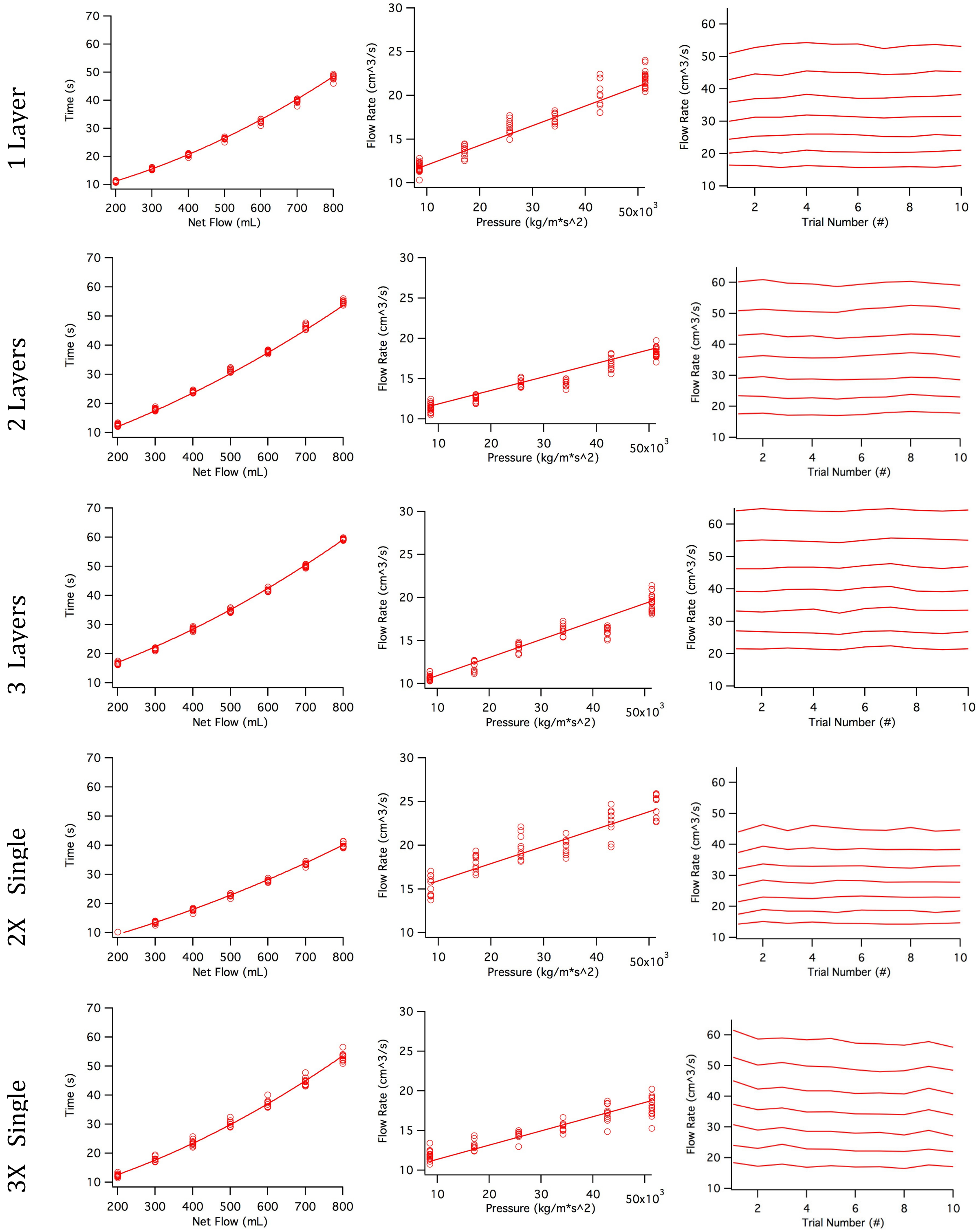
Time v. Net Flow

Model Function: f(x) = a*x^2 + b*x + c

Trial	A	B	C	RMSE
1 (24hr)	.000412	-.0275	22.88	7.734
2 (48hr)	.000954	-.2044	52.16	9.53
3 (72 hr)	.001334	-.0855	29.36	11.45

Flexible Polyurethane

Time v. Net Flow | Flow Rate v. Pressure | Flow Rate v. Trial Number



Time v. Net Flow

Model Function: f(x) = a*x^2 + b*x +c

	A	B	C	RMSE
1 Layer	2.3 E -05	.028	3.13	.522
2 Layers	2.95 E -05	.038	3.58	1.138
3 Layers	3.85 E -05	.0228	5.103	.646
2 Single	3.18 E -05	.0385	3.63	.579
3 Single	3.65 E -05	.0343	8.36	.514

Flow Rate v. Pressure

Model Function: f(x) = a*x + b

	A=(1/Effective Resistance)	B	Correlation	RMSE
1 Layer	.0009384	6.802	0.9608	1.011
2 Layers	.0006355	7.889	0.9529	0.755
3 Layers	.0008020	6.285	0.8649	1.147
2 Single	.0007986	11.45	0.9124	1.338
3 Single	.0005950	8.641	0.9268	0.900

Flow Rate v. Trial Number

	Correlation	RMSE
1 Layer	.9928	1.497
2 Layers	.9961	1.257
3 Layers	.9955	1.372
2 Single	.9957	.9576
3 Single	.9938	1.534

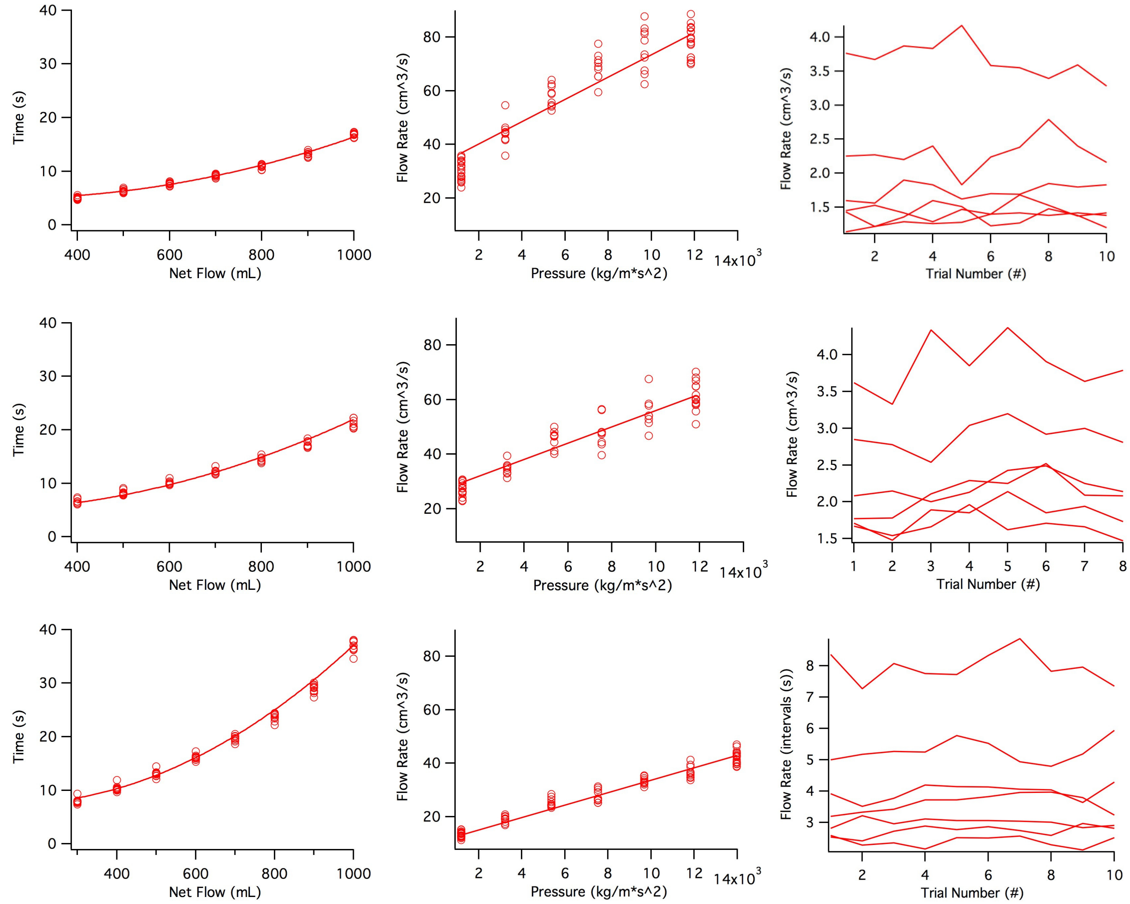
Spherical

Time v. Net Flow | Flow Rate v. Pressure | Flow Rate v. Trial #

Just PU

PU & 1 Cloth Layer

PU & 2 Cloth Layer



Time v. Net Flow

Model Function: f(x) = a*x^2 + b*x + c

	A	B	C	RMSE
Just PU	2.016 E -05	-.0095	5.84	.449
PU & 1 Layer Cloth	1.966 E -05	-.0039	5.19	.573
PU & 2 Layer Cloth	3.817 E -05	-.0102	13.08	.901

Flow Rate v. Pressure

Model Function: f(x) = a*x + b

	A=1/(Effective Resistance)	B	Correlation	RMSE
Just PU	.00455	28.58	.9161	7.389
PU & 1 Layer Cloth	.00317	24.57	.9289	4.701
PU & 2 Layer Cloth	.00220	11.54	.9750	2.169

Flow Rate v. Trial Number

	Correlation	RMSE
Just PU	.9178	7.315
PU & 1 Layer Cloth	.9297	4.674
PU & 2 Layer Cloth	.9756	2.146

Effective Resistances = 1/(Proportionality Constant) taken from Flow Rate v. Pressure Plot

	Cloth 1	Cloth 2	Cloth 3	FPU 1L	FPU 2L	FPU 3L	FPU 2S	FPU 3S	Sphere 1	Sphere 2	Sphere 3
Effective Resistance	6097.6	10932.5	12863.4	1065.6	1573.6	1246.9	1252.2	1680.7	219.8	315.8	454.6

Data Analysis

Cloth

The cloth layer trials revealed interesting properties about cloth and its potential for implication in the filter water. For the most part, the cloth layers behaved as expected. As the number of layers increased, the effective resistance felt by the water increased, resulting in an inverse correlation between number of layers and flow rate.

It is important to note the erratic behavior of water through 2 cloth layers. Unlike 1 or 3 layers, which produced relatively uniform data, the RMSE from 2 layer data was significantly greater. This is most likely due to instability in the 2-cloth arrangement that is not present in the other arrangements. This instability could be explained by rapid, small separations between the two layer, randomly affecting the effective resistance, that were not possible with the 1 layer configuration or subdued in a 3 layer configuration.

A goal of this project is to identify the material's ability to sustain a constant flow rate throughout successive trials. This can be deduced both visually from the Flow Rate v. Number of Trials plot, and quantitatively by correlations of .939, .689, .913 per 1, 2, 3 cotton layers respectively. Using simply cotton layers is not a reliable method to solely rely upon creating a predictable flow rate of the passage of water.

In the first 3 sets of trials, the very first trial was significantly faster than the others. This can be explained by one of two ways, either the first passage of water changed the inherent properties of the cotton (i.e. the organization of individual threads) or the successive trials were affected due to the saturation of the cloth layers from the first trial. To identify the cause, trials were run at 24-hour intervals to allow cloth layers to dry before each set of trials. From the data collected, we can see that the first trial is no longer a substantial outlier, suggesting that the original discrepancy in flow rate is due to the inherent organization of the cloth's threads that was adjusted in the most flow-optimal organization by the first passage of water. Additionally, we observed a dramatic increase in the time taken by water to pass through the layer. This is very significant, and can be explained by scaling on the cloth's surface. This has relevant implications for a final overall design, but its effect can be minimized through a routine descaling process on the uppermost cotton layer.

Flexible Polyurethane Foam

The properties of the FPU were tested in 5 different configurations. We observed the internal resistance of the foam to the passage of water increasing with the volume of the foam layer. However, an inconsistency arose in the multiple layers structure of the FPU section. This inconsistency could be a result of small air pockets, or a discontinuous alignment between the various layers at their borders. Also, it can be partly attributed to timing difficulties previously mentioned in the sources of error section. These difficulties were further exacerbated by the relatively small time increments between measurements compared to the cloth trials. Additional trials will be required in order to confirm these effective resistances for various volumes of FPU.

However, we were able to observe that FPU was tremendously successful in areas where the cotton layers did not perform well, its ability to produce consistent flow rates throughout successive trials. We saw little to no variation in the flow rates over the number of trials, with all correlations above .99. This suggests that the FPU is an excellent candidate for the primary filter component responsible for creating a constant flow. This property is well explained by the synthetic and fixed composition of the foam, leaving it highly unlikely to experience structural changes as a result of water passage, unlike the cotton layers.

Spherical

The purpose of the spherical component was simply to try a different configuration, and see if the shape might exhibit any influence over the internal resistance. However, it is safe to say that while the spherical component's performance may have been comparable to the cotton layer, both with correlations breaking .9, by no means did it outperform the flexible polyurethane layers in achieving a constant flow rate. However, in later iterations of a prototype, proportionality constants acquired here could prove useful should a spherically shaped filter be more constructive in the final physical filtration unit design.

Data Analysis for Future Prototyping Dimensions

In their research, Prashant was able to find that water passed through silver nanoparticle enhanced FPU at a flow rate of .5L/min returned nil bacterium in the output water. Based on this outcome, a flow rate of .5L/min or 8.3 cm^3/s, is an appropriate target. Constants for future experimentation will be calculated for various volumetric specifications of the water cavity, by adjusting the radius and height. While the final prototype will likely have a specially fashioned volume, for the purpose of the next step of experimentation, which involves synthesizing and realistic simulations of water with high turbidity and bacterium, a simple cylindrical water reservoir will suffice.

The goal of the filtration section is three part. The first is aimed at decreasing turbidity and eliminating large particles/bacterium/viral matter. This is most efficiently and cost effectively achieved by simply layering cotton cloth. From our results we observed a large increase in effective resistance of the cotton layers for trials with a 24-hour period. This scaling effect is likely to be radically increased since in real-world simulations the water will have a significantly higher turbidity count than the water used in these trials. For this reason it is crucial that whatever configuration of cloth, either a large interior sac or a specialized layer component as in Figure 3, can be extruded easily for frequent maintenance and cleaning.

The second filtration component will be aimed at controlling the flow rate, while simultaneously beginning the decontamination process. This section will be a simple FPU cylinder. Proportionality constants acquired through this research will be useful for future prototyping, however, there are some stipulations that must be kept in mind. Firstly, the y-intercept for both Time v. Flow graphs (C factor) and Flow Rate v. Pressure graphs (B factor), were not 0 as would be expected in a realistic model. The difference in y-intercept can be explained the method used to initiate flow through the layers. Water was poured into the upper cylinders, as opposed to being released by a valve instantaneously. In future trials a valve system should be integrated in the experimental setup to help minimize this inconsistency. Useful constants for future trials can still be acquired by calculating the constants with a range of y-intercepts from 0 (the ideal case) to 10 (the worst observed case).

Projected flow rates based on gathered experimental data will rely on two variable factors, the effective resistance of FPU layer and the volumetric configuration of the upper water cavity. Using linear and quadratic approximations of data results facilitated these calculations. For the sake of reporting actual projections the volume of the upper water cavity will be set at 5 gallons capacity, with a 7.62 cm radius, and 1.04m height. This produces a pressure of ~10170 $kg/m*s^2$ at full capacity. The best performer at decreasing the flow rate of the gravity powered water was 3X single piece (750 cm^3) of FPU. For the previous volume, it is able to decrease the flow rate within the acceptable parameters using y-intercepts of up to 2. However, even the 2X single piece is projected to produce an acceptable flow rate of 8.12 cm^3/s with the y-intercept set at 0. Results can be seen in Table 1.

	2X Single FPU (450 cm^3)	3X Single FPU (750 cm^3)
A = (1/Effective Resistance)	.0007986	.000595
Y-intercept	Flow Rate (cm^3/s)	Flow Rate (cm^3/s)
0	8.12	6.05
1	9.12	7.05
2	10.12	8.05
3	11.12	9.05
4	12.12	10.05
5	13.12	11.05

Table 1.

There are obviously many adjustments and manipulations that can be made to achieve acceptable flow rates. These depend on the physical configuration of the next, improved experimental apparatus, but can be calculated using the coefficients acquired here. Furthermore, plotting the volume of FPU cylinder vs. its effective resistance returned a linear relationship, of the linear approximation, y=1.129*x + 806.2. If final filter parameters require a smaller volume of FPU, then this data can be used to calculate what effective resistance is required to achieve acceptable flow rates.

The third filtration function will occur when the water has passed through the FPU cylinder and is coursing through the set of concentric cylinders (Figure 5). Each wall of the cylinder will be lined with antimicrobial cotton cloth, not so that the water must pass through the cloth, but so the water will be in constant contact with the cloth, allowing the silver nanoparticles to exhibit their bacteria and viral sterilization functions. The cylindrical design is particularly useful as specific dimensions (openings between layers & width of concentric cylinders) can be adjusted to help control the flow rate and the contact time between the water and cloth-lined walls.

A final layer of the filtration component may include passing the water through an activated carbon layer, a frequent component of water filtration used to remove heavy metals and improve the overall taste of the water.

It is likely that denser FPU samples may result in an increased effective resistance and vice versa. A future cause for experiment may entail testing FPU's of various densities. Yet, it will be necessary to ensure that equivalent silver nanoparticle attachment properties are maintained throughout various FPU densities.

Conclusion

While knowledge about the application of silver, via chitosan, to various materials and its antimicrobial characteristics has been around for 10+ years, throughout all my research I have found nobody developing this cheap technology into viable, functioning filters with real-world applications. This is surprising since all research articles contained a phrase along the lines of, "This technology has vast implications for cheap, widespread water purifying techniques in developing regions."

The purpose of this research project was to explore alternative water filtration methods to develop a low-cost filter. This purpose became oriented into observing the properties of two materials, cotton and flexible polyurethane foam, to ascertain their potential for real-world use. The most relevant property of the materials is their ability to maintain consistent flow rates throughout multiple, successive trials, and in this regard, FPU outperformed the others. With functional models of these materials for both their flow rate and effective resistance, it will be simple to implement them into the final design, configured in a way to guarantee a desirable minimum flow rate, regardless of the number of successive trials or the time period between trials.

The next step in completing the overall filtration unit requires a closer look at the body of the filter that serves as water storage. This will involve determining the right materials, testing seam strength, and choosing final dimensions. Once these steps have been completed, data obtained in this research project along with the 3D printed concentric cylinders, can be applied to design an initial prototype ready for testing. Once it is physically fabricated, the next step will be synthesizing silver-nanoparticle loaded FPU volumes to test the antimicrobial performance of the filtration unit with bacterially contaminated water. Once a fully functioning prototype is achieved, it is off to developing regions to achieve this project's destiny of eliminating the needless illnesses and deaths caused by waterborne diseases.

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