KlarAqua

Bottom-up implementation of pure water solutions

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1 For a very good review of the process, as well as the different genera of bacteria that contain denitrifying species, see Mateju et al. Biological water denitrification – A review. Enzyme Microb. Technol. 1992 Vol 14 pp 170-183.

Business Report

Abstract:

This plan is the culmination of the tireless work of the members of the IPRO Business team in collaboration with their partners in Monterrey Tech University at Mexico. One of the earliest agreements we had reached while developing the business plan was to not limit it to getting people to buy filters, but rather serve provide decentralized, flexible, bottom-up solutions for water purification and in doing so, also address the larger concerns of economic well-being and physical health. Our major concern was the high failure rate of similar projects undertaken by well-funded agencies and so part of our efforts was directed towards understanding their causes, so as we could learn from them.

The end result is a plan that is both scalable and flexible and takes full account of the complexities that is inherent in a market, which comprises predominantly of consumers with extremely low levels of income.

This report will cover aspects related to Market Research, Filter Design, Marketing and Distribution as well as how it relates to our approach which incorporates bottom-up empowerment

Introduction:

A recent World Health Organization report estimates that a child dies every six seconds from a water-related disease, and the over five million people die annually due to unsafe drinking water. According to the World Summit of Sustainable Development, the major reason for lack of safe water is either due to scarcity of water or contamination of water sources. Lack of safe drinking water is due to both lack of investment in water systems and inadequate maintenance of existing systems.

UNICEF states that the lack of access to safe water is having a disastrous impact on children across the world. Reasons for this include shortage of water, poverty, and lack of education about the impact of drinking impure water. The World Health Organization estimates that at any given moment, approximately one half of all peoples in the developing world are suffering form one or more of six primary diseases (viz. diarrhea, ascaris, dracunculiasis, hookworm, schistosomiasis and trachoma) caused by poor water supply and sanitation. The social and economic impact on developing countries of such a high proportion of people suffering from such diseases is understandably large.

Project KlarAqua aims to effectively address this issue by means of implementing a low-cost water purification system, which is easy to manufacture and use at the grass-root level.

1. Organization Structure for effective implementation:

1.1. Lessons from the past = lessons for the future

One of our major concerns throughout had been and remains to be the significant lack of success displayed by more well-funded and established agencies in resolving water purification issues. In our efforts to fully understand the reasons for their limited success or lack of success, we came to the conclusion that lack of clean water more often than not is a symptom of a much more complex socio-economic issue, the depth of which is not fully understood or appreciated by most agencies. One of the reasons remains that the locals themselves have difficulty spelling out the underlying nature of the issues facing their community, for if they did they would also have found a solution to it. Since most projects assume the problem space to be well understood, implementation steps are engineered externally and then inserted into the problem area with poor to mixed results.

This complexity is compounded by the problem of diversity. More often than not, the lack of pure water maybe a symptom to problem which is not the same, depending on which part of the world we are in. Also the cultural diversity plays an important role in how the locals interpret the problem and their attitude towards any solutions proposed by outsiders. In short, the problem unfolds in ways unique to every situation and the environment that they unfold in chaotic and unpredictable. In such circumstances, people outside of the ‘problem area’ will find them handicapped by lack of knowledge and/or skills fully understand the problem space or implement solutions. So while a technical product can be developed from outside, the business has to be developed from within the problem zone which from this point will be referred to as the field.

1.2 Effective decision making for effective implementation

The business plan for KlarAqua intends to incorporate the flexibility required for business implementation solutions to emerge from the field in a manner that fully considers the unique situation on the ground. Our assumption here is that to implement an effective strategy, the management must have ‘situational awareness’ and since situational awareness can only be developed on the field, we can comfortably say that field managers are in the best position to sense what is going on and take effective steps to ensure that the objectives of the project KlarAqua are met viz. enhance accessibility to safe drinking water and consequently ensure economic and physical well-being.

Since KlarAqua is a not-for-profit organization, the focus will be on cost management, not profit. Hence every field manager will manage his territory as a cost center, finding innovative ways to effectively to leverage his limited resources to accomplish his objectives. The role of top management in this regard will be to provide overall guidance and support to the field managers. In addition to this top management will also co-ordinate activities between various field managers. Fig 1.2.1 represents the proposed organization structure.

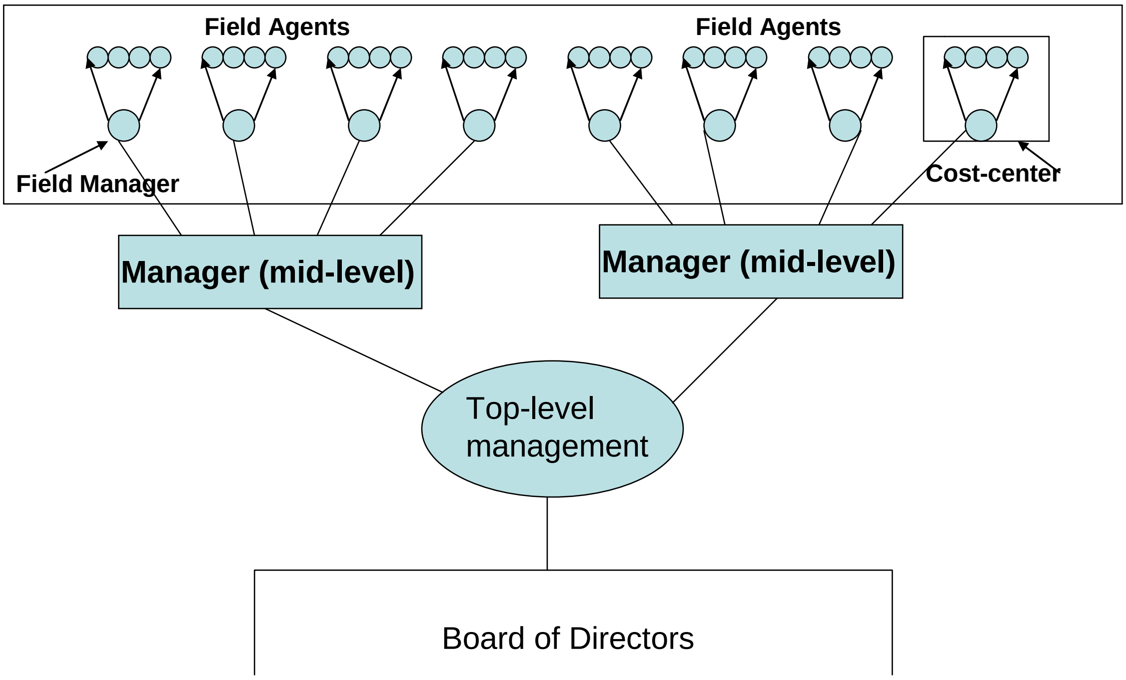

Figure 1.2.1 Proposed Organization Structure

This model is scalable because experienced field managers can be given new projects in new fields and previous experience will ensure that new learning curves are less steep than the old ones. As the field activity increases, a new level of mid-level management who are much closer to the field will can address immediate needs of the field managers while the top management will focus more on long-term goals except in situations of crisis in which case top management assumes more direct power. It is less advised to have more than three layers of management as that will far remove top-management from ground realties and would hinder information flow within the organization. Part of the organizational culture we hope to evolve for project KlarAqua also encourages the communication of its players through informal channels which at various times can prove more efficient than formal ones in diffusing knowledge throughout the organization.

2. Filter Design

2.1. Conception stage

From the inception of the project in August 2005, the design team was aware of the limitations and the physical conditions of the market in which the product must be accepted. With this in mind the filtration system was designed such that it can be manufactured using locally available materials at a low cost. The aim of the design team was to come up with a product that was seen to be culturally relevant, socially acceptable and economically feasible.

2.2. Product design

With this in mind our team developed a product, which can be made entirely by the local population using local materials, without industrial technology, and will have a lifespan of at least 5 years. The filter thus designed has the following components:

- 2 clay circular discs for filtering
- 1 clay bowl for filtering
- 1 five gallon bucket for storage
- 1 plastic holder for the bowl
- 2 plastic cones to fit the clay discs

The three-stage filtration system is designed to provide redundancy and to reduce risk of contamination from any possible direct path of flow. In addition they can also incorporate flexibility because some of the filters can be specifically treated to remove a dominant pollutant that is specific to a locality. Currently extensive testing is underway on the effectiveness of the filter in removing bacteria when coated with colloidal silver. Further details of design and testing are included in the Design Section of the report.

KlarAqua fully intends its products to hold fast to the guidelines of the World Health Organization with regards to water standards.

3. Market Research (Project KlarAqua in Mexico):

3.1. The market as we understand it

For the purpose of the project we an assume that our target market will be people living in rural areas with less contact with urban city centers and while not ignorant are suspicious, skeptical or at least uncomfortable with the way of life outside of their own. KlarAqua thus needs to be integrated into their life system as seamlessly and effortlessly as humanly possible. Also of importance to note here is that no two rural communities can be exactly alike, although similar in many respects. They are like patterns in a kaleidoscope that while similar never repeats. So lessons learnt from one place will apply at another, but not directly. This also means that the initial learning curve will be steep and that team on the field will have to take most of the initiatives, take most of the actions and make most of the decisions on the field to achieve the objectives required for the success of project KlarAqua. The people at the head office will more often find themselves in a position of providing general direction and specifying guidelines while leaving it to field workers as to how those translate into actual actions on the ground. This also means that for people at the headquarters to make better decisions and give better direction, they must have adequate field experience and occasionally perform field work to remain in tune with current field situation.

3.2. Specific steps in market research:

The primary step in market research will be to understand the consumer. The market research will have to focus on two specific components - one relates to understanding the cost structure required for the market to support the product. The other will be more abstract idea of the social setup into which the product is launched. While both components are equally important and can be conducted in parallel, only the former can be expressed in terms of hard numbers. The latter will involve less quantifiable more intuitive skill - the team members should learn to note social cues, recognize behavior patterns and form mental images of how the society functions, what works within the social context and then dare to test them out.

The most effective method for establishing a cost structure would be to first determine the potential market size. Our market is the 37% of those in the rural areas that do not have access to safe drinking water. In the more abstract sense what we need to know is the place of these people within their social set up and in what ways their life style and problems are different from the other 67%, besides from the obvious. How is their lifestyle different because they do not have safe drinking water, not as we see it but from our potential customer's point of view. This knowledge will help direct appropriate marketing efforts. From a cost structure point of view the question to be determined is the disposable income of our target group.

'**Disposable income'** from this point on refers to any income above the bare minimum required for survival under present circumstances. The presumption here is that such groups have a disposable income but it is not adequate enough to provide for safe drinking water under existing conditions. Part of market research will be to understand their spending habits - where they buy, what they buy, how much do they pay for it and relate this to a function of their wage. This data will help set the market price, which in turn will work its way into determining the costs of the piece parts involved in making the unit and the most efficient distribution channel to access our customer base most cheaply and effectively.

It will prove more beneficial to establish the distribution channel before marketing the product because we do not want to turn away at disappointed customers at the beginning while acceptance is still a delicate issue. Education and marketing will be two sides of the same coin. Marketing makes sure that education is relevant from the customer's point of view and educators make sure that marketing doesn't hype the product by making false, misleading or exaggerated statements, about the product's potential. Whatever the marketing message and the learning tools that we finally decide upon, it must make sense to consumers in their social context - contextualization is not optional but crucial.

Getting opinion leaders involved will form part of market research as well as marketing. Knowing the opinion leader is part of understanding the social setup. The exact time to access them will depend on several factors, the precise nature of which can only be determined on the field. If the opinion leader is highly inquisitive 'hand on' type it is probably advisable to include them at the early stages. On the other hand if the opinion leader resides in an 'ivory tower', it is unlikely that one can access them initially. Besides it is probable that they may be indifferent to the whole idea at the initial stage when chances for success are still uncertain. Still it would be advisable to get some form of tacit approval for the project at some point early on and not alienate them. They may prove to be an excellent source for guidance and may choose to play a more active role later on when the project shows potential. This can be viewed as a positive development because part of what determines the success of the project will be how much initiative the locals themselves can take towards the success of the project. One final successful outcome for the project would be if the whole set up is locally run and locally managed.

As a part of this stage, we will also examine the extent to which materials and know how to manufacture the unit are already available locally and if not should we choose to train local craftsmen or import, depending on which would prove more beneficial to the consumer. If training is done, the precise form it would take must also be best left to field agents to decide.

3.3. Some guidance tools for decision-making

Presented below are some criteria that we found useful in making our decision. However experience dictates that while useful such narrowly defined criteria can never be all inclusive. Hence their purpose is to act as a decision making aid. The final decision will be made by the appropriate workers who can subjectively decide on its usefulness and reliability based on their judgment and experience of field situations.

3.3.1. Entering a market

- The number of water borne illnesses and the amount of treatment given
- The types of facilities present in the community for water collection and storage
- The number of people in the community.
- The mean income of the families in the community
- The availability of potters in the community who can produce the filters

3.3.2. Establishing a project base

- Invest in a local Headquarter and run our own marketing.

3.3.2.1. Office cost for KlarAqua:

If KlarAqua invested in a company office in Monterrey or any area of Mexico, a preliminary cost is necessary in order to figure out how relevant the benefits of the proximity to the community is to our organization. The assumptions for the cost structure are shown in the appendix section. In the table below, the same inflation rate of 1.14% is used and all monetary value is in pesos.

Facility Costs	Expected Current Cost	2007	2008	2009
Building	460,000.00	465,244.00	470,547.78	475,912.03
Furnishings	8,000.00	8,091.20	8,183.44	8,276.73
Supplies	15,000.00	15,171.00	15,343.95	15,518.87
Staff	120,000.00	121,368.00	122,751.60	124,150.96
Operating	5,014,247.76	5,071,410.18	5,129,224.26	5,187,697.41
Total	**5,617,247.76**	**5,681,284.38**	**5,746,051.02**	**5,811,556.00**

Also, depending on whether or not KlarAqua decided to rent or buy it's own building in Mexico, the following comparison table shows the costs associated with that decision.

	Expected Current Cost	2007	2008	2009
Rent	350.00	353.99	358.03	362.11
Own	160,000.00	161,824.00	163,668.79	165,534.62

- Partner with another agency or organization in the area to leverage their knowledge and resources in which case cost issues have to be addresses in conjunction with these organizations

3.3.3. Marketing and education

- Market the idea and the product to the opinion leaders in the community.
- Market the idea to the school children through school, through entertaining shows or any media that influences the kids.
- Market the idea through the church or other organization that people spend a lot of time going through.
- Market the idea to families via word of mouth/ success stories.

3.3.3.1. Marketing tools:

- Use Brochures and handouts in the local language
- Use a movie or other media that is more interactive
- Use demonstrations and actual implementation to educate

Cost estimates for marketing (in pesos):

YEAR	**2006**	**2007**	**2008**	**2009**
Brochure	22,000	22,250.8	22,504.46	22,761.01
Video	222,588	225,125.5	227,691.9	230,287.6
Public Advertisements	111,000	112,265.4	113,545.2	114,839.6
Total	418,400	423,169.8	427,993.9	432,873

4. Establishing a local value network

4.1. The value network as we see it

Once market acceptance of the product is partly realized and skepticism has given way to tolerance for the product, then we can go about establishing a local value network. The '**value network'** in this case will include but not be limited to all the players involved in manufacturing, distributing and marketing the product. Anyone who benefits from KlarAqua is essentially part of the 'value network'. The idea here is that KlarAqua is not just a product but also a means to improve living conditions both economically and health-wise.

First and foremost the target of Project KlarAqua will be the end consumer - that they get a effective product at a reasonable price (from their view point). The local value network must be developed in such a manner that this interest will not get violated. Initial effort at developing the value network would involve finding local manufacturers and/or suppliers for piece parts. Part specification must be exact and in a form that the local manufacturers can understand. Field agents may initially feel obliged to assemble and test the locally developed units for consistency and effectiveness. Once these are established, it is plausible that even final assembly can be handed over to a local player. To ensure that quality standards are met, it would be advisable that all KlarAqua manufacturers and suppliers have a license for key parts they supply for KlarAqua products. The license may be renewed periodically and revoked if quality standards are not met consistently. In addition, random testing is also advisable to encourage meeting of quality standards.

Benefits of establishing a localized value network must include, but not be limited to - lower costs for the producer that can be passed on to then end consumer and improved economic conditions to those in the value network as a result. Another benefit is that the supplier and manufacturer being part of the same social network, as the end consumer will feel more obligated than otherwise to provide quality service. Market pressure driven by consumer's need for 'value for money' will also be a positive influence. The aim here is to create a set of interdependent players who have a stake in the ongoing success of KlarAqua and will ensure that the project sustains itself.

4.2. Some guidance tools for field managers in setting up the value network

Presented below are some questions that we will guide the field managers in decision making. Once again they are meant to be useful not exhaustive.

4.2.1. Production and distribution:

- Clay filters: Potters are in charge of the production. Do we set a price or do we let potters use their own discretion? Which best serves our end?
- Plastic holders: Do we manufacture? Do we get another organization to manufacture and at what cost? Do we sell to the potters or do we store and add to bucket?
- Complete assembled filter: Who does that? Who stores it and how much to sell it?

4.2.2. Quality control options

- Frequent visits to the potters to make sure that they understand the process are ensuring product quality
- Random testing to ensure quality of the products.
- Setting up a system with a local agency that goes through the community and documents and asks questions to see any issues that arise or concerns about the filters.

- Improving the design and allowing for feedback to ensure we do a better job of addressing or responding to any new issues.

5. Beyond Market Saturation

Once market saturation occurs and the value network localized, we essentially have a self propelled system, where individual players with vested interest conspire to ensure that the end users remain satisfied and they benefit economically keeping things that way. In other words market forces have taken over to ensure the welfare of the end consumers, the people whose welfare we are trying to ensure. At that point we can truly call the project successful. Project KlarAqua would have been internalized and assimilated into the local way of life. The role of the outsiders will be limited mostly to monitoring to ensure that consistent quality is being maintained. An independent team that has little stake in manipulating the results best handles this.

Summary of the unit production costs.

A preliminary production cost for the filter is shown below and the assumptions made and used for the cost model is given in the appendix at the end of this report. All of the costs are given in pesos and an inflation rate of 1.14% was used over the years.

Cost Per Unit	**Expected Current Cost**	**2007**	**2008**	**2009**
Small Clay Disk	10.00	10.11	10.23	10.35
Large Clay Bowl	9.00	9.10	9.21	9.31
Colloidal Silver	13.00	13.15	13.30	13.45
Cheese Cloth	0.00	0.00	0.00	0.00
Carbon	0.00	0.00	0.00	0.00
Sawdust	0.00	0.00	0.00	0.00
Bucket	38.00	38.43	38.87	39.31
Plastic Casting	21.00	21.24	21.48	21.73
Total	91.00	92.04	93.09	94.15

Technical Report

6. Design Approach

This section describes engineering criteria and test procedures involved with design and characterization of the KlarAqua water filter.

6.1. Design Considerations

KlarAqua is a low cost water purification system developed to promote health and economic well being in developing countries and other areas in need of clean and safe drinking water.

The design of the overall system takes the following factors into consideration:

- Use of locally available materials, such as clay
- As simple a design as possible in order to allow local production
- User-friendly and child-safe (i.e. no chemicals involved)
- Cost effectiveness

The team has settled on a plastic housing using clay filters to provide this service. Three layers of filtration will be used; each clay filter will be coated in a colloidal silver solution so that the filter will double as bactericide agents when water passes through them. Work is currently under way to incorporate arsenic and nitrate removal, as well a using a packed carbon bed to help eliminate bad taste and odor from water.

The next section details the final design of the KlarAqua filter housing. The evolution from previous designs up to this point can be found in the Appendix.

6.1.1. KlarAqua Filter

The final design of the KlarAqua filter has the following parts:

- Two clay circular disks
- One clay bowl
- One 5 gallon bucket for collection
- One plastic housing for holding filters (vacuum formed or locally made)
- Two plastic cones (for redirecting the water)

The figures below help illustrate the order of the pieces in relation to one another. Water will be stored in the top clay bowl, and as it flows out, will work its way through the two other, concentric clay disks (the last one smaller than the other). Ideally the net flow will be one liter per hour. Immediately below the clay bowl will be one of the plastic cones, redirecting the falling water towards the middle of the next clay disk. This is to reduce leakage, primarily, by keeping water from running down along the sides of the housing. In between this clay disk and the last, smaller disk will be room for a bed of packed carbon (to remove taste and odor). In addition, the last disk will be situated below another wide mouthed funnel in order to redirect water towards the center of it from the previous filtration step. Finally, the water will pass from the last clay filter into the bucket reservoir for use. A spigot will be located at the bottom of the reservoir for dispensing the filtered water. Combating leakage was a major concern of us, which has been successfully remedied using funneling cones for channeling and candle wax as a sealant. Sealing the edges of the plastic cones where they touch the sides of the plastic housing has proved to eliminate all leakage.

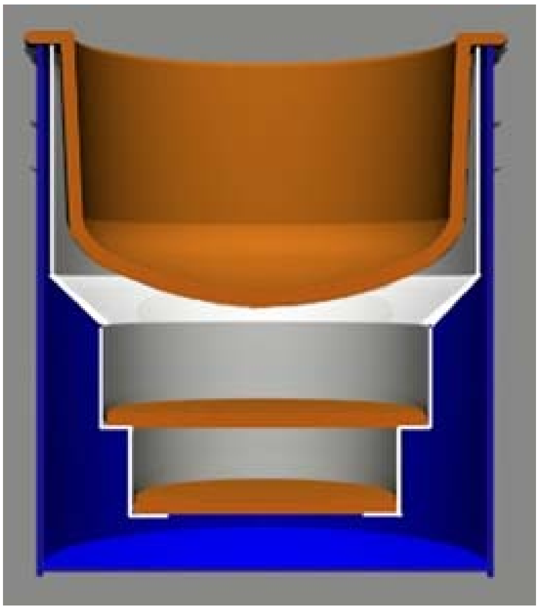

Figure 1. A colored side view of the filter housing in the bucket, with the clay pieces in brown.

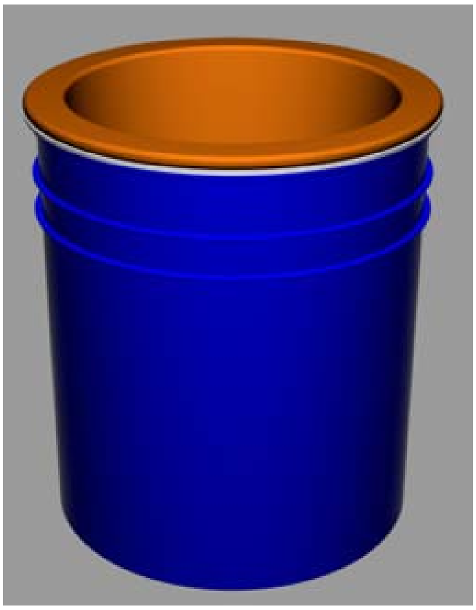

Figure 2. An outside view of the complete filter assembly.

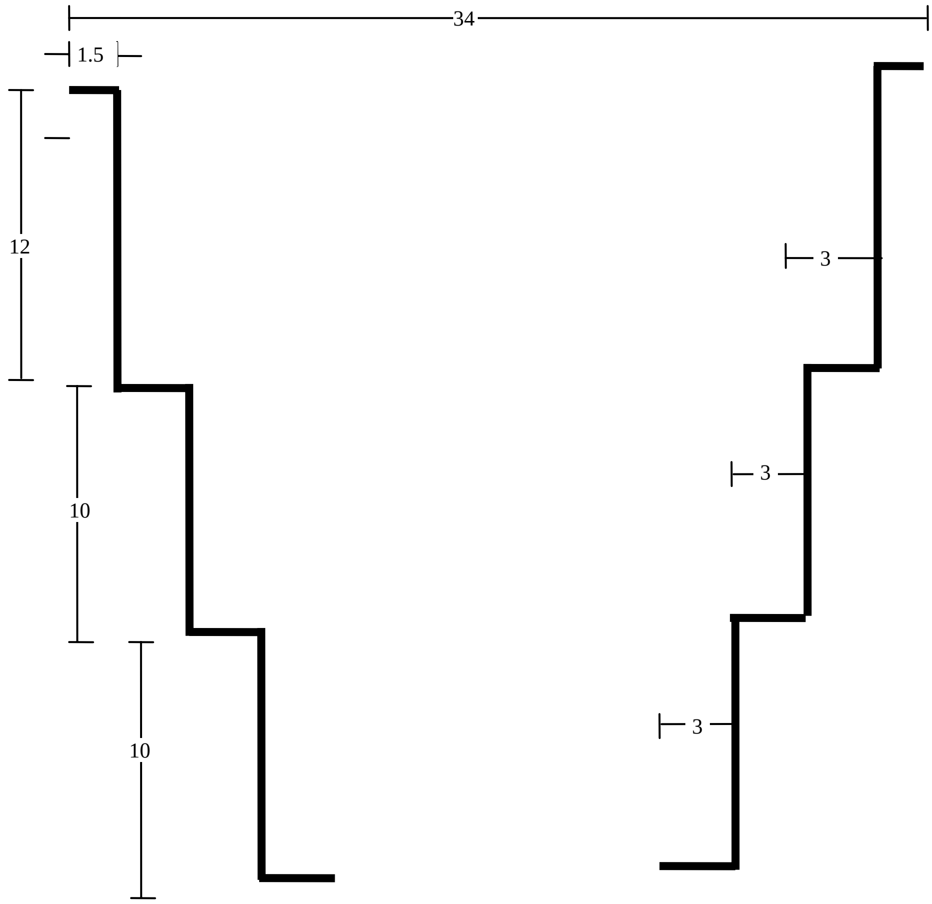

Figure 3. Dimensions of the filter housing, in cm.

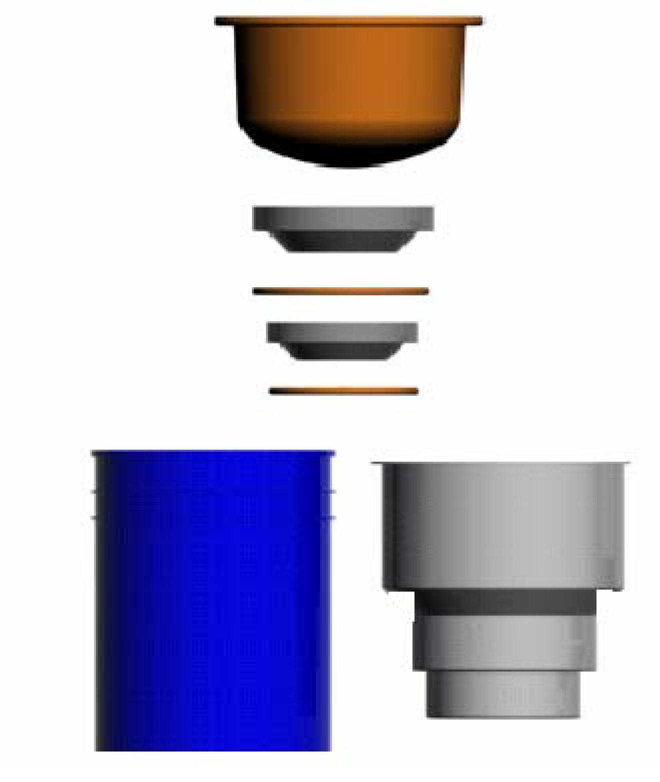

Figure 4. Profile of all the pieces of our filter.

6.2. Plastic Casting

In order to reduce the cost of construction for the prototype, we are manufacturing of the plastic cast. The ideal method of construction would be plastic injection because of the 90° angles on the housing between layers. But as IIT does not have a plastic injector, we were forced to use a plastic vacuum former.

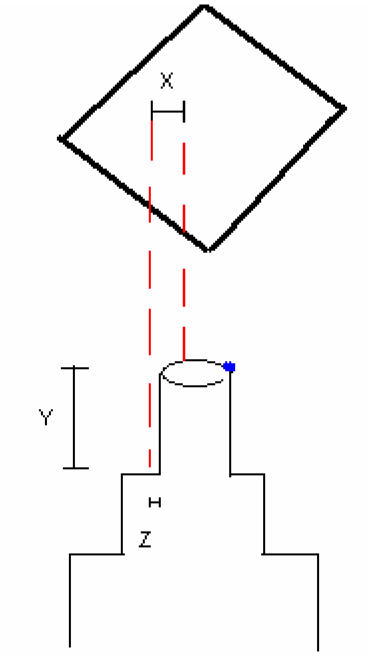

Figure 5. – Vacuum forming the flat plastic plate into 3D.

Plastic vacuum forming has some disadvantages compared to the injection method. For instance, we need negative pressure, and we start from a flat plastic layer instead of from a liquid plastic phase. The main problem with starting from a flat layer is that when the vacuum is applied to a desired form containing 90° angles, there is a very short distance (X) that will become stretched to a long height (Y) to form the 3D shape.

In Figure 5 it is possible to see the deformation that the flat layer will have when the vacuum is applied. The main problem is when a 1D distance (X) becomes a 3D volume (X+Y+Z).

The stress that the film must resist is high due to the expansion of the flat layer in the casting process. The existence of 90° angles in the cast enhances this problem.

The IIT labs do not have the capacity to produce a complete cast. Because of this, we are scaling down the cast to half of the actual size. With this smaller scale, we hope that the plastic stress diminishes enough to make the vacuum forming method feasible. In addition, we sought out companies capable of making the cast with an injection mold.

6.3. Materials

Detailed below are the various materials to be used in the construction of the entire filter. A brief description of how the materials were made or used is given.

6.3.1. Clay in Mexico

Since the working model will be made and used primarily in Mexico, it is important to be familiar with the types of clay that will be common there. There are many different types of clay in Mexico. Common surface clay can be found all over the country; in backyards, the beach, the desert, or near the mountains. The northern state of Durango has some of the largest clay deposits in Mexico. The clay there is known as bentonite (the commercial name for it is montmorillonite clay).

There are also other important deposits in several states, like in Puebla, Oaxaca, Tlaxcala, Zacatecas, and Guanajuato, but the composition of the clay varies. It generally contains high concentrations of iron, causing the color to vary from red to ochre to black. The clay found in these places is ferruginous (Domínguez).

6.3.2. Clay in U.S.

The clay we used in our experiments here at IIT came from a powdered form. Water was added to give it the desired consistency. This was cheap, but not altogether representative of the clay that will likely be used in rural areas of Mexico or other potential countries that will use our product.

6.3.3. Saw Dust

Saw dust was simply purchased in. This was used in making the clay filters by mixing it with clay to obtain a certain porosity. It was filtered to get particles of a certain size and smaller. The sieve size played an important part in flow rate of the clay filters, as will be seen later.

6.3.4. Colloidal Silver

There are several methods to prepare colloidal silver. Two methods are described below.

6.3.4.1. The constant voltage method

In this method, 12 to 30 Volts are passed through two silver electrodes submerged in distilled water. The water should be pure (especially of salt, because it will lead to the silver particles bonding with the sodium chloride to produce silver chloride instead). A small light bulb in the circuit will determine when the water is conducting and to record when the process has started. This method most commonly uses several 9V batteries wired in series. As the conductivity of the distilled water increases, and more silver particles are released from the electrodes, larger particles of silver will be produced. Eventually the silver particles will become so large that they fall out of suspension and fall to the bottom of the glass. This is an unsafe method of production, as larger particles of silver (when ingested) can accumulate in the body and cause in argyria.

6.3.4.2. The constant current method

It is similar to the above method except that a constant current regulator is used, which reduces the voltage as the conductivity of the distilled water increases. This ensures that the silver particles produced remain at a constant small size, thus reducing the risk of argyria. It is also possible that smaller silver particles are more beneficial for health as they can bond with and neutralize smaller potentially harmful microorganisms. A common solution is about 0.3 - 0.32% by volume colloidal silver. This translates into 1 drop of silver for 2 liters of water, or approximately 2 drops per gallon. The constant current method was used in our experiments.

6.3.5. Plastic Casting

The prototype used glued pieces of plastic from various other buckets and custom made, vacuum molded pieces. The Appendix has a list of potential plastic companies for injection molding the final product in both the USA and Mexico.

7. Filter Composition

Using clay disks and bowls mixed with sawdust grants a permeable structure that will allow flow of water through them. When fired, the sawdust will vaporize, leaving pores throughout the clay. When brushed or imbedded with colloidal silver, the surface of the disks will also act as a bactericide. The method of construction is given below.

7.1. Procedure for Making the Disks

The actual construction of the disks is worthy of note so that others might recreate the procedure we have developed here.

7.1.1. Preparing the Mixture

The first part in the creation of the disks is to make the mixture of clay, sawdust and water. The steps involved in the creation of the mixture of clay, sawdust, and water can be summarized into four basic steps:

1. Select the ratio of sawdust to clay. Measure the appropriate amounts of both components (the ratio is by volume).

2. Sieve the sawdust to achieve constant particle size, which in turn would ensure uniform pore size in the clay disks.

3. Mix the clay with the sawdust. Using the previously selected ratio, combine the appropriate amount of clay and mix until a homogenous mixture is obtained.

4. Water is added and mixed small amounts at a time, until the entire mass easily sticks together.

It is important to note that in the weight of the sawdust after it was sieved. Since the weight of the sawdust is directly related to the particle size, one volume unit sieved with, say a size 9 mesh, will be different than a size 28 mesh. So, the mesh size of the sieve makes a difference in the physical volume of sawdust being used at different ratios. Our experiments indicate that the ratio of sawdust to clay is directly proportional to the flow rate and the strength of the disks. Higher volume of sawdust results in higher flow rates and more fragile disks.

The particle size of the sawdust is also an important factor in determining the flow rate of the disk. Comparison tests indicate that; the bigger the particle size, the higher the flow rate obtained. The particle size of the sawdust is also relates to the cohesiveness of the final mixture, with the mixture being less cohesive as particle size increases. Thus it is important to note the optimal ratio and particle size to achieve consistent flow rate through a rugged filter.

The addition of water in small portions is important for creating a homogeneous mixture of clay and sawdust each time. This is to make it is easy for the whole mass to stick together, ensuring that water is the bonding agent of clay to sawdust.

It is important to note here that the clay used was in a powder form, much finer than that used by the team in Mexico. We believe that it is one of the reasons the composition was dusty after firing.

7.1.2. Molding and Drying

Once the mixture is complete, the next step is to form the disks. To do this, plastic container where used as molds to make the mixture into the shape we wanted. When putting the clay in the mold it was necessary to wrap the mixture (clay, sawdust, and water) in PVC plastic to prevent the mixture from sticking to the mold.

7.1.3. Disk Firing

The disks were fired using a Kiln available in the Alumni Hall Laboratory on IIT's campus. The kiln features programmable firing times and temperatures, as well as rates to attain those temperatures. This allows flexible and individualized firing processes, and this feature was used extensively in firing the different sets of disks.

After some disks were fired, we noted that adjusting the time of firing is very important in order to reduce the dusty composition on the disks and to prevent any fractures from forming. See Table 2 in the Appendix for specific information on the programming used, as well as the section describing specific details on the firing order.

Figure 6. A picture of the kiln with some clay filters and a bowl ready to be fired.

7.1.4. Disk Analysis

In order to quantify some properties of the various disks that were made, several experimental tests were done. Porosity and flow rate in particular were tested, so that we might later correlate their effect on the bactericide aspect of the filters. Flow rate was tested by simply adding a known volume of water to a filter and measuring the time for it to completely pass through the filter. Dividing the volume by the time gave us units of flux. However, the disks often retained a volume of water in them. By submerging the disks in a known volume of water and letting it soak we could measure the volume retained. These values were recorded, and can be seen in the Appendix, along with some other properties of the disks.

8. Performance Evaluation

The next step was to find the effectiveness of bacterial removal of the clay, as well as potentially removing other water contaminants like nitrate or arsenic. Also, we would like to remove any bad tastes or odors associated with water by using a packed carbon bed, when possible.

8.1. Bacterial Test

The most important function of the clay filters is to remove harmful bacteria from the water. So, we tested the clay filters to determine the extent to which they could kill bacteria. The filters were made as explained before at several different sawdust- to-clay ratios. We used the bacteria *Pseudomonas aeruginosa* as a test because of its difficulty to kill and the high danger it poses in any water supply.

8.1.1. Procedure

The bacterial group created a procedure to test clay filters for bactericide efficacy. To start with, a soy broth solution had to be made as a nutrient for the bacteria, *Pseudomonas aeruginosa*. Trypticase soy broth (15g) was mixed with 0.5 L of deionized water, then slowly heated and stirred. It was kept boiling for 10 minutes, then activated bacteria was added to the broth. The solution had to be kept incubated at 30°C, and Figure 7 shows the bacterial broth in an incubator.

Figure 7. The bacterial broth inside of the incubator.

The bacteria had to be maintained throughout the experiment, so every two days the solution was centrifuged to isolate the bacteria, then put into a newly made broth solution. A larger flask was used to provide enough air for the bacteria to last until it could be resupplied with nutrients.

In order to prepare the disks for testing, we needed a control and experimental disk for the different ratios we wanted to test. The control had no brushed silver on it, while the test disk had 2mL of colloidal silver brushed onto its entire surface. A soft brush was used to try and prevent abrasion. After the disks had dried, they were washed and soaked to remove clay particles.

Before addition of the bacterial solution to the disks, the bacteria was removed from the broth, washed, and added to water. To clean the bacteria in this way, liquid medium was removed from the incubating flasks (about 40mL per disk) and put into centrifuge tubes. These were spun down at 10,000 x g for about ten minutes, then the filtrate was siphoned off. Water was then added, and this bacteria/water solution was run through the filters. Each filter had 25mL of the ‘dirty’ water run through it, and the sample water was collected and examined for bacterial remnants. Figures 8 and 9 show the washed bacteria before adding it to water.

Figure 8. The bacteria after centrifugation.

Figure 9. The spun down and filtered bacterial solution.

The filters were set up as shown below in Figure 10 and 11, with each filter resting in a funnel suspended above a flask. The time to empty was recorded to get a flow rate (as well as to see if there were any significant differences in flow rate). One sample was collected before any filtration as a comparison, and then the controls and corresponding experimental samples were all collected and labeled. Fluoroscopy was used to analyze the filter solutions with the BacLight kit.

Figure 10. The setup of clay filters above flasks with the bacterial solution inside.

Figure 11. A close-up of the clay filter containing the bacterial solution.

Each batch of collected water was mixed with Components A and B of the BacLight kit. Then, 3μL of dye mixture was added to them. These solutions were thoroughly mixed and incubated at room temperature for fifteen minutes before examining them. About 5μL of each was used to create a bacterial suspension on a slide with a cover slip. A fluorescence microscope was used to view the slides. The dye color coded the still-living bacteria to easily be seen in green lighting, and red light was used to illuminate the remains of dead bacteria.

8.1.2. Results

The experiment revealed a high concentration of live bacteria before being introduced to any filter. This was expected, and throughout the experiments, showed that the bacteria were successfully being kept alive. Figure 12 shows this picture.

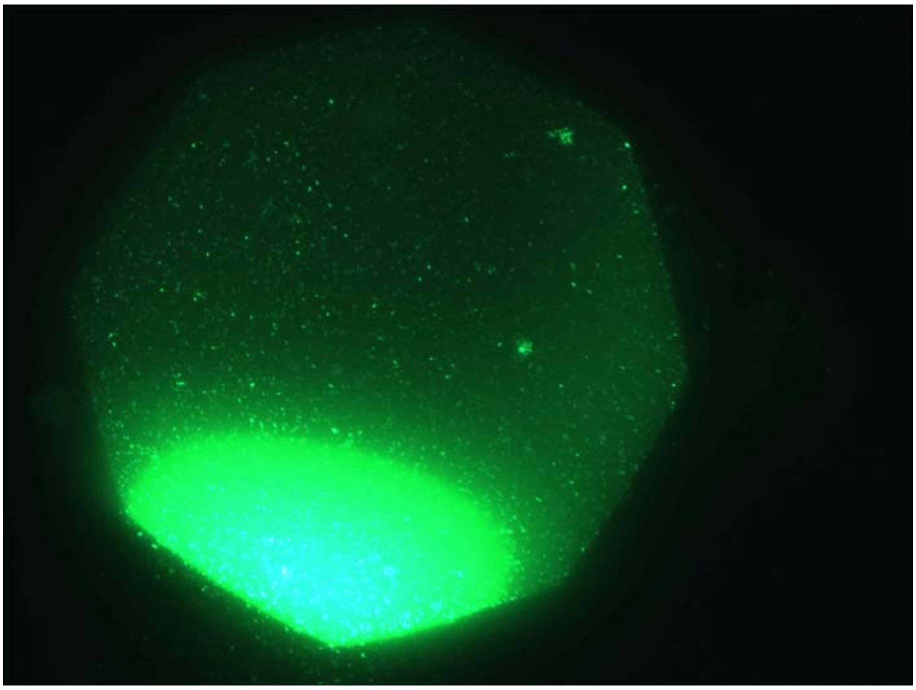

Figure 12. Bacterial solution before filtration.

The bright green dots represent live bacteria. Keep in mind that there are some scratches and spots on the lenses and on the cover slip that are also visible. No dead bacteria were seen under red light, and that picture is not shown here.

After filtration, we looked at live and dead bacteria again. All the results were similar, so only one example is shown here. There were minimal bacteria left after filtration, but still some that were alive. This is promising, but practically all the bacteria have to be killed for this filtration to be effective. The dead slide also showed few, if any dead bacteria, suggesting that the bacteria is dying and getting stuck within the filter itself, or some other, as yet undetermined scenario. Figures 13 and 14 show the live and dead pictures, respectively.

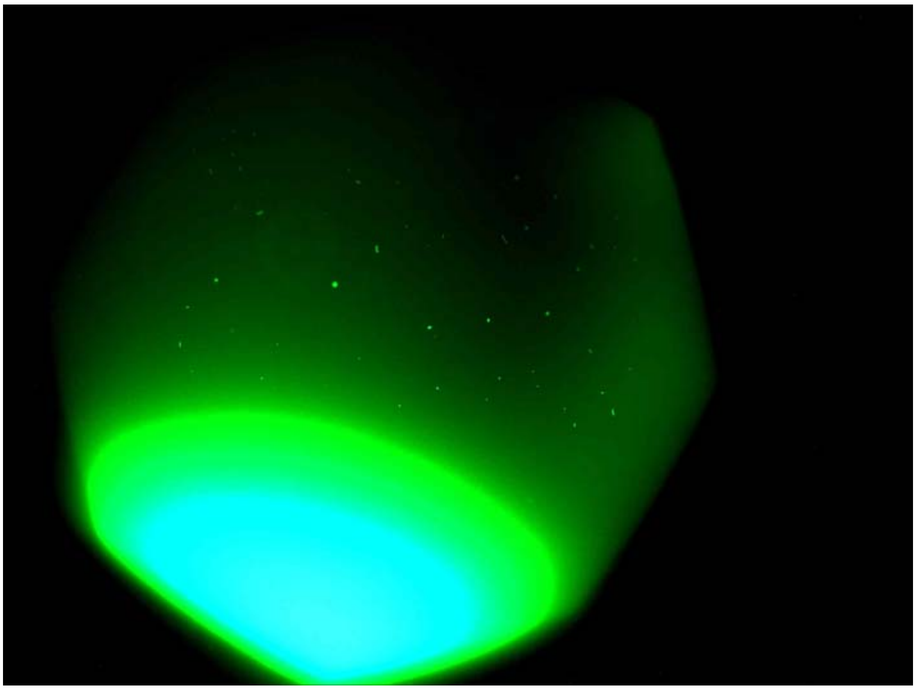

Figure 13. View of live bacteria after filtration.

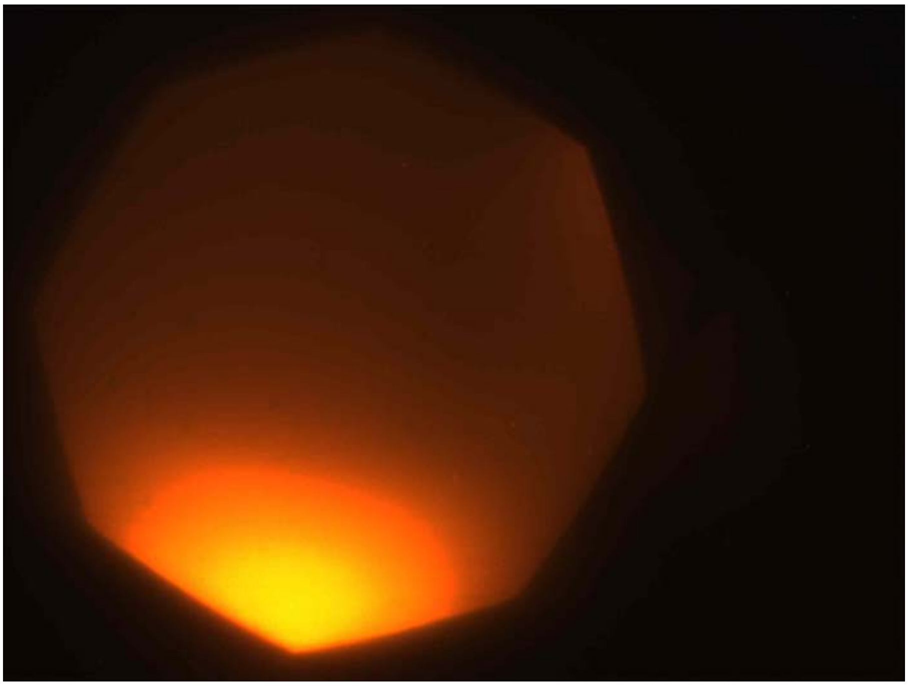

Figure 14. View of dead bacteria after filtration.

8.1.3. Discussion

It was noted during the experiment that the samples from the experimental filters (those brushed with colloidal silver) contained clay particles in them, while the controls did not. It should be mentioned that dry brushing the control might help eliminate factors of variance like this in future experiments. In addition, it would be beneficial to have a clean run through all of the samples, in order to displace clay particles from the inside of the filters. Simply let 25mL of clean water run through all the filters after brushing and note the amount of clay particles that come out.

Another small detail to note was the fact that the brushes used for applying colloidal silver were presoaked in the solution before applying 2mL of it, to ensure as consistent a measurement as possible. The maintaining of the bacteria also could have been simplified if we had access to an incubator with shaking and heating function along with a method of air injection.

The fluoroscopy results do not prove anything conclusive, except that we should perform further testing of different ratios of sawdust to clay and different volumes of colloidal silver to see their effects on the bacteria removal. While it seems the bacteria are being killed, more conclusive evidence is needed. Testing for the effects of different ratios and volumes of silver on them could also provide insight into the optimum combination of variables to kill water based bacteria.

While it is possible that dead bacteria are accumulating within the clay filters, it could fairly easily be tested by running more samples through the same filters. In the future, more tests will be run to see the effect of multi-tiered filtration and repeated/frequent/constant use of the filters to determine their longevity and effectiveness.

8.2. Nitrate Removal

Nitrate contaminated water is linked with multiple health complications. These range from methemoglobinemia (blue baby) to hyperthyroidism (goiters) to neural tube defects in babies to cancer [7]. Due to the continued and increased use of pesticides in many third world countries, nitrate contamination in the ground water is increasing. As such, a large number of studies have been done examining different methods of nitrate removal. It is then a very important contaminant for KlarAqua's filter to address. While not directly tested by our research group, we have done research into the subject, and the findings are shown below.

Nitrate removal from water supplies can be achieved through numerous methods. Traditional methods for nitrogen removal from wastewater are biological processes (de-nitrification, nitrification), chemical processes (breakpoint chlorination, selective ion exchange) and physical operation (ammonia stripping). Other operations or processes are conventional treatment (primary, secondary), biological processes (bacterial assimilation, harvesting of algae, oxidation ponds), chemical processes (chemical coagulation, adsorption), physical operations (ammonia stripping, electro-dialysis, filtration, reverse osmosis), land application (irrigation rapid infiltration, overland flow)[2,3]. Many of the above are solutions for large filtration plants, and are not suitable for a small-scale filtration project.

8.2.1. Potential Methods

8.2.1.1. Biological De-nitrification[4]

Bio de-nitrification relies on a heterotrophic/autotrophic bacteria as well as a carbon rich environment. Water and the nitrate/pesticides are insufficient in providing a usable carbon source to the bacteria since the carbon content contributed by both is fairly low. As such, researchers use a carbon source to contribute to the process: ethanol, methanol, acetate, cotton, newspaper, wheat straw, sawdust, and oil.[5]

Volokita et al. showed that newspaper could be used in bio de-nitrification.[6] Experiments were carried out in a column with 600g of newspaper. By weight, the column could remove

2 Ne¸se Öztürk*, T. Enn˙il Bekta¸s. Nitrate removal from aqueous solution by adsorption onto various materials. Journal of Hazardous Materials, Volume 112, Issues 1-2, 9 August 2004, Pages 155-162

3 The list is by no means exhaustive, plenty of other methods exist: combined membrane bioreactor/powered activated carbon absorption, biofilm-electrode reactor / absorption processes...

Aslan, Sukru and Turkman, Aysen. Combined biological removal of nitrate and pesticides using wheat straw as substrate. Process Biochemistry 40 (2005) 935-943.

4 For a very good review of the process, as well as the different genera of bacteria that contain denitrifying species, see Mateju et al. Biological water denitrification – A review. Enzyme Microb. Technol. 1992 Vol 14 pp 170-183.

5 Rocca et al. An heterotrophic/autotrophic de-nitrification (HAD) approach for nitrate removal from drinking water. Process Biochemistry 41 (2006) 1022-1028.

6 Volokita et al. Biological De-nitrification of Drinking Water Using Newspaper. Wat. Res. Vol 30 (1996) No 4 pp 965-971.

0.730 mg of nitrate per gram of paper. Removal of nitrate could be maintained for up to 4 months. This is one of the few studies that have remarked on the length that the carbon source can last for. Of note, is that de-nitrification is heavily dependent on the temperature. A drop of 15 degrees Celsius can reduce the ability of the column by as much as a third.
Aslan and Turkman utilized a submerged biological de-nitrification system with ethanol as the electron donor/carbon source in order remove various pesticides – specifically nitrate.[7] Over a period of 4.5-8 hours, removal rates as high as 95% are possible with this system. However, one of the possible points of contention is the very use of bacteria for the de-nitrification in a low-cost filtration project. It could very well represent unnecessary complications to the project.

Rocca et al. utilized zero valent iron (ZVI) in addition to the carbon source (cotton) in order to create a symbiotic relationship between the heterotrophic and autotrophic bacteria. The ZVI functioned to reduce the dissolved oxygen, thus favoring the heterotrophic de-nitrification, which then incurs cathodic hydrogen that supports the autotrophic de-nitrification. The reason for using the autotrophic bacteria in addition to the heterotrophic is threefold: one, no alkalinity addition would be required, using two de-nitrifiers should increase the efficiency of the reactor, and three, use of the ZVI would prevent ammonium inhibition of the biological processes.[8] 99% nitrate removal is possible with this system.

In addition to the above, Aslan experimented with combining a bio de-nitrification system with a sand filter system. The sand filter assisted quite well in further removal of pesticides as well as providing good turbidity.[9]

8.2.1.2. Organically Modified Clays

Organically modified clays – organoclays, consists of bentonite modified with quaternary amine chains. In the past, organoclays have been used oil, PCB, phenols and such from water. However, if the amount of quaternary amine is varied, the organoclay can function as an ion-exchange resin and remove nitrates. One thing to note however is that organoclays

7 The system also removed trifluralin, fenitrothion, and endosulfan. (Aslan, 935).

8 (Rocca, 1023).

9 Aslan, Sükrü. Combined Removal of pesticides and nitrates in drinking waters using bio de-nitrification and sand filter system. Process Biochemistry 40 (2005) 417-424.

have not been approved by the FDA for use in drinking water.[10] Whether this is based in some harmful side-effect present in the organoclays, or simply because no effort has been made to attain approval is unknown at this time. The ratio of the mass of nitrate absorbed to the mass of the clay is 4.23% over a period of 20 minutes.[11] The amount absorbed is dependent on the contact time. Thus, the amount of clay needed is dependent on the necessary flow rate as well as the nitrate concentration in the water.

8.2.1.3. Activated Carbon

The most promising method is removal through the use of activated carbon. Activated carbon can be purchased commercially or created by turning any carbon source into charcoal. A high heat source is needed.[12] Commercially purchased activated carbon can be fairly expensive. Of note, is that Mizuta showed that bamboo charcoal created in a high temperature furnace is approximately 15% more effective in removing nitrate/nitrogen.[13]

Something to keep in mind is that alternative methods may be useable. For example, Turkey possesses most of the world's reserves of sepiolite – an inexpensive, fibrous silicate clay mineral. Öztürk and Bektas showed that sepiolite could remove nitrogen with the same if not greater efficiency as commercially activated carbon – When they activated sepiolite with HCl, it removed twice as much nitrate as the activated carbon.[14]

8.3. Arsenic Removal

Arsenic contaminated water is a large problem in many third world countries. The health effects can range from cancer to cardiovascular/neurological diseases. The usual methods involve fairly costly procedures that are not available in poor communities. As such, research has gone into alternative means to remove arsenic from drinking water supplies. Similarly to

10 Whether this is all forms of organoclays or not, I'm not quite sure. I was only able to find one company that manufactured them, and they provided me with said information.

11 Alther, George. Polar Organoclay to Remove Perchlorate and other Recalcitrants from Water. Biomin, Inc.

12 I'm not quite sure what the minimum temperature is to create good charcoal. The study that I'm basing this on however blasted bamboo at 900 degrees Celcius.

13 Mizuta et al. Removal of nitrate-nitrogen from drinking water using bamboo powder charcoal. Bioresource Technology, Volume 95, Issue 3, December 2004, Pages 255-257

14 Ne¸se Öztürk*, T. Enn˙il Bekta¸s. Nitrate removal from aqueous solution by adsorption onto various materials. Journal of Hazardous Materials, Volume 112, Issues 1-2, 9 August 2004, Pages 155-162

nitrate removal, KlarAqua has simply looked into potential means of eliminating this contaminant from water supplies with our filter. Some potential methods are described below.

8.3.1. Potential Methods

8.3.1.1. Oxidation

Oxidation alone doesn't remove arsenic from solution, and is usually combined with another removal process such as coagulation, absorption or ion exchange. What oxidation does accomplish- is that it usually converts arsenite (As III) to arsenate (As V). Most systems for arsenic removal are fairly inept at removing As III; thus the reason for the conversion. Chemicals that are typically used for oxidation include, but are not limited to: gaseous chlorine, ozone, permanganate, manganese oxides, hydrogen peroxide, and potassium permanganate.

8.3.1.2. Coagulation and Filtration

Documentation on this method is quite extensive. Typically, coagulation and filtration utilizes metal salts or lime softening. Alum, ferric chloride, ferric sulfate, and ferrous sulfate are commonly used metal salts. The process for arsenic removal in coagulation and filtration occurs through three main steps: precipitation of Al (AsO_4) or Fe (AsO_4), co precipitation of the soluble arsenic species into the growing metal hydroxide phase, and absorption of the arsenic to the metal hydroxide. After which, filtration is required to remove the sorbed arsenic. Without filtration, only 30% of the arsenic is removed, with filtration, over 96% can be removed.[15]

8.3.1.3. Ion Exchange Resins

Normally used in water softener applications, it can also be modified to remove arsenic and nitrates. Acidic resins are negatively charged, and are then loaded with a cation that can easily be displaced and replaced by the nitrate/arsenic/sodium during the water treatment phase. The converse is also true. With respect to arsenic though, As (III), arsenite is uncharged. Thus, it needs to oxidized to As (V) in order to be removed by the ion exchange resins. Ion exchange resins are quite capable of removing over 95% of the arsenic

15 For a more in depth look at the precipitation and absorption process, see Robins et al. Removal of Arsenic from Drinking Water by Precipitation, Absorption, or Cementation. Technologies for Arsenic Removal from Drinking Water. Publishers. 2001. ISBN: 984-31-1305-6

concentration. In low concentrations, the resins' can remove a total amount of arsenic equal to roughly 1000 times the bed volume of the resins. Arsenic removal is not dependent on the pH and influent concentration.

8.3.1.4. Activated Alumna

Removal is similar to ion exchange resins, however the rate of removal is slower than resins, and leakage is more often noted in activated alumna systems. Activated alumna can successfully remove arsenite and arsenate at efficiencies over 95%. However, the removal method is limited by the pH of the influent. The capacity of arsenic removal of activated alumna is roughly 4mg of arsenic per gram of alumna. Activated alumna can successfully remove selenite, fluoride, sulfate, and chromate. With respect to the ion-exchange resins, activated alumna is found more often in communities and the household level since no other chemicals are needed, and it can be operated for months at a time before regeneration is necessary.

8.3.1.5. Membrane Methods

Basically, synthetic membranes are created with selective permeability. The two main classes of membrane filtration are high pressured and low-pressured membranes. The pore size of high-pressured membranes is best suited for the removal of arsenic. However, they need to be operated at pressures from 75 to 250psi. Membranes can easily remove at least 95% of arsenic. In addition, they have been shown to remove 99.9% of bacteria as well as other chemicals/compounds in the water. The downsides of membrane technology however, are the cost and high pressure required for operation.

8.3.1.6. Emerging Technologies

Recently, lots of research has gone into various methods to create low-cost, low-tech arsenic removal systems. One of these is Fe-Mn oxidation. The mechanism is equivalent to that found in coagulation and filtration. One of the main problems to this method however, is that water stored in household containers after treatment; has a high risk of bacterial contamination due to the exposure to iron.

In addition to the activated alumna mentioned above, there exist quite a few other metal oxides with an affinity for arsenic. In recent years, a low-cost method has been developed that involves coating sand (or any other granular substance) with metal oxides. Iron oxide coated sand has been shown to remove approximately 150 bed volumes of 1000ug/L arsenic. Other materials are greensand and granular ferric hydroxides, both have been shown to be fairly effective in removal.

In addition to the mentioned synthetic ion exchange resins, however, natural ones exist as well. Zeolite minerals are quite porous, and possess large surface areas and ion-exchange properties. The zeolites, clinoptilolite and chabazite were shown to be able to remove 1000ug/L of arsenate from over 235 bed volumes.

8.3.1.7. Other Studies

Hussain et al. demonstrated multiple methods for the removal of arsenic in drinking water. Of note, is the method that involves arsenic filtration through the use of wood charcoal and sand.[16] By passing water through multiple layers of sand and wood charcoal, Hussain et al. was able to remove 90-99% of the nitrate in the water with flow rates from 12-192ml/min.[17] . The effectiveness of this method before the charcoal has to be changed was not reported on by Hussain et al. Depending on the lasting potential of the method, this may be a suitable method for arsenic removal in a low-cost water filtration device.

Saha also demonstrated multiple methods for the removal of arsenic in drinking water. Table 1 shows the arsenic removal ability of multiple materials. Saha collected data by using the batch sorption test with a 6-hour contact time.[18]

The study then focused on the last four materials from the table and measured their removal abilities in a column setup. What's most notable of the above however is that normal materials in the communities may be utilized to remove a decent portion of the arsenic. While, it may not meet WHO standards for drinking water, lowering the amount of arsenic in the water by 50% is still incredibly important. As such, we may want to study the potential of some of the more common materials from Table 1 in a column setup.

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16 The other two methods involved sedimentation and treating the water with Calcium Oxide. While, these are suitable methods for large filtration projects, their utility for a small, water filtration device is questionable. They both add complexities that the users of the device would not want to deal with.

17 Hussain et al. Approaches for Removal of Arsenic from Tubewell Water for Drinking Purposes. Bangladesh University. Technologies for Arsenic Removal from Drinking Water. May 2001.

18 Saha, J.C. Comparative Studies for Selection of Technologies for Arsenic Removal from Drinking Water. Bangladesh University. Technologies for Arsenic Removal from Drinking Water. May 2001.

Adsorbent	Dose (g/l)	% Removal	
		As(III)	As(V)
1. Kimberlite tailing	10	25	40
2. Water hyacinth	10	45	70
3. Wood charcoal	10	19	37
4. Banana pith	10	12	18
5. Coal fly ash	10	20	28
6. Spent tea leaf	10	25	42
7. Mushroom	10	22	35
8. Saw dust	10	28	36
9. Rice husk ash	10	5	12
10. Sand	10	15	22
11. Activated carbon	10	50	65
12. Bauxite	10	58	80
13. Hematite	10	40	60
14. Laterite	10	45	70
15. Iron-oxide coated sand	10	72	90
16. Activated alumina	10	90	96
17. CalSiCo	5	90	98
18. Hydrous granular ferric oxide	2	92	99

Figure 15. The table shows the removal capabilities of various materials. As(III) is arsenic III, and As(V) is arsenic V.

8.3.2. Methods of Arsenic Removal Being Tested in Bangladesh

8.3.2.1. Auto Attenuation

Simply collect groundwater from wells and let is stand for a specified period of time. If the water possesses high concentrations of iron readily oxidizes and results in the removal of As (III) and As (V).

8.3.2.2. Filtration with Sand and Iron Fillings

A tube filled with sand and zero valent iron fillings, in which water is passed through, can result in 97% removal of arsenic at concentrations of 45-8600 ug/L. However, BaSO4 needs to be added to the water if it’s not already present.

8.4. Taste and Odor Removal

While not fully tested, there is reason to believe that a packed carbon bed will help eliminate taste and odor from water. Room has been made available for this modification between the last two clay filters for this. The area between the filters will simply be filled with the carbon, so that the water may be cleansed just before reaching the reservoir.

9. Conclusions

Our testing has granted insight into what further sections need more analysis and what proposed ideas might or might not help us obtain our goal of a cheap, effective, user-friendly water filter. The plastic housing, bucket, and cones will need to be manufactured and provided to the user, but the other materials can be obtained locally or created with easily accessible materials. The clay filters can be modified very heavily in a variety of ways, but the main concern now is to make sure that bacterial removal works as efficiently as possible while delivering a reasonable flow rate. The multitudes of combinations that can be made have not yet been fully tested, but the approximate values have been found for finalizing an optimal design. As mentioned in section III, further testing can be done in the fields of nitrate, arsenic, taste, and odor removal. All of these combined together will provide the user with a working water filter that is self-sustainable in the context of their community.

10. Appendix

10.1. Previous Designs

10.1.0. Initial Design

The initial design consisted of a plastic bucket containing a plastic cast designed to hold three clay disks, giving two reservoirs for holding water. Reservoir one has contaminated water and creates a hydraulic head (the top reservoir), while reservoir two collects and stores treated water (bottom reservoir). The hydraulic head on top of the filter enhances filtration rate, and allows the user to add large quantities of water versus small quantities to the device.

Advantages

- Different situations can be addressed through the use of three filters; specifically other contaminants besides bacteria can be dealt with.
- Filter is lightweight.

Disadvantages

- Greater leakage between disks.
- Collection of water occurs in the same container.

It is important to note that if there is not 100% removal of bacteria and the water is collected in the same reservoir, the filtered water there will serve as an incubation media for bacterial growth. The bottom reservoir cannot easily be emptied if there is a side valve in the bucket.

Figures 0.1 through 0.5 illustrate the initial design of the filter housing from various perspectives. There is still the problem of flood and canalization in the first step, and there is no hydraulic pressure head after the first step. But there are plenty of steps for sufficient filtration with the three layers, and the housing will store the water to be treated above the first clay filter.

Some early design considerations were the type of plastic to be used in the housing and the desired volume of water to be treated.

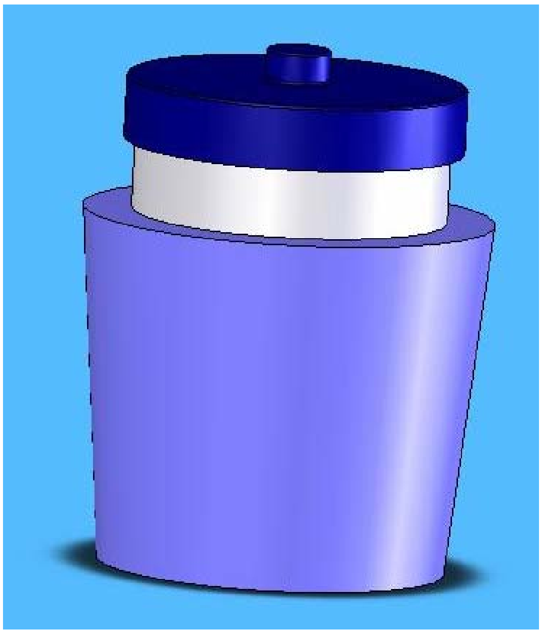


Figure 10.1.0.1. **Entire Assembly.**

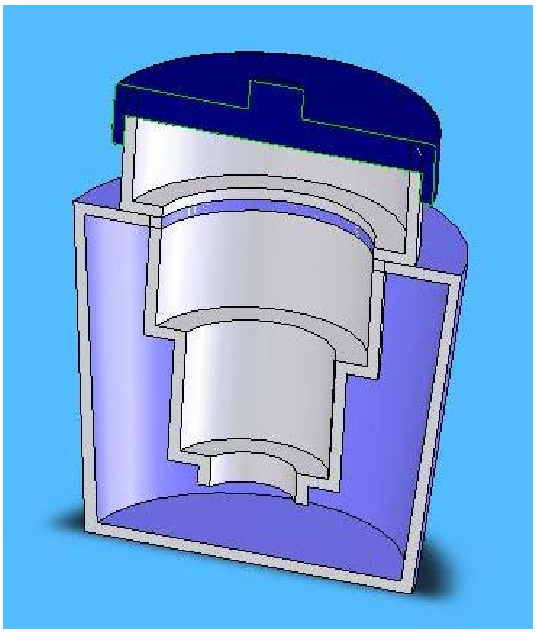


Figure 10.1.0.2. **Cross-sectional view of container.**

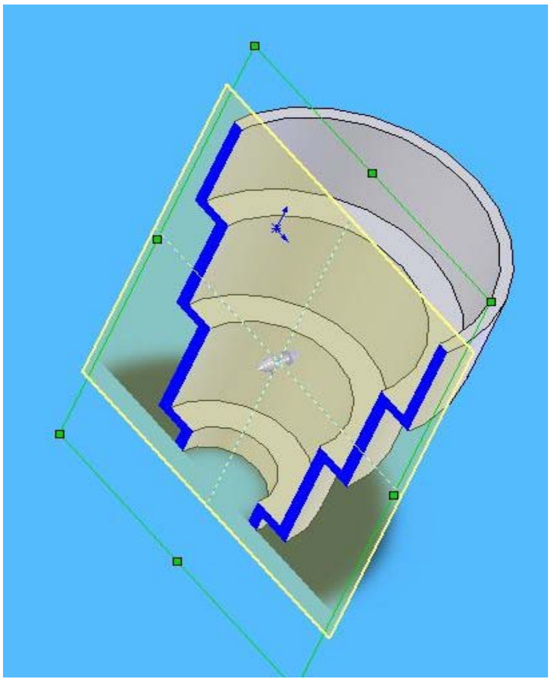


Figure 10.1.0.3. Cross-sectional view.

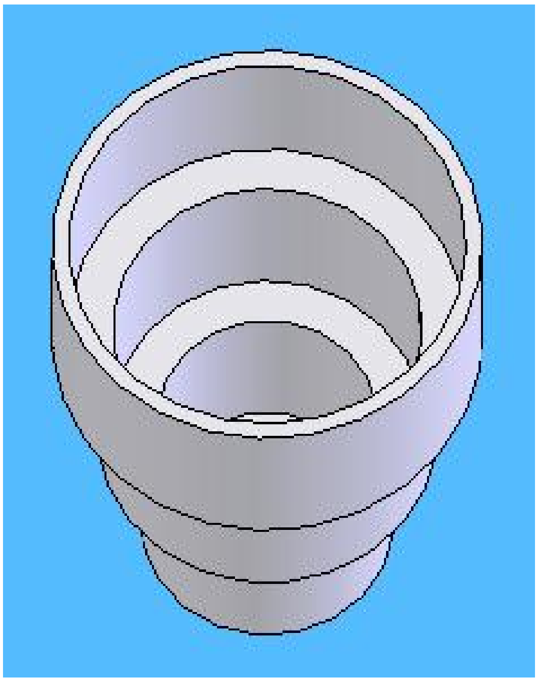


Figure 10.1.0.4. Filter housing.

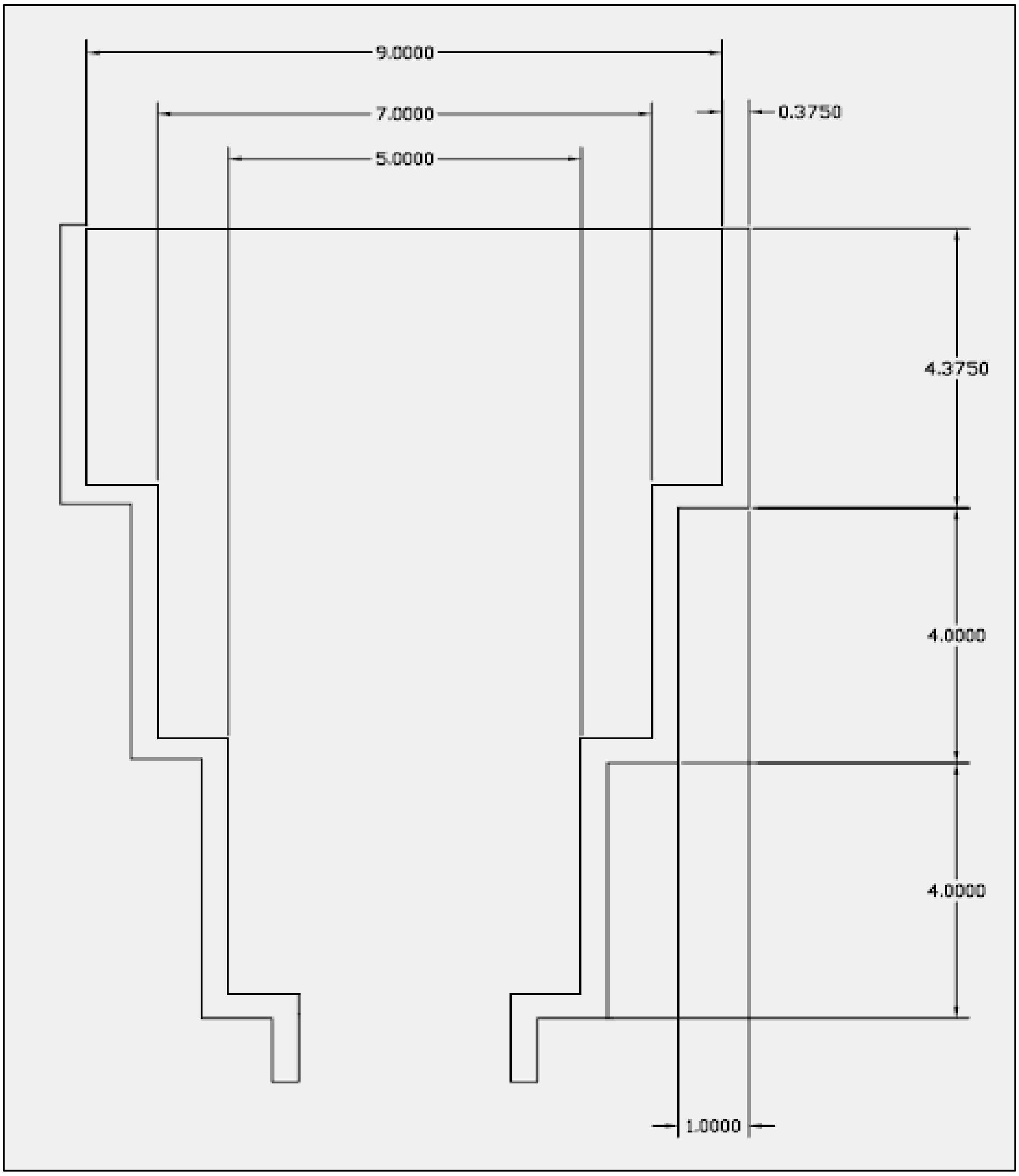


Figure 10.1.0.5. 2D model.

A series of improvements to the previous design were made. The following sections detail the different designs KlarAqua considered before settling on our optimal design. Disk 1 refers to the topmost filter, while Disk 3 refers to the last and smallest disk at the bottom of the filter.

10.1.1. Design 1

The design consists of the plastic bucket, the plastic cast, and 2 plastic cones that connect disks 1 to 2 and 2 to 3. Also, a plastic lid is placed over the first disk in order to prevent leakage.

Advantages

- The possibility to address different contaminants with the versatility of 3 layers.
- Light weight.
- Leakage is prevented in the second and third stages.

Disadvantages

- Leakage in the first stage.
- Impossibility of having a hydraulic head on top.
- Collection of water in the same container
- Added complexity with the presence of cones.

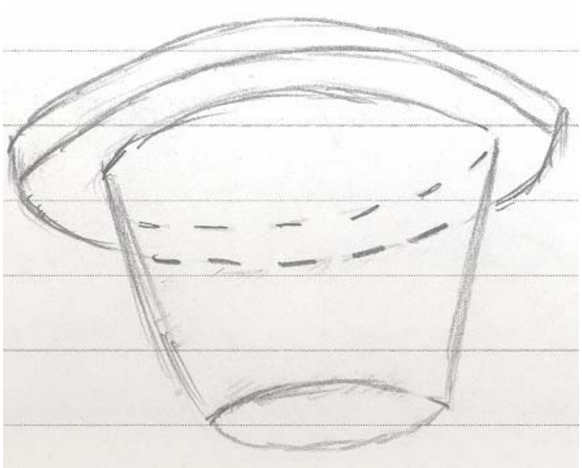


Figure 10.1.1.1. Perspective of proposed cone.

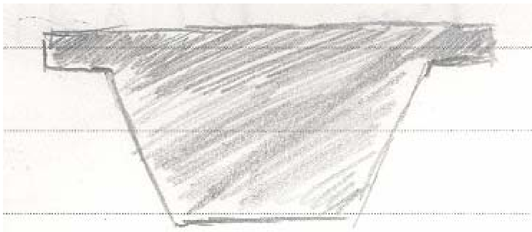


Figure 10.1.1.2. Profile of proposed cone.

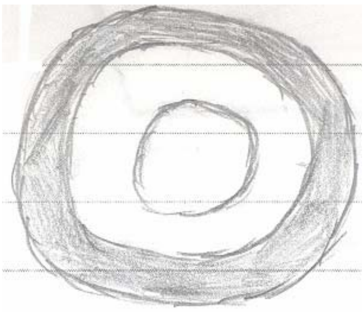


Figure 10.1.1.3. Top down view of cone.

lid.

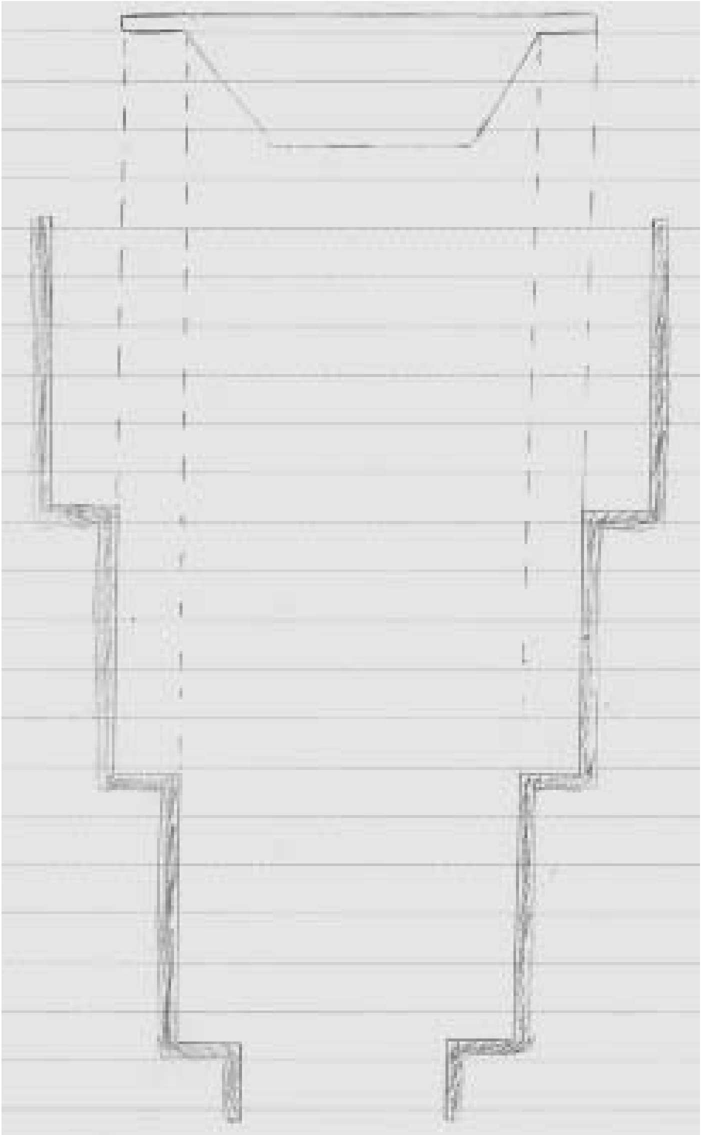


Figure 10.1.2.4. Placement of first cone in housing.

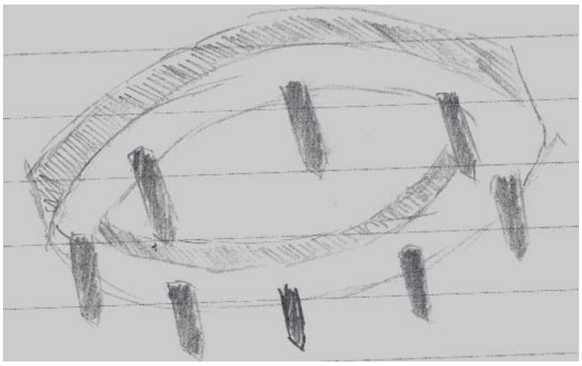


Figure 10.1.1.5. Perspective view of lid.

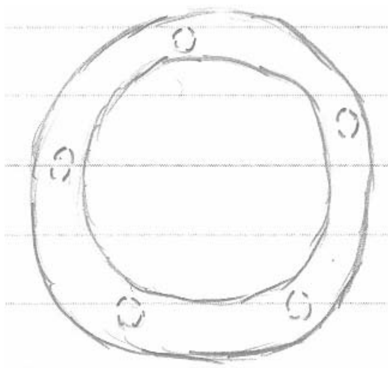


Figure 10.1.1.6. Top down view, lid.

10.1.2. Design 2

This design consists of the plastic bucket, 2 plastic cones, the plastic cast, 2 clay disks, and 1 bowl of clay.

Advantages

- The possibility to address different contaminants due the versatility of 3 layers.
- Light weight.
- Leakage is prevented in all stages.

Disadvantages

- Collection of water in the same container.
- Added complexity with the presence of cones.

Instead of using a flat disk for disk 1, a clay bowl can be used that is similarly brushed with colloidal silver. This will prevent leakage, since all the water to be filtered will be filter through this bowl before moving through the rest of the filters.

Regarding this second design, some different shapes for the disk were explored and the following issues arose. Depending on the flow rate, the surface of the disk would be best suited as flat, curved, or with another specific shape. If the flow is concentrated at the center, then there might be depletion of colloidal silver.

A slight concavity in the disks was suggested as a response to these issues, or alternatively, we propose the creation of pathways in the disk if a very high flow rate is found.

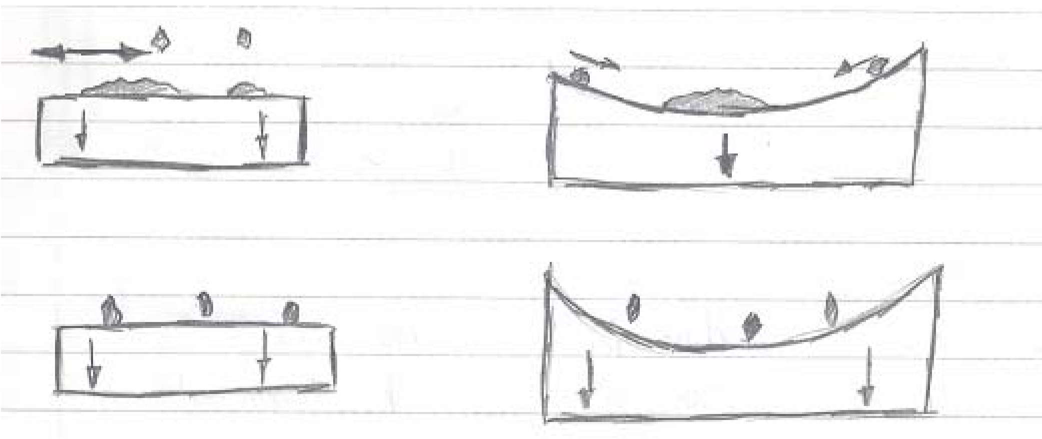


Figure 10.1.2.1. Suggestions for concave surface of disk. The disks on the right force water through the center if flow rate is slow enough.

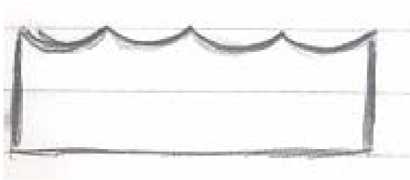


Figure 10.1.2.2. Creation of pathways

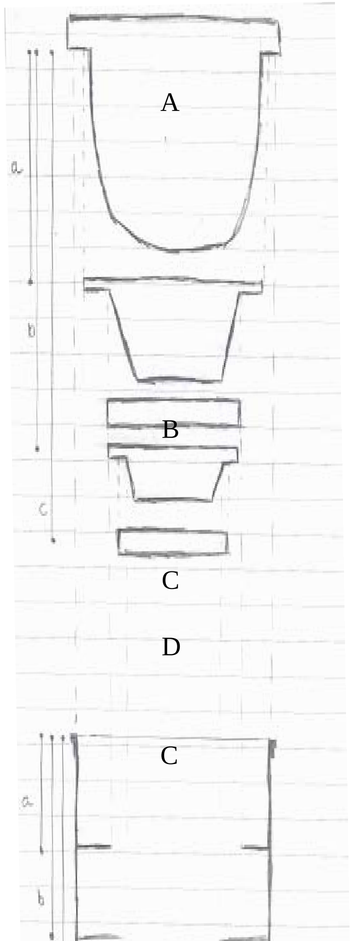


Figure 10.1.2.3. Filter structure for Design 2. A is the clay bowl filter; B represents the first plastic cone to direct filtered water away from the edges of the housing; both C’s are clay filter disks; D is the second plastic cone.

10.1.3. Design 3

In order to avoid flooding the design was changed for a slope shape in the first step. Also we decide that the best approach is to have a packed bed between the first and second step, and another between the second and third step. With the packed bed the leakage is prevented at the edges.

The packing material is planned to be activated carbon for removing odor and taste and organic modified clay to remove nitrates.

Advantages

- The possibility to address different contaminants due the versatility of 3 layers.
- Light weight.
- Leakage is prevented in all stages.
- Collection of water in a separate entity.

Disadvantages

- Increase in cost and maintenance for the filter.

This plastic cast is very similar to the final design, and the guiding design for the prototype. The pictures below illustrate the dimensions and complete assembly.

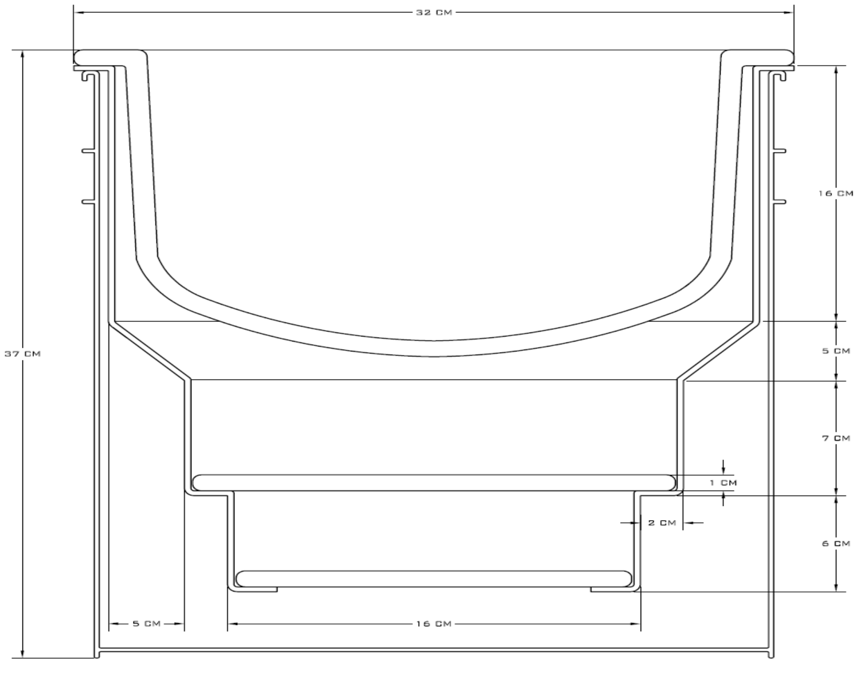
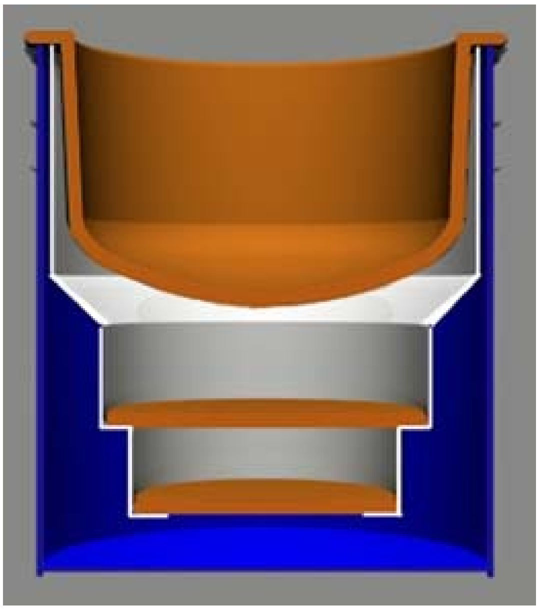


Figure 10.1.3.1. Dimensions and placement of disks in Design 3.



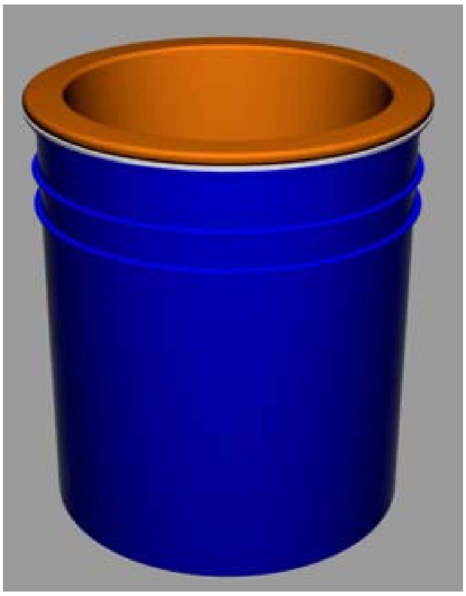


Figure 10.1.3.2. Cross-section of filter. Brown = clay. White = plastic filter. Blue = bucket.

Figure 10.1.3.3. Filter Perspective with storage bucket

<u>10.1.4. Design 4</u>

For the NCIIA presentation, we needed to have a working prototype, so we decided to delay the packed bed filtration step and instead construct a sieve tray column with the disks. The issue with the packed bed was that no cost benefit-analysis or economic feasibility had been done. Lacking such data, we did not want to include something we could not back up.

Due to the change from packed bed to sieve tray, the problem of leakage arises again. In order to prevent this we decided to place simple seals over the structure and change the shape of the disks to a stubby “T” and removing the concavity. All these changes are made in order to prevent leakage.

The best way to stop leakage is not by treating it, but preventing it. In order to prevent it, we need to make sure that the water does not pass near the edge of the disks, where it can flow down along the filter housing without passing through the filter. This is achieved by placing seals not only around the disk, but also above the disk so the water cannot get to the edge. The best type of seal will be one similar to a dike (Figure 4.1), but as that is difficult to form, this design will focus on round seals (Figure 4.2).

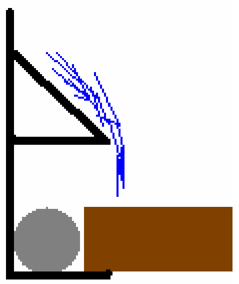


Figure 10.1.4.1. Example of dike seal and around stopper around "T' disk shape.

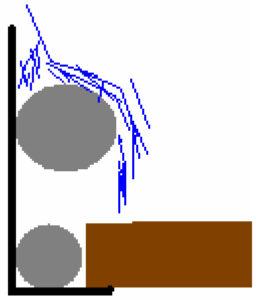


Figure 10.1.4.2. Example of round seals around "T" disk shape

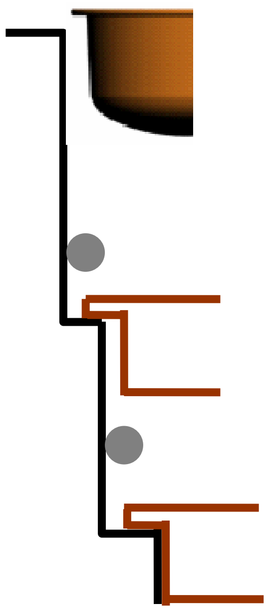


Figure 10.1.4.3. Cross-sectional profile of complete filter structure.

10.1.5. Design 5

Design 5 is almost the same as that in design 4, except that normal round disks are used.

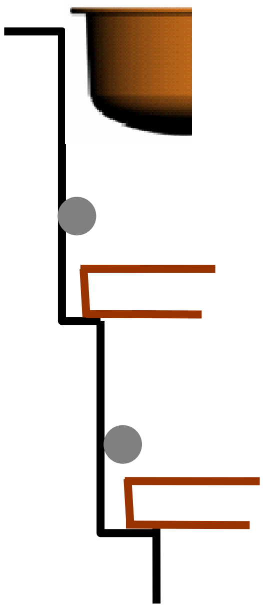


Figure 10.1.5.1. Filter Structure.

When doing tests in the lab we discovered that placing seals was not a good solution for the leakage. Even though it works better than not having anything to direct flow, the solution was overly complicated for the relatively small performance gain we saw. When using flow distributors (like the plastic cones from design 2) the best results where obtained. Because of this, the next design consists of the shape of design 3 but with flow distributors from design 2.

10.1.6. Design 6

For the reasons previously mentioned, the last design is based on one clay bucket and 2 clay disks with a plastic cone and a packed tower between the two clay disks. The packed bed simply uses particulate carbon to further filter the water for taste and odor.

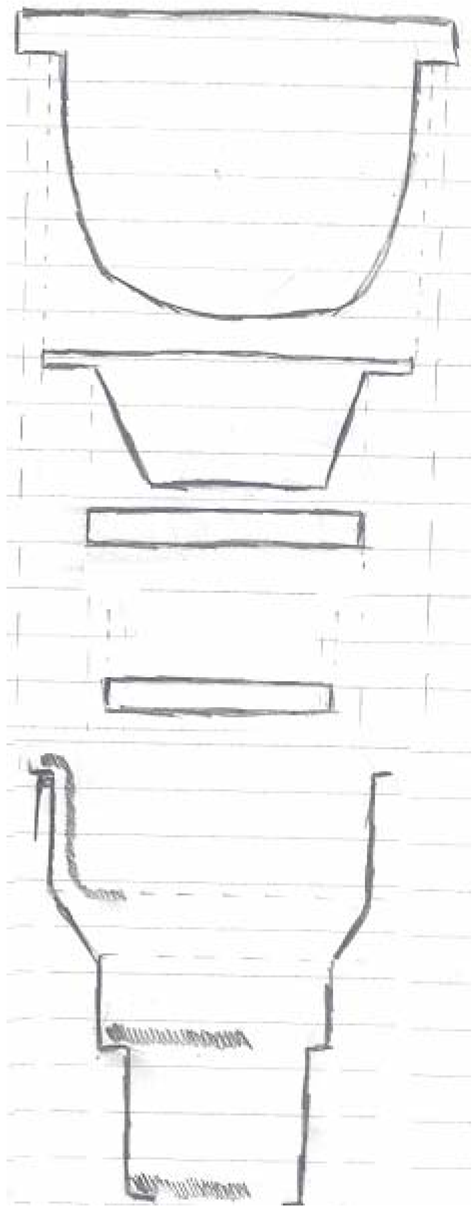


Figure 10.1.6.1. Last design. From top to bottom, the pieces are: clay bowl; plastic cone; clay disk 1; clay disk 2; plastic housing (shown with silhouettes of where the clay pieces will fit).

10.2. KlarAqua and the players who interact with it

Project KlarAqua was conceived as a joint effort by the Illinois Institute of Technology and the Monterrey Tech University at Monterrey, Mexico. Students and staff from both institutes have played a considerable role in throughout the evolution of the project and will continue to do so under various capacities, including but not limited to Members of the Board and Senior Management. In addition KlarAqua will have a Funding Director who overlooks the allotment of funds and a Program Director who runs the project. It is highly foreseeable that a network of student volunteers will play a significant role during implementation of the project on at the field. The figure displays the nature of interaction between the various members

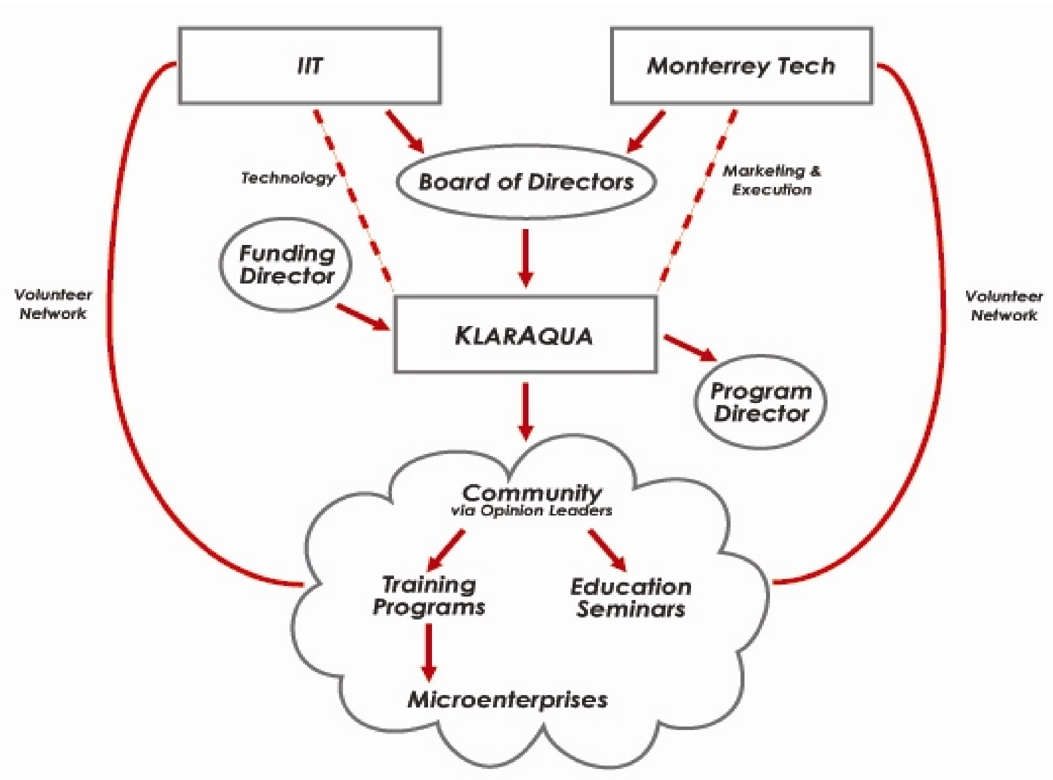


Figure 10.2.1. KlarAqua and the Players who interact with it

10.3. Plastic Suppliers

Below are some of plastic casting companies we found. Some of them we have already contacted or tried to contact to get an injection mold formed for the housing.

10.3.1. U.S.A.

Listed here are some contacts in the United States for plastic industries.

- Anfinsen Plastic Molding, Inc. 195 N Farnsworth Ave, Aurora, IL.
- ARRK. Rapid Prototyping. 800-735-2775. Contact Peter Vigil, pvigil@arrk.com, 858-626-2323.
- BDH Plastic Molding Co. Maywood, IL
- BJ Plastic Molding Company, Inc. 778 County Line Road, Bensenville, IL
- Cal-Mold, Inc. www.tstonramp.com/~calmold/. 888-465-6653. Sales, George Alvarado, galvarado@snapware.com, 951-361-6435.
- Plastic Power Corporation. www.plasticpower.net. 4046 Tugwell St. Franklin, IL 60131. 847-233-9601.

10.3.2. Mexico

Here are some contacts of plastic industries in the Monterrey area.

- Adhesivos y Plasticos, S.A. de C.V. (APSA), administracion@diprocesa.com, 81144130.
- Jalco Plasticos y Envases, S.A. de C.V. 83914254.
- Mayoreo de Plasticos, S.A. de C.V. (Comercio al por Mayor de Envases), 83757052.
- Plasticos de la Fuente, S.A. de C.V. Comercio al por Mayor de otras Materias Primas o Materiales de uso Industrial no Mencionados Anteriormente, 83424416, 84794604.
- Plasticos Especiales Garen, S.A. de C.V. Comercio al por Mayor de Envases, 83547171, 83547441.
- Plasticos Villagran, S.A. de C.V. Fabricacion de Articulos de Plastico para el Hogar, jhvillanueva@axtel.net, 81343010.
- Poly-Ex S.A. de C.V. Inyeccion de Articulos de, Plastico Maquila Ensamble, Plasticos de Ingenieria, Diseño Fabricacion y Ensamble, Diseño y Fabricacion de Moldes para Inyeccion Sistema de Calidad Certificada ISO 9001, 8351-7676.
- Internacional Quality Plastic. Fabricacion de Moldes, Maquila de Inyeccion de Plastico, Soldadura para Ultrasonido, 8385-0102, 8385-0104, 8385-0105.
- Regio Pet, S.A. de C.V. 818 842-050.

10.4 Assumptions during Cost Analysis

10.4.1. Unit Costs Assumptions

- Small Clay Disk: Cost of a small tile based on Monterey's first pilot study Feb 28th
- The cost of the small clay disk is accounting for 2 disks because the design of the filtering product is 2 small disks
- Large Clay Disk: Cost of a large bowl type object based on Monterey's first pilot study Feb 28th
- Colloidal Silver Solution assumed cost at 13 pesos and able to be picked up at many local stores
- Cheese Cloth
- Carbon
- Sawdust expected cost of 0 pesos because they are the waste of many products in saw mills and farms which can be easily obtained
- Bucket 38 pesos that can be picked up at any local hardware store
- Plastic Casting: Injection Molding is expected to cost 50-70% less to product in other countries than in the US. http://www.xpectra.com/
    - Their facility in Juarez Mexico houses 20 presses
    - Waiting on email for a projected cost
    - As of now the assumption on cost for molding is projected in the US as most likely $.70-1.00 per lbs http://www.azinventors.org/Meeting%20Notes/plastics.htm
    - Going off a $.50 in American Currency and using an exchange rate calculator from http://www.xe.com/ucc/ is about 5.55 pesos
    - However Amanda's research leads to 21 pesos for the casing and cones
- Inflation rate was figured out by looking at the total rate of inflation in Mexico over 10 years from 90-04 went up 16% so it averaged 1.14% inflation per year

10.4.2. Facility Costs

– These costs total costs to purchase the necessary equipment to have an up and running facility

- Building (Assuming KlarAqua is going to be run out of a smaller office type building with possible storage of the vacuum molded interior of our product with about 10 employees running the facility)

    - As far as costs are concerned with the building of a new facility this will vary depending on the location of the facility however in some of the research I have found is about 25-30$ American per square foot. This includes architect fees, permits, plumbing, etc.
    - 277.70-333.23 pesos per square foot of building
    - 416,550-499,845 pesos for a 1500 sq ft facility, average 458,197 or 460000
        - http://www.mexconnect.com/mex_/dtbuild.html
- Rent (1st year KlarAqua) This will be the costs of renting space at Monterey Tech. for the first year, this should provide us with electricity, phone line and space
- Furnishings (office furniture and other office related furnishings such as KlarAqua advertisements) My assumption was based off a small 3 piece set for a house which should be some what similar to an office
- Supplies (pen's, pencils, filing cabinets, computers etc.)
    - Costs include 2 computers and a printer from Dell, and extra money allocated towards paper, pens and pencils, staplers, and what ever is needed
- Staff (Yearly average salary)
    - The Organization basing salary off of projected living expenses in Mexico which is estimated from ½ to 1/3 of that in the U.S.
        - With the above information I researched the average administrative salary in America ($47,584) and cut it in into 1/3 ($15,861) and converted to Pesos
        - According the UNICEF website the average income in Mexico is 75,176.85 Pesos (assuming the average was given in U.S. Dollars)
            - www.unicef.org
        - With the above assumptions I assume the average cost per employee would most likely be closer to 75,000 Pesos per year. I would expect some to be lower and some to be higher depending on the responsibility of the employees (on the spread sheet I have put 75000*2 (expected average cost per staff multiplied by the expected number of staff)
        - However after talking to some people who are actually from Mexico the above assumptions are a little bit high so what I have decided to do

was predict the amount of 60000 pesos per person since we decided to have 2 individuals running the company

    - http://www.escapeartist.com/efam2/mexico_mike.html

- Operation will be a function of cost per year to run the facility with respect to electricity, gas, phone, and water (however renting from Monterey tech may have these fees associated with the cost of renting the facility)
- **Insurance this will be the cost of insurance The Organization not sure exactly how it will go but should include liability, fire, theft…. stuff along those lines
- Vehicle: Should be comparable to that of the US if not more expensive
    - To purchase a vehicle it would cost about 160000 pesos ($15000)
    - http://www.mexperience.com/liveandwork/living_in_mexico.htm#CostOfLiv
    - The cost per renting a car per day is 350 pesos
- Electricity was found on a website that is a pre-vacation in Mexico resource site that you can book information and such in there
    - Average cost for electricity is 2.56 Pesos per KWHr
        - http://www.swenergy.org/factsheets/NMfactsheet.pdf
        - Average use of 6700 KWHr per household per year, The Organization assuming that should be a ball park on our organization
- Natural gas was found as above
    - 3.5-5.5 pesos per Ltr so about 4.5 pesos per Ltr.
        - www.swenergy.org/factsheets/NMfactsheet.pdf
        - Getting an average usage per household is 39200 cubic feet and gas cost about 4.5 pesos per liter I came up with the cost of 1,110,020.39
- Basic phone charges are 167 pesos per month

Electricity	2.56	Per KWHr	17152
Natural Gas	4.5	Per Ltr	4995091.755
Basic Phone	167	per month	2004
Water	Variable		

10.4.3. Advertising Costs

-This should include the costs of getting our product known, however these are possibilities and not guaranteed

- Brochure-this should be the cost to print off a certain amount of brochures
  - The cost of printing off a single brochure was 2 USD will be about 22 pesos per brochure and 1000 of them for the year 22000 pesos
- Video-this is a video to show while the company is going off telling a small story while displaying our product
  - This topic was talked about in class and was estimated to be about 20,000(222588 pesos)
- Public Advertisements-This includes any kind of advertising needed to be completed
  - The Organization estimating about 10,000 USD = about 111000 pesos
- Travel Expenses-the costs of going from community to community should include gas, food, and lodging
  - Gas: I figured about 12 miles to the gallon for a truck and then converted to liters
    - about 3000 miles driven every 3 months for a total of 12000 miles total (111 liters per tank of gas with 16.64 pesos per liter of gas)
  - Housing: I figured about 25 pesos a night to stay in a village with about 3 visits per month and 12 months gives 900 pesos
  - Other consists of food and emergency money while in these villages
    - Food The Organization figuring 3 meals a day for the villages (60 pesos per meal at 3 meals a day and 3 visits a month for 12 months) 6480 pesos and to include emergency cash about 7000
    - http://www.mexperience.com/guide/essentials/priceindexnov2005.php
- Intellectual Property- This should include the cost of trade-marking our product and patents

10.5. Disk Composition

The first compositions that we used were 6:7 and 7:7 ratios of sawdust to clay. This is on a volume basis, and translating these ratios to percent weight gives a 15% by weight sawdust and 85% clay for the 6:7 ratio and 17% sawdust and 83% clay for the 7:7 ratio. The sieving number used was 10 (opening size of 2000 microns or 0.78 inches, aka size 9 mesh).

The clay disks and bowls were fired for approximately 16 hours. The first segment increased the temperature at a rate of 108^{o}F/hr until it reached 200^{o}F where it was held for 2 hours. After that we increased the temperature at 100^{o}F/hr until it reached 1157^{o}F.

The first flow tests on the 6:7 and 7:7 disks and bowls did not perform as well as hoped. The drying time was too short, and the fired bowls and disks were dusty from a lack of bonding between the particles of clay and sawdust. After the first filtration, the corners of the bowls broke, suggesting they were not strong enough for our purposes. The thickness of the disks was also too large, lowering flow rate to an unacceptable level. It took 10 hours for only 100 mL of water to pass through the bowls and 7 to 8 hours for 20 mL of water to pass through the disk samples.

For the second mixture, we used the composition suggested by our team in Mexico (they had obtained a much more desirable flow rate). We tried to increase the percentage of sawdust, which is directly proportional to the flow rate. The thickness of the disks was also reduced to have a lower flow rate measurement so results could be obtained in a shorter period of time.

First we made 10:7 sawdust to clay ratio (23% sawdust and 77% clay by weight). The method of firing was slightly changed as well. The temperature was increased from room temperature to 212^{o}F at a rate of 122^{o}F/hr, where it is held for 2 hours, and then the temperature is increased by at 212^{o}F/hr until it reaches 752^{o}F. Again, that temperature is held, but for 4 hours, and the temperature increased at 212^{o}F/hr until it reaches 1580^{o}F. This temperature is held for 24 hours before the oven is shut off and the disks removed.

We also made a mixture with a ratio of 15:7 (30% sawdust and 70% clay by weight), the ratio used by the students at Monterrey Tech. They had used a different type of clay, and we found that for of type of clay we used, their mixture was not suitable. We made two disks at this composition and found that there was too much sawdust and the not enough clay to promote the necessary bonding. Instead, we slightly increased the clay in the mixture (making it a 15:8 ratio, sawdust to clay, or 28% sawdust, 72% clay by mass). The result was better, but the mixture still had problems with bonding.

After all these samples, we also believe that the mesh size of our sawdust might be too big for the powder clay that we are using. The sieving was number 30, meaning the openings were 600 microns wide or 0.0234 inches (size 28 mesh). To alleviate this problem, we are going to try to make the mixture with a smaller mesh sawdust. Thanks to this analysis we now recognize the influence that size of the sawdust provides to the mixture.

For further testing of disks and bowls, different ratios were used for each experiment. The ratios used are mentioned in each experiment, but the basic procedure described here was still used. The specific kiln used was an Olympic Kiln, model129FLE/120 V. Contact information for Olympic is given below:

Phone: 800-241-4400; Fax: USA: 770-967-1196
Mailing Address: P. O. Box 1347, Flowery Branch, GA 30542
Physical Location: 4225 Thurmond , Tanner Road, Flowery Branch, GA 30542

10.6. Summary of Disk Properties

Disk Variables												
	RATIO						Diameter (cm)					
ID	Clay	Saw Dust	Mesh screen	Program Used	Dry Time (Hr:Min)	Observations	Before Diameter	After Diameter	% Shrinkage	Time to Empty (Hr:Min:Sec)	Volume Recovered (mL)	Flow (mL/hr)
1 disk	7	10	Mesh 9	4	37:16	Small Disk	7.35	7.35	0	N/A	N/A	N/A
2	7	10	Mesh 9	4	37:16	Flow rate pool	8.75	8.6	1.71428571	1:20:00	27 of 30	0.01575
3	7	10	Mesh 9	4	37:16	Flow rate pool	8.55	8.4	1.75438596	1:31:00	28 of 30	0.01846154
4	7	10	Mesh 9	4	37:16	Flow rate pool	8.5	8.45	0.58823529	N/A	N/A	N/A
5 disk	7	10	Mesh 9	4	37:16	Small Disk	7.35	7.3	0.68027211	N/A	N/A	N/A
1 disk	8	15	Mesh 9	4	37:46	Disk Prototype	12.6	12.4	1.58730159	N/A	N/A	N/A
2 disk	8	15	Mesh 9	4	37:46	Disk Prototype	12.4	12.3	0.80645161	N/A	N/A	N/A
3	8	15	Mesh 9	4	37:46	Flow rate pool	7.85	7.6	3.18471338	0:11:08	29 of 30	0.15628743
4	8	15	Mesh 9	4	37:46	Flow rate pool	8.15	7.8	4.29447853	0:11:45	28.5 of 30	0.14553191
5	8	15	Mesh 9	4	37:46		7.4	7.4	0	N/A	N/A	N/A
1 bowl	7	14	Mesh 28	4	37:32	Bowl Prototype	17.1	16.9	1.16959064	N/A	N/A	N/A
2 s.pool	7	14	Mesh 28	4	37:32	Small Pool prototype	6.2	6.15	0.80645161	N/A	N/A	N/A

3 s.disk	7	14	Mesh 28	4	37:32	Small disk prototype	6.9	6.8	1.44927536	N/A	N/A	N/A
4 b.disk	7	14	Mesh 28	4	37:32	Big Disk Prototype	12.95	12.85	0.77220077	N/A	N/A	N/A
	RATIO						Diameter (cm)					
ID	Clay	Saw Dust	Mesh screen	Program Used	Dry Time (Hr:Min)	Observations	Before Diameter	After Diameter	% Shrinkage	Time to Empty (Hr:Min:Sec)	Volume Recovered (mL)	Flow (mL/hr)
5 up pool	7	14	Mesh 28	4	37:32	Flow rate pool	7.45	7.4	0.67114094	0:40:54	28.5 of 30	0.04180929
6 dw pool	7	14	Mesh 28	4	37:32	Flow rate pool	7.3	7.3	0	0:40:03	28 of 30	0.04194757
1 sm Disk	7	14	Mesh 28	4	37:34	Disk Prototype	6.45	6.3	2.3255814	N/A	N/A	N/A
2 big disk	7	14	Mesh 28	4	37:34	Disk Prototype	12.6	12.5	0.79365079	N/A	N/A	N/A
3 Pool	7	14	Mesh 28	4	37:34	Flow rate pool	7.95	7.55	5.03144654	N/A	N/A	N/A
4 Bowl	7	14	Mesh 28	4	37:34	Bowl Prototype	16.95	16.8	0.88495575	N/A	N/A	N/A

10.7. Kiln Settings

Kiln Records					
Run	Description	Initial Temp (°F)	Final Temp (°F)	Time (Hours:Minutes)
1	Kiln treatment first run (It is necessary to secure the door)	70	1160	15:47
2	Kiln treatment second run	64	1160	16:34
3	Firing of the disks with ratio 6:6 (Sawdust:Clay)	69	860	16:45
4	Firing of the disks with ratio 6:7 (Sawdust:Clay)	67	860	16:43
5	Pools and disks ratio 10:7 (Sawdust:Clay)	62	1580	37:35
6	Prototype disks ratio 15:8 (Sawdust:Clay)	44	1580	37:46
7	Prototype disks ratio 14:7 (Sawdust:Clay)	76	1580	37:32
8	Prototype disks ratio 14:7 (Sawdust:Clay)	69	1580	37:34
9	Pools for bacteria test 10:7 (Sawdust:Clay)	64	1580	37:34
10	Pools for bacteria test 14:7 (Sawdust:Clay)	69	1580	37.17

References

1. World Health Organization, Fact Sheet N° 112, November 1996. http://www.water.org/assets/PDF/factsheet112.PDF
2. World Summit for Sustainable Development, Johannesburg South Africa, 4 September 2002.
3. UNICEF, Press Release, Oxford, 25 January 2005.
4. Domínguez, J.M. & I. Schifter. Las arcillas: el barro noble. Fondo de Cultura Económica. México, 1995.

Project Schedule:

Phase I: August 2005- May 2006

- Definition of vision, mission and strategy of KlarAqua as a non-profit organization
- Research clay/sawdust/colloidal silver ratios for maximally purification

- Research methods of application of colloidal silver (integration into filter before firing, brushing onto filter after firing, etc) for minimization of excess silver usage
- Design filter to reflect this research in light of cost-effectiveness and ability for local production
- Analysis of similar product housing design in terms of flow rate, leakage, lifespan and cultural relevancy
- Design of filter housing which reflects analysis results and meets KlarAqua's vision
- Development of partnership with University of Monterrey for in-depth, local market analysis and business planning
- Market evaluation and business plan development

Phase II: May 2006- August 2006

- Completion of product testing and bacterial analysis testing.
- Visits to Monterrey to assess the cultural and situational environment in Mexico.
- Development of educational tools and programs to increase water safety knowledge in potential communities with help from the University of Monterrey.

Phase III: August 2006- December 2006

- Incorporation and start of KlarAqua as a registered company.
- Pilot study and onsite evaluation of potential community.
- Expand the business using the proposed business plan.