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Low-Tech Water Treatment Facility

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ABSTRACT

A low-tech, economical and sustainable treatment system for the purpose of removing petroleum hydrocarbons from polluted water is necessary to reduce disease and promote the continued livelihood of indigenous people in the northeastern region of Ecuador. In order to achieve clean water without the use of modernized equipment, we propose a multi-stage system that collects water from a channel, provides flow through a Flocculation Chamber, settles out particulates, and removes petroleum hydrocarbons by filtering through Granular Activated Carbon.

I. INTRODUCTION

Based on the current water pollution crisis in the northeastern region of Ecuador, the construction and design of a water treatment plan that requires no electricity and is constructed using only materials local to the region it will be servicing. The plant should be low-tech because the target region lacks technological and financial resources. Also, due to its geography and insufficient infrastructure, transportation of resources from a foreign location is not a viable option. As a result, the best design will require no modern technology and have a high preference for locally available materials. The plant will be designed to produce 40 gallons per day of recreational grade water for each of 100 people, though with more research and testing, it may be feasible to produce drinking water as well. Even providing only recreational water will allow the people to drink what clean water they can from catchment systems, and use the water from this system for farming, bathing, etc.

II. BACKGROUND

Pollution Due to Drilling

From 1964 to 1992 Texaco extracted oil from the northeastern region of Ecuador, polluting the region with production water, waste oil, and drilling fluids. An estimated 18 billion gallons of waste water and 17 million gallons of waste oil contaminate the region in unlined pits that feed into the ground, ground water, and surface waters (T.R.A.G. 2008).

Affected Indigenous People

The indigenous tribes of the region rely on natural resources for survival, and many communities have been forced to relocate as a result of losing their farmland and livestock. In addition, the peoples face increased sickness from consumption of and bathing in the contaminated waters (Chevron Toxico, 2009).

Current Efforts for Clean Water

Thirty thousand members of the indigenous community filed a lawsuit against Texaco, a lawsuit that would settle at $27 billion. Unfortunately, the court case has been ongoing for over 15 years and it is likely that it will continue without result. Ecuador is a developing nation and does not have the expertise or money to remediate the region. As a result, any relief must come through charity or be self-created. The court appointed expert, Richard Cabrera, proposed three regional water treatment facilities requiring 400 km of piping, 20 years of construction, and over a half a billion dollars to complete (Cabrera, 2007). This proposal is not viable because it does not solve the immediate need for clean water, and it would not be favorable to create further infrastructure within the Amazon Rainforest. The indigenous people would view the water treatment infrastructure the same way they would the pipes that were installed by Texaco. In addition, many of the communities are nomadic and an infrastructure of piping could force the indigenous people to remain in one place for clean water.

In certain areas, the World Health Organization has constructed a few water catchment systems to supply drinking water. However, the volume of water produced is only sufficient for a few small communities.

III. CASE STUDY

The treatment facility described in this report is designed to produce an intended target of 40 gallons of water a day for each of 100 people. The facility has been designed using a particular river as a case study: the Rio Aguarico in the northeast region of Ecuador near Lago Agrio, the area central to the oil pollution. The Rio

Aguarico has an average discharge of $900\ m^3/s$ and an average speed of $2\ m/s$ (Buckalew, 1998).

Because we could not go to Ecuador and collect data on a specific site and community for the purpose of design and a better understanding of peoples' skill sets, we made a list of assumptions.

IV. ASSUMPTIONS

- The indigenous people have woodworking skills.
- They can fire clay to make tiles and pots if necessary.
- They can make rope for the pulley system.
- The system can function for 16 hours every day under the supervision of one or two indigenous workers.

V. METHODOLOGY

The following methodology shows the path we followed to create this project, realize our limitations, and produce a feasibility study given a large quantity of unknown information.

1. Researched in areas relating to Water Treatment, Low-Tech Filtration, Mechanical Design, Resources found in Ecuador, Community life in the affected region, Affects of Crude Oil on Water and People
2. Formulated preliminary system to help concentrate research
3. Visited a Water Treatment Plant to see how it operates and gain feedback from those who are experienced in water treatment.
4. Made sketch of system flow
5. Made cartoon of preliminary design layout
6. Decided on a local river on which to base calculations

7. Calculated necessary design parameters
8. Decided which parts of the design needed to be tested
9. Created test for GAC filtration
10. Sent sample to lab for results
11. Further evaluated design

VI. FORMULATION

Based on our initial assumption of 40 gallons per day for 100 people, the target output of water from the waterwheel was determined in the following manner:
One gallon of water is approximately equal to 0.03785 cubic meters.

$$1\ gallon =\ .0037854\ m^3$$

From there, the total number of gallons/day is calculated.

$$100\ people * 40\ gallons = 4000\ gallons$$

No efficient system is designed without losses. This project assumes about 20% of total water losses in the system due to spillage, friction, and evaporation. The result is that a greater volume of water per day will need to be pumped. This calculation is shown below.

$$4000\ gallons * 1.2\ (for\ losses) = 4800\ gallons$$

In terms of rate, the system is decided to operate 16 hours of the day. Dividing the total gallons needed per day by the hours of operation yields a target hourly rate of water volume going into the system by the waterwheel component.

$$\frac{4800}{16}\ gallons\ per\ hour = 300\ gallons\ per\ hour$$

Water Tank

Settling takes 30 minutes, and with a buffer of 10 minutes for equipment movement etc., 20 minutes are left.

$$\frac{300}{20}\, gallons\ per\ minute = 15\ gallons\ per\ minute = .25\ gallons\ per\ second$$

For calculating the volumetric flow rate, 0.25 gallons/sec is multiplied with .003785 m3/gal to get m3/s as shown below.

$$Q = \ .25\frac{gal}{s} *\ .0037854\frac{m^3}{gal} = .00094635\frac{m^3}{s}$$

The following equation and constants can be rearranged to find the height of the water in the tank from the center of the rounded outlet. In this design, the outlet rests on the bottom of the tank.

$Q = c_o A\sqrt{2gH}$

$c_o = c_c c_v$ (established coefficients corresponding to an exit hole that is rounded)

$c_c = 1\ c_v = .98\ c_o = .98$

$A = \frac{\pi}{4}D^2$ (area of the outlet hole)

$D = \ .02\ m$

$$H = \frac{\left(\frac{Q * 4}{C_o * \pi * D^2}\right)^2}{2 * g}$$

$H = .482\ m$

$Water\ Depth = \ .482m + .01m = .492\ m$

Settling Tank

We do not know how much flocculent will be added to the water because we do not know what will be used as the flocculent. Because of this, we assume that there will be a 20% addition to the volume of the water as shown in the calculation below.

$$300\ gal * 1.2\ (addition\ of\ flocculant) = 360\ gal$$

To find the dimensions of the settling tank, we converted from gallons to cubic meters and picked reasonable dimensions given the nature of the tank. These calculations are shown below.

$$360\ gal * \ .0037854\frac{m^3}{gal} = 1.36\ m^3 = 2.78\ m * .71\ m * .71\ m$$

$$1.36\ m^3 + 40\ gal\ leeway = 1.51\ m^3 \approx 3\ m * \ .71\ m * .71\ m$$

We then calculated the distance that the outlet spout should be from the bottom of the tank. The calculation is shown below.

$$2.773\ m * .25\ (for\ sludge\ plus\ 5\%\ assurance) = .7\ m$$

The following equation reuses the flow equation above to solve for the diameter needed to achieve the desired outflow from the settling tank.

$$Q_{s,out} = \ .00094635\frac{m^3}{s} * 2\ \left(to\ acheive\ 30\frac{gal}{\min}\right) = .0018927\frac{m^3}{s}$$

$$D = \sqrt{\frac{Q * 4}{.98 * \pi * \sqrt{2 * g * H}}} \approx 2\ cm$$

VII. DESIGN DECISIONS

The facility design includes a Water Tank to provide constant flow, 4 Flocculation Chambers, 4 Settling Tanks, a Granular Activated Carbon (GAC) Filter, and a Lined Reservoir. In addition, a pulley system powered by a waterwheel provides the Water Tank with a water supply greater than its outflow. A full-scale system with only 1 Flocculation Tank and 1 Settling Tank is shown below. The means for adding flocculent is not shown.

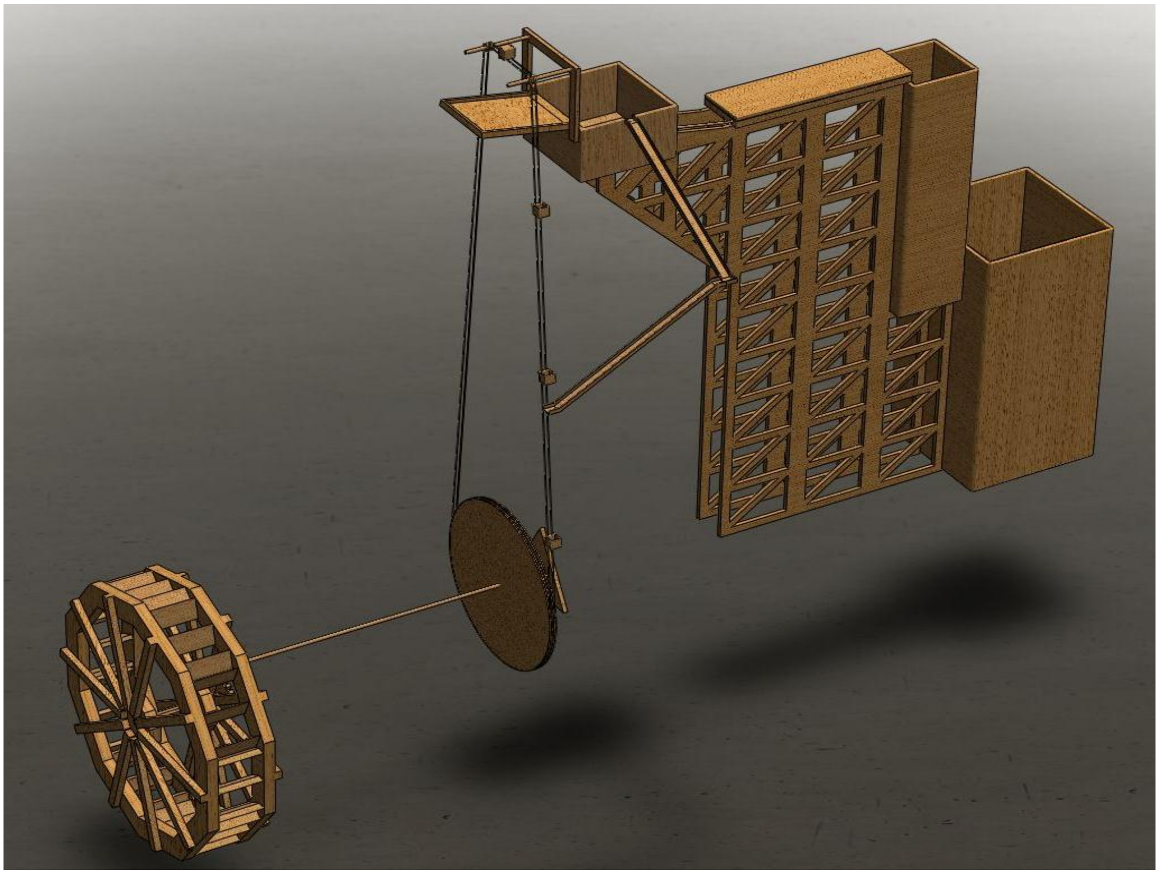


Figure 1: Full Scale Treatment Plant

Water from the Water Tank will flow into a Flocculation Chamber for twenty minutes with flocculent mixing into the water through a funnel above. The water will then be directed to the second Flocculent Tank and so on. The flocculent tank will dump the water and sludge into a Settling Tank. After 30 minutes of settling, the spout on the settling tank will be opened to allow the water to pour into the GAC filter. The water will filter through and pour into the Lined Reservoir. The specifications of each of the components of the facility are included below.

Water Tank

- _.6 m tall * 1 m wide * 1 m long_ (internal dimensions)
- Overflow channel located $.5\ m$ from floor of tank
- Rounded hole outlet $2\ cm$ in diameter resting on floor of tank
- Screens fixed in the channel from Water Tank to Flocculation Tank will be needed to reduce speed
- Large corked hole for cleaning on floor of tank (size does not need specification.)

Flocculation Tank

- Enclosed system $inlet\ 2\ cm * 2\ cm, outlet\ 4\ cm * 50\ cm$
- $2\ m\ long *\ .5\ m\ wide * .04\ m\ tall$ (internal dimensions)
- Internal channels $.04\ m\ wide$
- 31 internal slats $2\ cm\ wide * 3\ cm\ tall * 46\ cm\ long$
- Alternating slats attached to roof
- Alternating slats attached to base
- Roof slats secured also to one side of tank
- Base slats secured to opposing side of tank

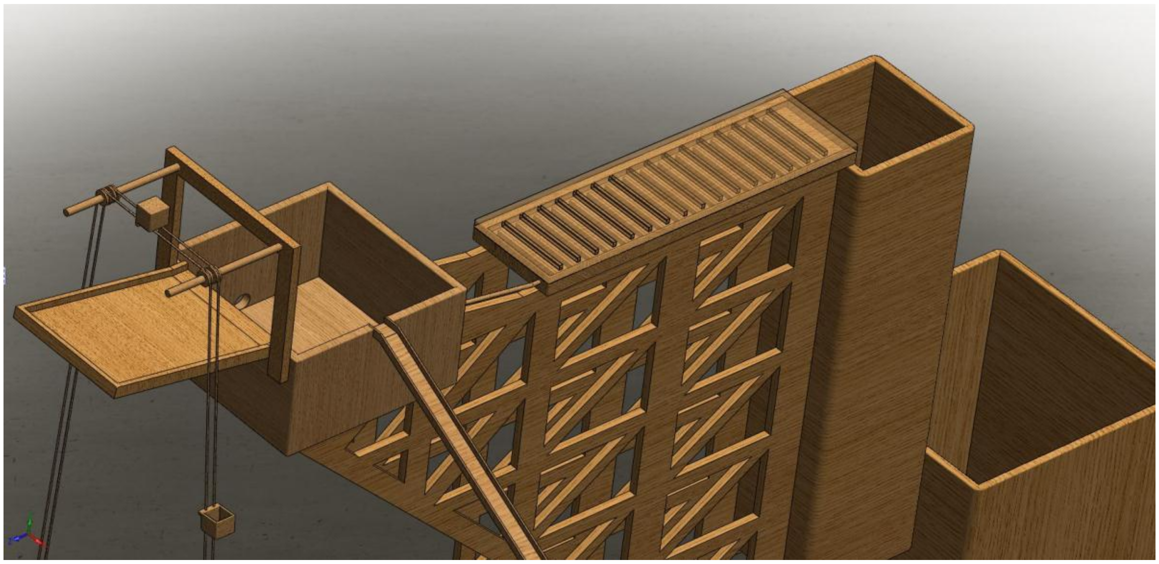


Figure 2: Close-up of Flocculation Chamber with Transparent Cover

Figure 2 shows a how the Flocculation Chamber would look if the top was transparent. The flocculent to be used is currently unidentified. It is preferable that a plant similar to the moringa seed of Africa (Senall, 2007) be used. Added flocculent volume is estimated at 20%, assuming a max sludge allowance of 20% and a 100% flocculent to sludge conversion. The proposed flocculation system is shown in Figure 2 above.

Settling Tank

- $3\ m\ tall * .71\ m * .71\ m$ (internal dimensions)
- Assumed water/sludge height $2.77\ m$
- Spout located $.7\ m$ from base of tank, $2\ cm$ in diameter
- Large spout located at base of tank for cleaning. Size specification not necessary.

GAC Tank

- $3.1\ m\ tall * 1.5\ m * 1.5\ m$ (internal dimensions)
- GAC is $2\ m$ high from clay tiles
- Clay tiles with tiny holes $.1\ m$ from bottom of tank
- Outlet of $1.5\ m * .1\ m$ into in-ground, wood-lined reservoir

VIII. WATER RETRIEVAL

Throughout history, various technologies have been developed to utilize hydropower. This power can then be used for irrigation or operating machinery. One of the most well known developments in hydropower is the water wheel. Current hydro turbines are a result of water wheel development. Initially, water wheels were used to divert water from a river or flowing body of water for irrigation. As this technology developed, water wheels were later used as power converters to grind grain, saw wood, and power textile mills (Cech, 2005). Continuing in the low-tech theme of this paper, we investigated types of water wheels, their efficiencies, and their feasibility in a location of unknown elevation and large environmental change from season to season (flooding), as is the case with many of the rivers in Ecuador.

While there are no shortcomings of innovative designs and modifications, waterwheels usually fall into three basic categories. The categories are overshot, breast shot, and undershot waterwheels. As one might expect, the naming comes from the level at which water enters the wheel, be it from the top, from the side (axis level), or from the bottom (Muller U. G., Performance). These categories are discussed in detail below.

Overshot wheels, as one would expect, harness the most out of potential energy from "falling" water that enters buckets near the top of the wheel on one side, making it “heavier”. Elevation differences and gravitational pull are the main driving force of overshot waterwheels. This wheel is considered highly efficient because most of the potential energy is harnessed. Overshot waterwheels are suitable for settings with high head (elevation) differences and a low volumetric flow. Variations of this wheel include the back shot wheel (water turns the wheel backwards once it hits the wheel from the top) (Denny, 2005). Generally speaking, these are most desired when enough head is available.

Breast shot waterwheels have water entering the wheel at approximately the axis level. The diameter of these wheels is twice the height from the water entry level. This type of waterwheel harnesses both the potential (slight height difference) and kinetic energy (due to flowing water) of the river/channel (Muller, 2004). Breast shot waterwheels require high volumetric flow rates to operate in an efficient manner.

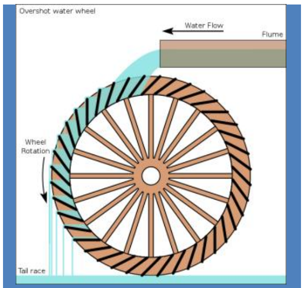
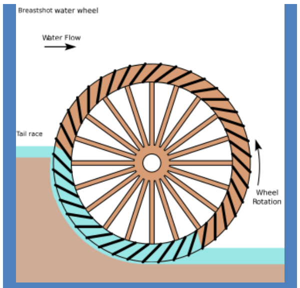
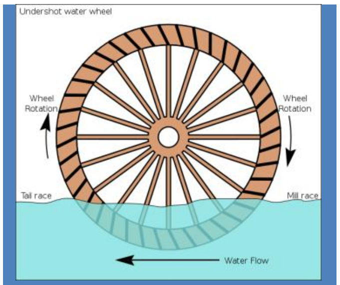
The last variation of waterwheel is the undershot type. These types of wheels have water “pushing” the blades from the bottom. Although regarded as the most inefficient, undershot waterwheels have no head requirement. Furthermore, they are the simplest type to construct and maintain. Initially, they were designed as impulse wheels but further experimentation further increased overall efficiencies by grasping potential energy in water that is slowing down (by gate or channel control). This is reflected in the Zuppinger design (Denny, 2005).

Much research has been done to boost efficiencies of waterwheels. One aspect found to have a great effect on overall efficiency is having a controlled inflow. For example, having a gate with a weir ensures a laminar flow that further reducing turbulence. Another example would be controlling the angle/position of where the water hits the blade. Furthermore, research shows that having a controlled outflow (inclined tailrace) further increases efficiency. Finally, blade analysis can be done but this is outside the realm of this project (Muller, Water Wheel).

Due to the lack of information available from the region, we constructed a selection matrix. Table 1 is intended for aiding in the selection of a waterwheel type based on variables available in the environment (head, volumetric flow, etc.) and each type's advantage/disadvantages. For example, if the region has sufficient head (elevation of water), then the optimal waterwheel type would be the overshot design. Another important aspect one might look at is the available volumetric flow in the channel. If it is abundant then the undershot wheel is plausible. The darker highlighted boxes denote the most optimal situations for each of the 3 main variables. Finally, summary of these considerations are listed at the bottom.

Table 1: Decision Matrix for Water Wheel Design

	Overshot	**Breast Shot**	**Undershot**
Head Range:	2.5-10 meters	1.5-4 meters	0.3-2.5 meters (Low Head)
Volumetric Flow Range:	0.1-0.2 m3/s per meter width	0.3-0.65 m3/s per meter width	0.5-0.95 m3/s per meter width
Order of Efficiency:	1	2	3
Highest Reached Efficiency:	~87%	~87.3%	~77%(Zuppinger)
Most Efficient with following Controlled Inflows:	N/A (Due to fully harnessing elevation potential difference).	40%<Q_target<60% of Qin	50%<Q_target<100% of Qin
Variations:	Backshot		Zuppinger/Poncelet
Advantages	Low flow, highly efficient, harnesses most potential.	Preferred for low head, high volume flows	No head requirements, rather simple construction, can be installed on

			floating platforms.
Disadvantages	Intended for constant flow, requires high head, harder construction.	Requires trash rake	Increasing efficiency requires controlled inflows (harder construction)
Picture			

In terms of this project, the Undershot Zuppinger would most likely be the best water wheel design for the purpose of our system. There is unlikely to be a large elevation change to allow for the use of an Overshot wheel. In addition, the Undershot Zuppinger water wheel is simple to construct, requires no wheel walls, employs simple curved blades, operates efficiently in a large range of flow, and requires only a fraction of the volumetric flow the case study river can provide.

IX. WATER WHEEL DESIGN PARAMETERS

- "Backwards" inclined curved blades
  - Offset blades to -30deg from radius
  - Lower portion curved to 60deg arc w/ Radius=Head
- Operates best in head differences of 1-2m(3.28-6.56ft)

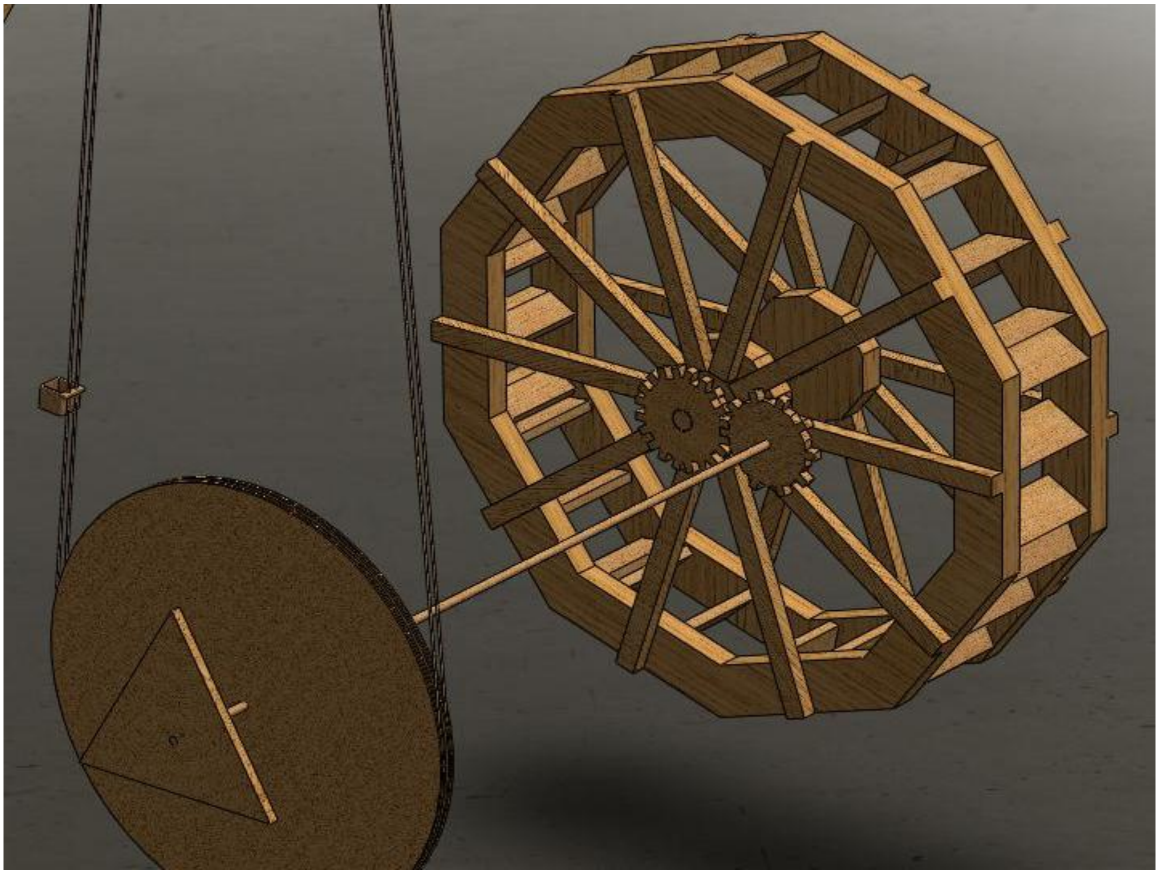


Figure 3: Sample Water Wheel Construction

The water wheel will use gears to power a pulley system that will continuously transport water in buckets to the Water Tank. Figure 3 shows a simple water wheel construct powering a pulley system.

X. TESTING

The GAC filtration process is the only process that actively removes Total Petroleum Hydrocarbons (TPH), so we felt that it was the only test we needed to perform. The flocculation process would likely remove a minor level of TPH that adheres to particles, but otherwise only improves water clarity. If not, chemicals will be needed, or the system can function without increasing clarity. All the equations for water flow are ideal, but the daily amount of water planned for is increased by 20% to account for any losses throughout the system.

To test the GAC filtration we cleaned an $8\ ft. long * 1\ in\ diameter$ PVC pipe and filled it 6.5 *ft. high* with fish tank GAC. The bottom end of the PVC was covered with tinfoil, secured with elastics, and poked with a pin to make several tiny holes. Figure 4 below shows the pipe and tinfoil set up.

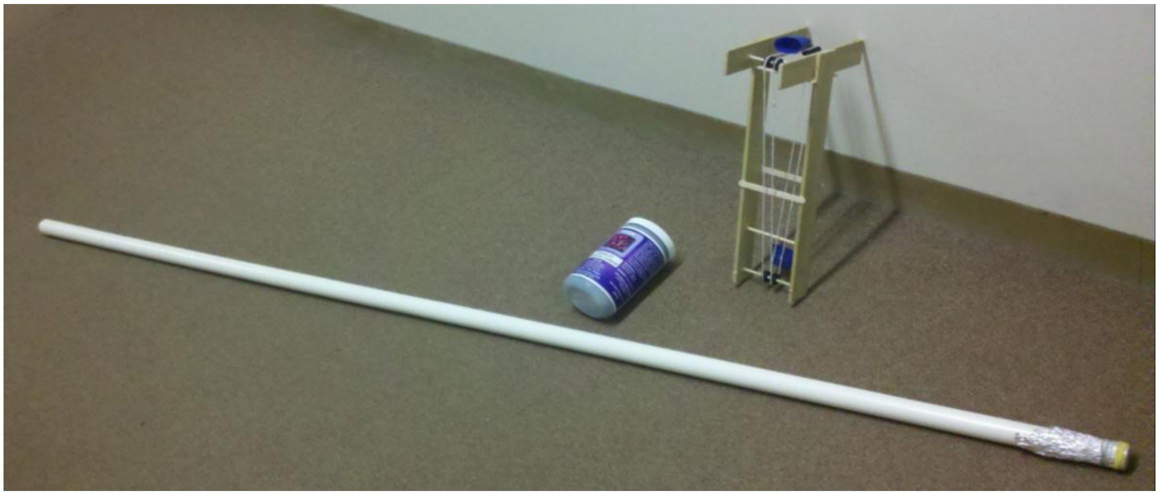


Figure 4: GAC Test Set Up and Mock Pulley System

We created contaminated water by mixing TPH 100 mg of petroleum hydrocarbons provided by the lab into tap water. The combined volume was 1 liter with pollution equivalent to 100 ppm. We then slowly poured the contaminated water through the GAC and collected the filtered water at the bottom. The filtered water was then sent to Microbac Labs to be tested using the EPA1664A method.

Results

The resolution of the test was 5 mg/l. The results showed that there was less than 5 mg/l TPH left in the sample. This value is equivalent to less than 5 ppm. This is a positive result because it shows the ability of the GAC to remove TPH, but the level of TPH in the initial sample, 100 ppm, was already at the standard for drinkable water in the United States and below the drinkable standard in Ecuador, 1000 ppm.

XI. SOURCES OF ERROR

There were many sources of error in this project. The largest source was our inability to obtain a polluted sample of greater than 100 ppm TPH. The polluted samples exhibited in the court case varied from 100ppm to 1000000ppm. In addition, due to cost we were only able to test one sample. Furthermore, when testing the sample, we did not prime the GAC by filtering clean water before sending the polluted sample through. This may have caused more TPH to be filtered by the dry GAC absorbing water. Our sample input did not equal the volume output.

XII. CONCLUSIONS

The results we have compiled are not conclusive enough to warrant immediate action, but the positive results shown warrant further research and testing. Given the results of our experiment and our background research we have determined that a low-tech water treatment facility could be created for the continuous removal of petroleum hydrocarbons from polluted water using local materials. We also conclude that a waterwheel powered pulley system could carry the continuous water supply needed to maintain the head required for the proposed water treatment system’s operation.

XIII. FUTURE RECOMMENDATIONS

The next steps for this project would include selecting a more specific community in the contaminated region, collecting a water sample from the region—or at least create a sample more closely representative of the actual contamination level—testing multiple samples through the GAC filter to evaluate consistency and longevity of the filtration medium, and investigating the necessity for flocculation as well as potential natural mediums for use as flocculent. Flow tests would also be necessary to evaluate realistic loss parameters and the necessity and usefulness of screens to impact flow velocity.

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