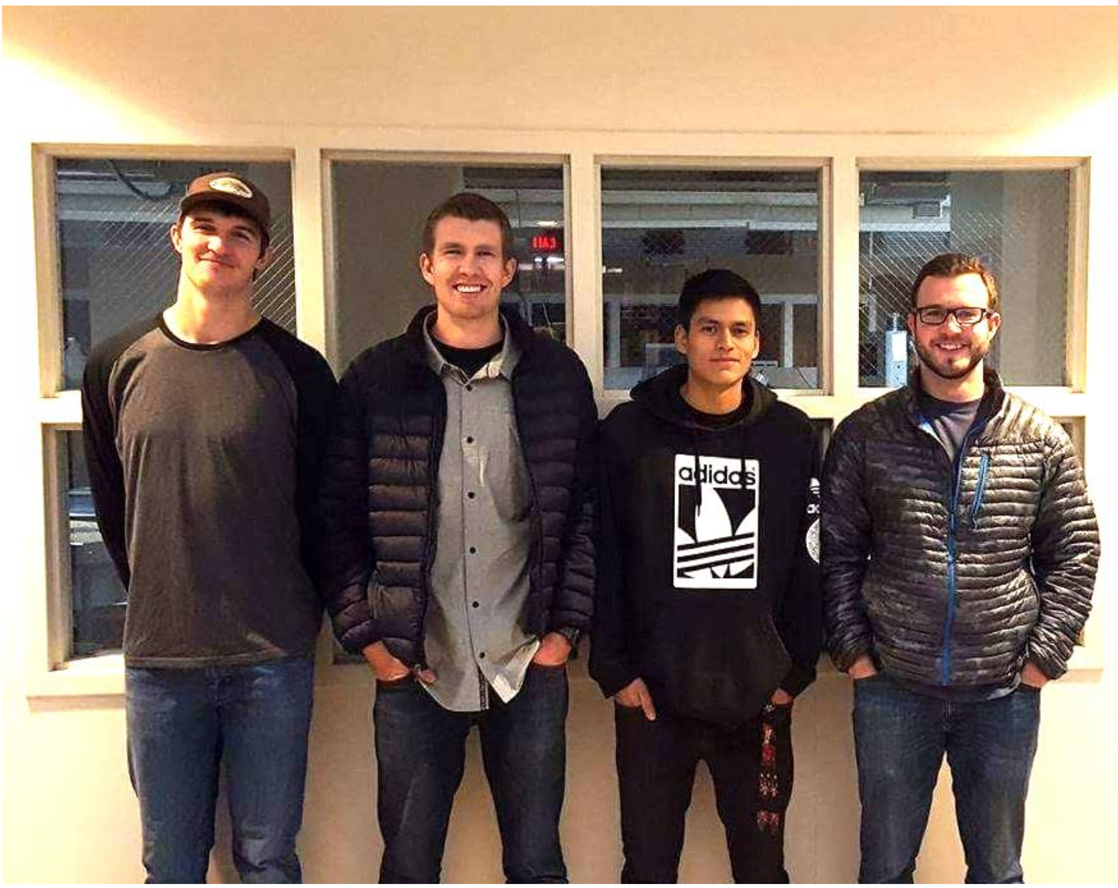
Dear University of Idaho Facilities,

Included is a final report on the water tower sediment project. The team with H2Only has been working hard to create an operational system that will solve the problem of sediment buildup in our water towers. We have considered your specifications and requirements and succeeded in meeting them. Included in this report is an executive summary of our project with the background and design process to back it up. Please note the many design considerations that have been used to arrive at the final product we have decided upon. We hope that you will be satisfied with our work and look forward to the implementation of the system.

Sincerely,

The H2Only Team

H2Only
The Sediment Solution



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Executive Summary

The team with H2Only has designed an automated sediment removal system for the University of Idaho chilled water tower. The university needed a solution that was more cost effective than the current method of sediment removal. The tank needed to remain operational while the cleaning occurred and any clean water that was reusable needed to be recycled. The system needed to be hands free in order to replace the need for technicians inside the tank. As sediment builds up in the bottom of the tank complications begin to occur throughout the entire system. Bacteria grows in the sediment while the deeper sediment can be resuspended and sucked through the piping system throughout the university. The system alleviates the need for divers and the draining of the tank on routine tank cleanings.

Our system will be implemented permanently in order to keep the tank clean at all times. Whenever the sediment builds up to a specific height a sensor will tell the system to engage and get rid of the buildup. A single rotation of a vacuum sweeper around a central post will clean the entire tank in one cycle. The vertical head in the tank due to gravity acting on the 87 feet of water creates a large pressure head at ground level. This pressure is used to create a vacuum through the pipes in the system as it is released into atmospheric pressure. This alleviates the need for a pump to move the sediment outside of the tank.

In order to get rid of the issue of tubes being tangled inside the tank a slip ring like device has been designed. It is intended to be mounted to the center support and allow the rotation of the sweeper without the need for flexible tubing. The slip ring will also act as a pivot for the suction arm, giving it a point of contact to rotate about. The slip ring will be sealed and strong enough to support the load applied to it.

The drive the sweep arm a single drive wheel will be attached to the very end, nearest the tank wall. A waterproof motor with a slow rotation rate will drive the wheel and thus swing the arm around the tank floor clearing the sediment off of the bottom. The wires to power the electric motor will be run down the arm and to the column where they will be harnessed and run to the control box on the exterior of the tank. From here, the technicians can make adjustments to the motor and monitor the cleaning cycles.

Background

The water towers in Moscow and across the nation are plagued by sediment build up. Bio-organisms as well as mineral deposits settle to the floor of these enormous tanks creating a layer of dark, slimy sediment. This creates a habitat for bacteria like E-coli to grow and thrive. When the sediment builds up deep enough it can be sucked through the water piping system and out to residential homes.

This is a problem that every water tower experiences and, to date, the solutions are largely impractical. The expensive removal process requires either draining the tank and flushing the sediment out or sending in a dive team with specific equipment to vacuum out the sediment. The University of Idaho spends hundreds of thousands of dollars per cycle when cleaning their tanks. This is a large sum of money that we believe can and should be avoided. A permanent and automatic system implemented in each tank would get rid of the need for continuous expensive cleaning. Once installed, the cleaning system could last for decades and pay off its initial cost within one or two cleaning cycles. The quality of water in the city of Moscow would also drastically improve.

The University of Idaho Facilities came up with and sponsored the project. They offered guidance and resources throughout the school year. Future implementation through the University of Idaho is likely.

Problem Definition

Our main goal was to create an effective, efficient system with the ability to clean the tank and a manufacturing and installment cost of less than one cleaning cycle. Our goals for the system are as follows: a system that removes the majority of the sediment with each cleaning cycle, sensors that detect the sediment level once it builds up to a certain point and the system automatically begins operation, a permanently installed system that requires little maintenance, a system that could separate the water and the sediment and return the clean water, and lastly a cost effective solution.

Our specifications for the small scale and full scale are as follows:

Small Scale

- Scalable to full scale dimensions
- Avoid resuspension
- Evenly distributed suction through slit
- Demonstrate proof of concept

Full Scale

- Remove 95% of sediment each time system operates
- Continue tank operation while cleaning
- External sediment separation and recycle of clean water
- Low level of necessary maintenance
- Fully automated operation

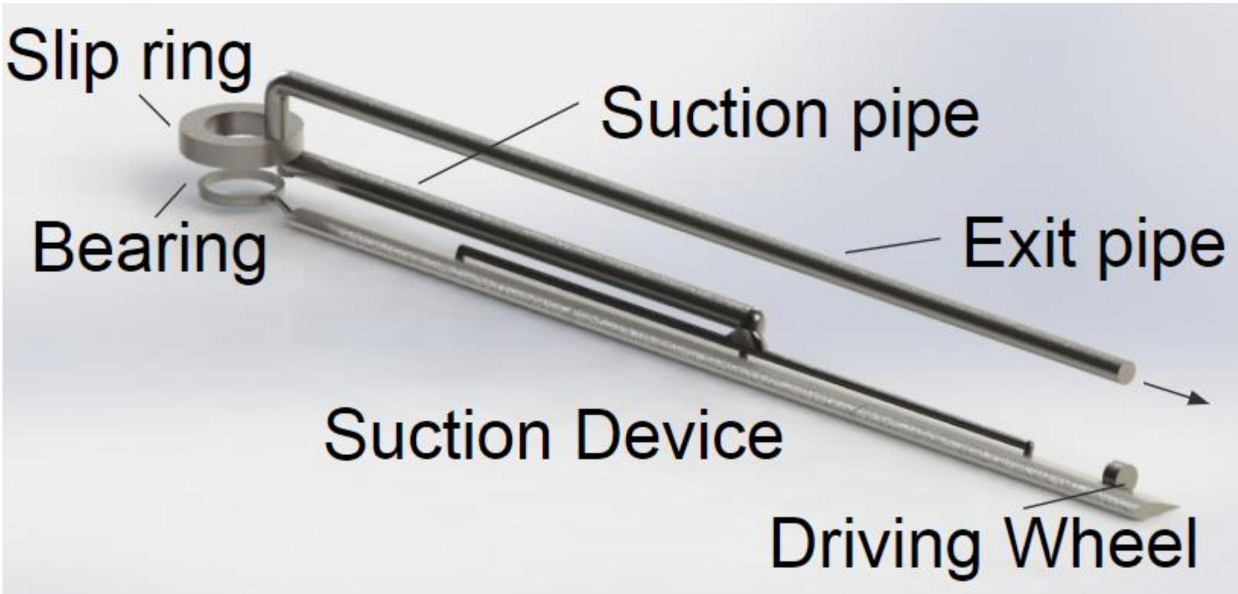
Concepts Considered

Initially we considered four designs: a full sweeping suction device, a vacuum on a lead screw, a diaphragm in the tank, and a suction device with multiple tubes. Below are a list of pros and cons we came up with when we decided on two possible solutions.

Device	Pros	Cons
Full Sweeping Suction Device	Complete removal with single armature rotation Minimal moving parts Simple design Inexpensive Low likelihood of complications	Minimized suction force due to large suction slit Inability to maneuver over and around obstacles Lack of suction control Possibility for clogging throughout system
Vacuum on Lead Screw	Can handle larger sediment buildups Large, localized suction force Potential to be very versatile Not as prone to internal buildup and clogging	Many mechanical parts Expandable tube Lengthy tank cleaning duration Inability to maneuver above and around obstacles Heavy steel lead-screw
Diaphragm in Tank	More localized suction High flow rates Turbulence would help loosen up sediment It would clean all tank areas	It would need a large frame to support it Costly to power the raising and lowering of the frame Material would be costly as well
Multiple Tubes	It could reach all the areas of the tank It would remove the sediment the fastest	Material would be costly for large tanks Costly to create all the suction needed for all the hoses

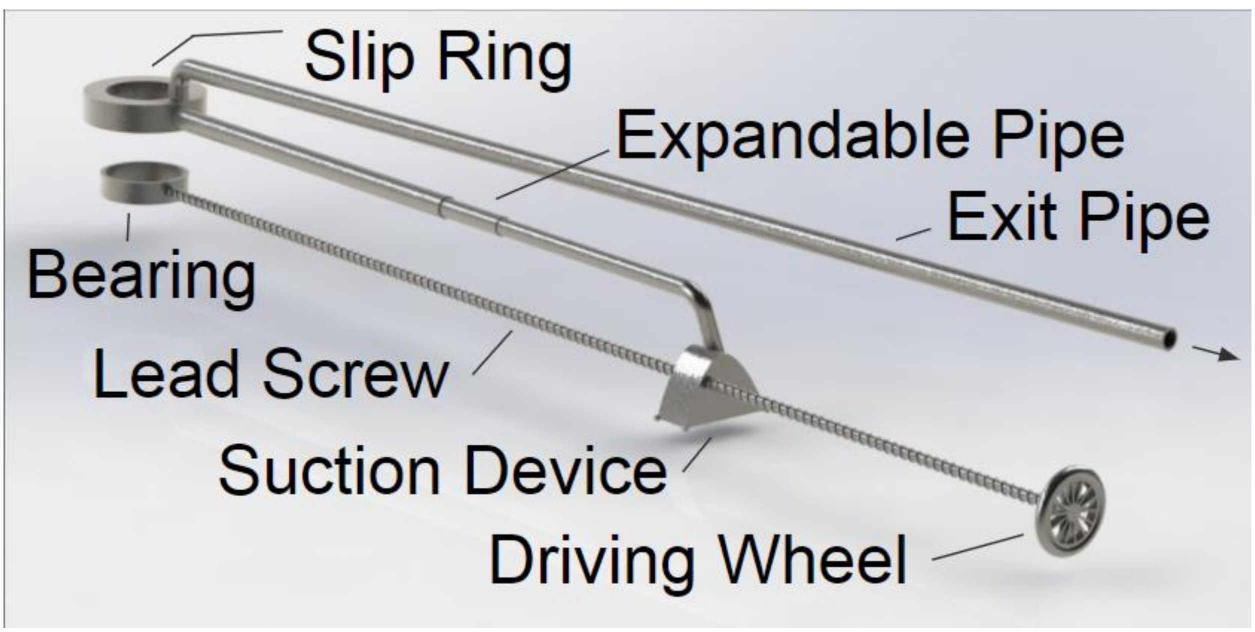
After going through the pros and cons of each design we decided to focus on the full sweeping suction device and the vacuum on a lead screw. After further evaluation we chose to pursue the full sweeping suction device because this proved to be the most practical to implement full scale.

Full Sweeping Suction Device



A sweep arm separated into three sections that spans the radius of the tank. The arm is driven by a wheel at its tip and incorporates our slip ring design.

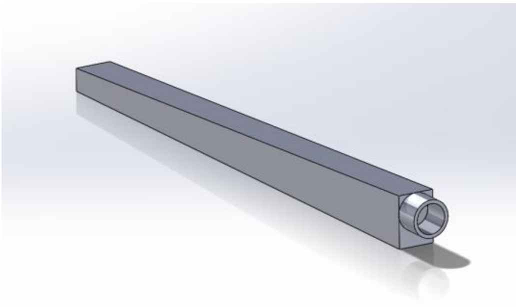
Vacuum on Lead Screw



A single vacuum head on a lead screw driven by a motor. As the lead screw moves around the tank the vacuum head moves normal to the tank diameter. This will act like a printer head as it displaces sediment from the bottom of the tank.

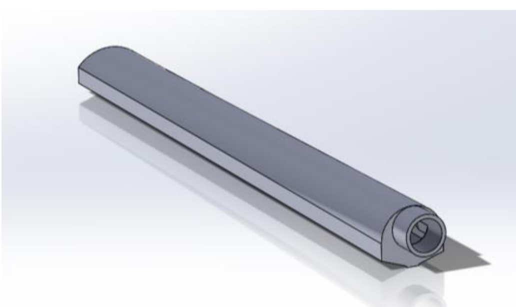
Sweep Arm Profile

Profile 1 (Rectangular cross section with flat bottom)



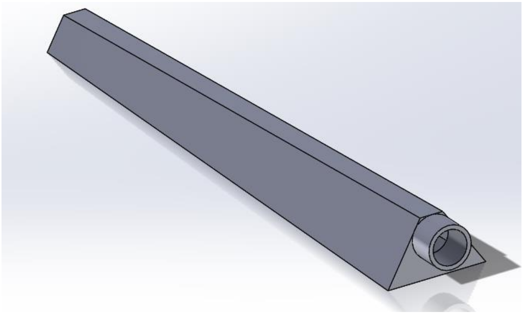
The rectangular sweeper utilized a flat bottom and tapered cross sectional area; largest at the hub and smallest at the tip. The taper was used to create a more even suction force throughout the length of the suction slit. The flat bottom was intended to create a flow field between the floor of the tank and bottom of the sweeper. The water moving through the channel would pull the sediment from the floor of the tank and into the suction device. This design would be the easiest to construct in house by University of Idaho facility employees because of its' square shape. This could be manufactured in many ways. For example, A piece of C channel welded to a flat plate would create a usable suction arm profile. Because the sweeper arm rotates so slowly around the tank turbulence and resuspension are not an issue. This means that creating a more aerodynamic shape is not necessary. In the prototype model, shoveling of sediment proved to be an issue with this simple design. Large piles of sediment would build up on the front face of the sweeper stopping the flow of water and sediment through a portion of the arm. Generally this occurred at the tip.

Profile 2 (semi-circle cross section with tapered bottom face)



Using our mathematical model we were able to distinguish that turbulence is not an issue with our system. This makes the semicircle cross section of this sweeper unnecessary. The tapered bottom however proved to work very well for removing sediment. The taper on the bottom face of the arm created a nozzle with the floor of the tank which increased water flow rate over the sediment and alleviated the shoveling issue we had with the rectangular sweep arm. The cross sectional area of this design is also tapered for more even suction throughout the length of the arm. This proved to be our most effective sweep arm.

Profile 3 (Trapezoidal cross section with flat bottom)



With initial tests proving that the trapezoidal sweep arm caused substantial shoveling and a lack of suction this design was not concentrated on much. However, our hypothesis was that the large flat face would cause an accelerated water flow in the channel between the floor of the tank and the bottom face of the sweep arm. Whether this is true or not was not proven during our experimentation. Further testing may show better results from this sweep arm profile. The cross sectional area of this sweeper was also tapered like the rectangular and semi-circle sweep arms.

After testing all three arms we conclude that the best sweep arm for the application would be a rectangular cross section with a tapered bottom face. This design incorporate the best attributes of all three sweepers. The rectangular cross section is easy to manufacture in house and the tapered bottom creates a nozzle that will create enough suction to remove the sediment.

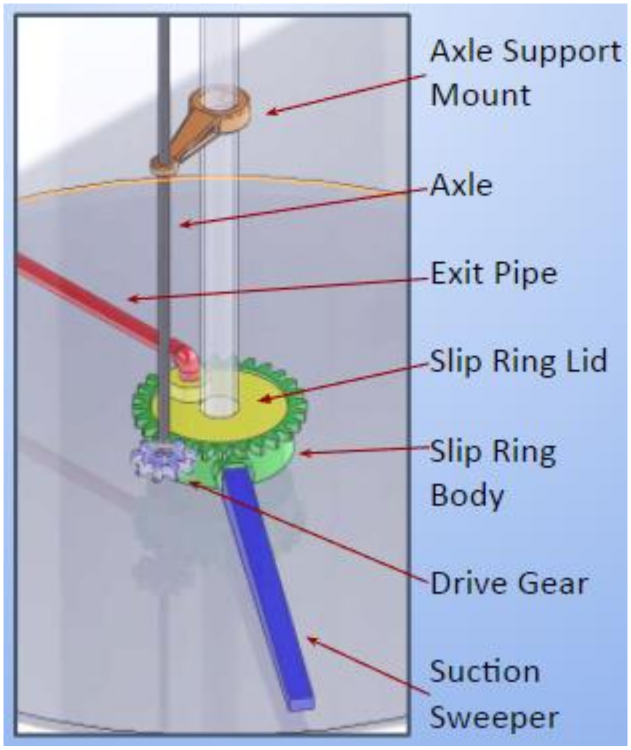
Concept Selection

We eliminated all of our concepts except for the sweeping suction concepts in our first meeting following our brainstorming meeting. In the following instructor/client meeting, we came to a joint decision to continue with the the full suction sweeper instead of the lead screw sweeper.

Later, during our testing, we determined that the best sweeper profile was the semi-circle cross section with the tapered bottom face. The cross section didn’t matter too much since our sweeper wasn’t rotating quickly enough to create turbulent flow, but the tapered bottom helped funnel the sediment towards the suction slit.

System Architecture

Our final design is made up of a suction sweeper that rotates radially around the bottom of the tank. There is a slit from the base to the tip of the sweeper that opens up into the hollow inside of the sweeper. The sweeper is connected to what we have decided to call a slip ring for lack of a better term. The slip ring is a central cavity that fits around the center pole and rotates with the sweeper. The lid of the slip ring is fixed to the exit pipe and does not rotate. A lip and lubrication seal the body and lid of the slip ring. There are gear teeth on the outer edge of the slip ring body that are driven by a smaller gear attached to an axle. The axle extends up to the top of the tank and is guided by supports that are connected to the center pole. At the top of the axle, a large gear is attached which is driven by a smaller gear that is connected to the stepper motor. The stepper motor is held in place by the motor mount, which sits on two of the three arms that hold the center pipe in place. The mount also connects into the hollow cylindrical center of the arms.

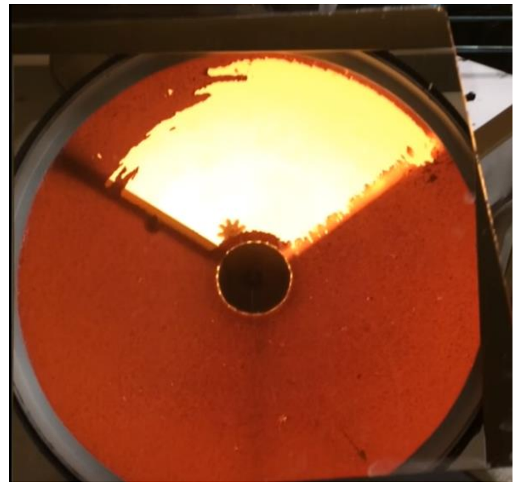


Design Evaluation

Methods

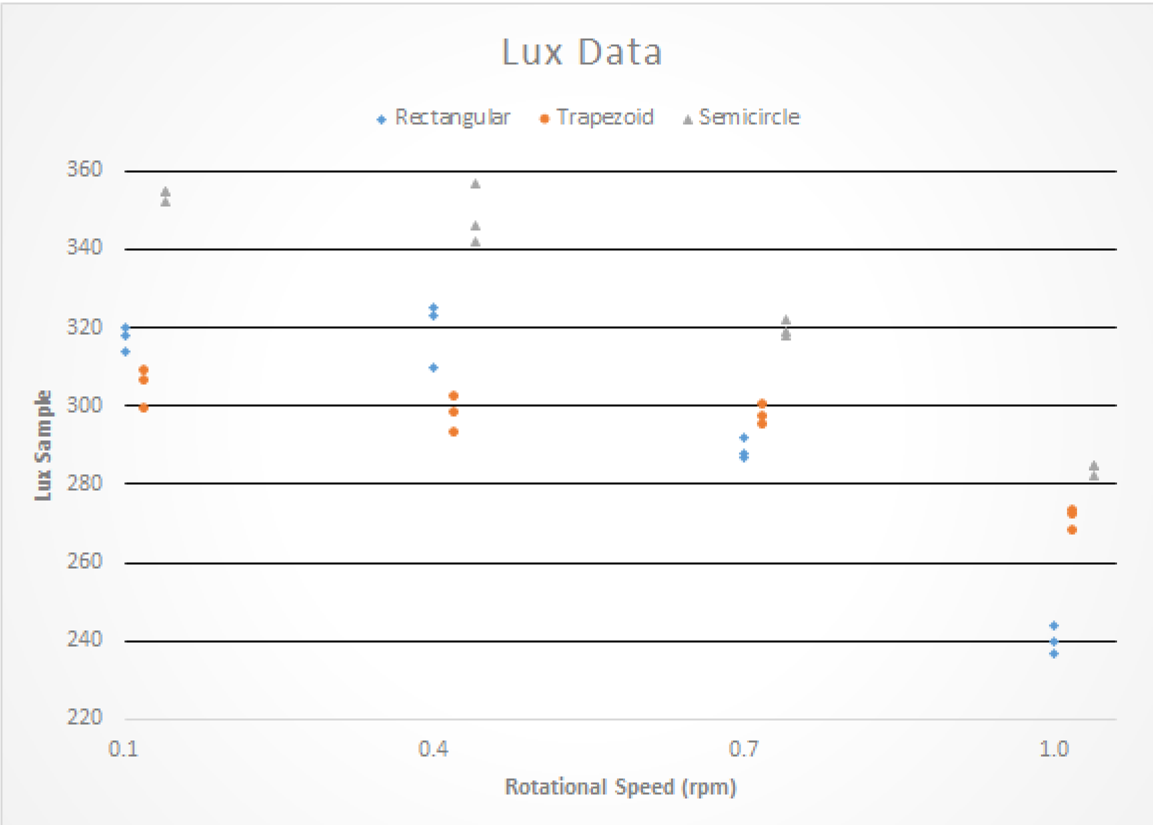
The testing apparatus was used to measure the amount of sediment that was removed from the tank in a single cycle. The equipment used was assembled as shown in Figure 3. From the bottom up, a Lux meter was attached to the end of a 2 inch diameter by 12 inch long piece of PVC pipe. A stopper was inserted 8 inches from the bottom of the pipe which was used to hold the test tube pictured. The test tube was wrapped in electrical tape in order to direct the light from the lamp through the water sample held in the test tube. When a sample was ready to be tested the test tube was inserted into the pipe, and the lamp was then used as a cap over the PVC pipe to direct the light through the water sample. The lamp was used to produce a constant light intensity for each sample measurement. The sediment absorbed and reflected some of the light passing through the sample which allowed the Lux meter to read the remaining amount of light. The varying amounts of passed light gave comparable data points between cleaning cycles.

First, a sample of clean water was tested to give an optimal Lux reading. A sample of dirty, pre-cleaning cycle water was then tested to give a lower limit lux meter reading. The sediment in the tank was then left for an hour to settle. Once settled, a cleaning cycle was run with a specific sweeper suction arm profile and rotational speed. After the cycle was complete the remaining sediment was suspended evenly throughout the water in the model tank and a third Lux meter reading was taken. This value represented the effectiveness of the cleaning cycle.



Results

Lux Data				
		Suction Sweeper		
		Rectangular	Trapezoid	Semicircle
Rotational Speed (rpm)	0.1	314, 320, 318	299, 306, 309	352, 355, 355
	0.4	310, 323, 325	298, 293, 302	342, 357, 346
	0.7	292, 288, 287	297, 300, 295	322, 319, 318
	1.0	240, 237, 244	268, 272, 273	285, 282, 285



Discussion

From the graph of lux data, it can be concluded that the semicircle sweeper design was the most effective at all rotational speeds. All of the designs had similar lux meter readings for a rotational speed of 0.1 rpm and 0.4 rpm. The trapezoid design had similar readings for a rotational speed of 0.1 rpm, 0.4 rpm, and 0.7 rpm. The optimum speed for these constant lux meter readings would be the fastest rotational speed, because if the suction sweeper rotates faster, the cleaning cycle will be completed faster and less water will be removed from the tank. When the rotational speed was increased further, the lux meter readings began to decline. This was because the rotational speed of the sweeper was moving too fast so the sweeper did not have enough time to remove all of the sediment and patches of sediment were left in areas. These conditions were not optimal because the most important parameter is sediment removal.

Conclusions

Test results showed that the most effective suction sweeper arm was the semi-circle cross section with a tapered bottom. This shape resulted in the most amount of sediment removed proven by a higher average Lux meter reading at every rotation speed. The effective cleaning cycle was due to the tapered bottom creating a nozzle with the floor of the model tank. This created an increase in water velocity over the sediment resulting in a larger shear stress on the sediment. The rectangular and trapezoidal suction arms created an even suction across the sediment and a potential increase in flow friction. Flow friction decreased the water velocity over the sediment decreasing suction effectiveness. A similar issue with the rectangular and trapezoidal suction arms was a shoveling effect which would create a buildup of sediment on the front face of the arm and result in a clog. The nozzle on the tapered arm alleviated this issue.

While varying the rotational speed of each design, it was determined that 0.4 rpm was the optimal speed to rotate the sweeper. As the sweeper was continually operated further above 0.4 rpm, the Lux meter readings began to diminish. This was due to insufficient suction over the period of time the sweeper was in a certain area. The suction can also be increased by increasing the amount of head, but that results in removing more water from the tank.

To move forward a tapered suction sweeper should be utilized for maximum effectiveness. A rectangular top and side walls would be implemented for ease of construction. The optimal rotation speed of 0.4 rpm would be used to create the most effective suction sweeping arm system.

Future Work

To move forward with this project there are --- main things to concentrate on. The sweeping device needs to be altered from the prototype design for full scale implementation. The suction slit in the bottom face of the sweep arm should be optimized for even suction throughout its length. A separator should be designed and tested to separate the water from the sediment in an external unit. The slip ring should be designed at full scale to avoid leakage and be easily installed within the tank.

Suggestions

- Install a motor on the tip of the full scale sweeper, or utilize the head pressure to rotate the sweeper (water wheel attached to actual wheel)
- Use either a centrifugal hydrodynamic separator or an external tank to separate the sediment from the water. In the external tank, the sediment could be allowed to settle and the water could be sucked off the top of the tank, or the water could be evaporated (boiled) and the sediment would be left behind.
- Use tapered bottom on sweeper to avoid shoveling sediment.
- Linearly decrease cross sectional area of sweeper from pivot to tip.
- When manufacturing sweeper arms, use rectangular cross section with a tapered bottom face. This will be the easiest to manufacture in house and create the best suction result. When manufacturing, welding two pieces of purchasable metal C channels or angle iron lengths will create the desired shape. Possible combinations include: C channel and flat plate, two pieces of equal length angle iron with a tapered inside cross sectional area, C channel and a piece of angle iron to create tapered cross sectional area. The excess material should be trimmed off after the suction arm has been constructed.

Appendices

EES Code

```
"H_2_Only Sediment Cleaning Model Tank"
"Known Variables of Model Tank"
f$='Steam_iapws'
T=70
x=0
L_in=8*convert(in,ft)
W_in=1/16*convert(in,ft)
D_out=3/8*convert(in,ft)
D_2in=3/16*convert(in,ft)
H_mtank=18*convert(in,ft)
D_mtank=23*convert(in,ft)
g=32.174
g_c=32.174
rho=density(f$,T=T,x=0)
mu=viscosity(f$,T=T,x=x)*convert(lb_m/(ft*h),lb_m/(ft*s))
gamma=rho*g/g_c

"Known Variables of Actual Tank"
H_tank=88
D_tank=67

"Head needed to scale to actual tank"
H_tank/D_tank=H_mneed/D_mtank
"H_p=H_mneed-H_mtank"

"Center Post Diameter Needed for Model Tank"
D_ctank/D_cmodel=D_tank/D_mtank
D_ctank=2

"If out model hose was scaled to larger model"
D_tank/D_mtank=D_outtank/D_out

"Outlet diameter for 6 inch actual tank scaled to model"
D_tank/D_mtank=6[in]/D_outtanktmodel

"Inlet and outlet area"
A_in=L_in*W_in
A_2in=2*pi*D_2in^2/4
A_out=pi*D_out^2/4

"Volume of model tank"
Vol_mtank=pi*D_mtank^2/4*H_mtank
Gal_mtank=Vol_mtank*convert(ft^3,gal)

"Mass and Volumetric flow rate"
m_dot_in=rho*A_in*V_in
m_dot_out=rho*A_out*V_out
Vol_dot=m_dot_in/rho*convert(ft^3/s,gpm)
m_dot_in=m_dot_out
P_bottom=rho*g*H_mtank/g_c""*convert(psf,psi)
```

```
"Finding pipe friction"
R_e=rho*V_out*D_out/mu
epsilon=0.01*convert(mm,ft)
f=moodychart(R_e,epsilon/D_out)
f_T_2in=0.25/(log10(epsilon/D_2in/3.7))^2
f_T_tube=0.25/(log10(epsilon/D_out/3.7))^2
L=10

"Finding velocity in 2 inlet pipes"
Vol_dot*convert(gpm,ft^3/s)=A_2in*V_2in

"Bernoullis Eq Top of tank to outlet"
P_top/gamma+V_top^2/(2*g)+z_top"+H_p"=P_out/gamma+V_out^2/(2*g)+z_out+(f*L/D_out+K_exit+K_ent)*V_out^2/(2*g)+(2*K_elb_2in+K_branch)*V_2in^2/(2*g)
V_top=0
P_top=0
P_out=0
z_top=0
z_out=-7
K_exit=1
K_ent=0.5 "guess for now"
K_elb_2in=30*f_T_2in
K_branch=C*(1+(y_b/beta_b^2)^2-2*(1-y_b)^2-2*(y_b/beta_b)^2)
C=.55
beta_b=0.5
y_b=0.5

"Bernoullis Eq Top of tank to top of tube to test for cavitation"
 P_top/gamma+V_top^2/(2*g)+z_top"+H_p"=P_v/gamma+V_v^2/(2*g)+z_v+(f*L/D_out+K_exit+K_ent)*V_out^2/(2*g)+(2*K_elb_2in+K_branch)*V_2in^2/(2*g)
V_v=V_out
P_v=(p_sat(f$,T=T)-14.7[psia])*convert(psi,psf)

"Sediment Dimensions"
Vol_sed=(H_sed*pi*D_mtank^2/4)
H_sed=1/8*convert(in,ft)
P_in/gamma+V_in^2/(2*g)+z_in=P_out/gamma+V_out^2/(2*g)+z_out
z_in=0

"Power eqations of pump"
"hp=m_dot_in*g/g_c*H_p*convert(lb_f*ft/s,hp)"
```

Solution

Main

Unit Settings: Eng F psia mass deg

A_{2in} = 0.0003835	A_{in} = 0.003472 [ft^2]	A_{out} = 0.000767 [ft^2]
β_b = 0.5	C = 0.55	D_{2in} = 0.01563
D_{cmodel} = 0.05721 [ft]	D_{ctank} = 2 [ft]	D_{mtank} = 1.917 [ft]
D_{out} = 0.03125 [ft]	$D_{outtank}$ = 1.092 [ft]	$D_{outtankmodel}$ = 0.1716 [in]
D_{tank} = 67 [ft]	ε = 0.00003281 [ft]	f = 0.03087
f$ = 'Steam_iapws'	$f_{T,2in}$ = 0.02373	$f_{T,tube}$ = 0.01987
g = 32.17 [ft/s^2]	Gal_{mtank} = 32.37 [gal]	γ = 62.3 [lb$_f$/ft^3]
g_c = 32.17 [lb$_m$*ft/(lb$_f$*s^2)]	H_{mneed} = 2.517 [ft]	H_{mtank} = 1.5 [ft]
H_{sed} = 0.01042 [ft]	H_{tank} = 88 [ft]	K_{branch} = 1.375
$K_{elb,2in}$ = 0.7118	K_{ent} = 0.5	K_{exit} = 1
L = 10 [ft]	L_{in} = 0.6667 [ft]	μ = 0.0006552 [lb$_m$/(ft*s)]
$\dot{m}_{in}$ = 0.2089 [lb$_m$/s]	$\dot{m}_{out}$ = 0.2089 [lb$_m$/s]	P_{bottom} = 0.6489 [psi]
P_{in} = -418.5 [psf]	P_{out} = 0 [psf]	P_{top} = 0 [psf]
P_v = -2064 [psf]	ρ = 62.3 [lb$_m$/ft^3]	R_e = 12989
T = 70 [F]	$\dot{Vol}$ = 1.505 [gpm]	Vol_{mtank} = 4.328 [ft^3]
Vol_{sed} = 0.03005 [ft^3]	V_{2in} = 8.743 [ft/s]	V_{in} = 0.9656 [ft/s]
V_{out} = 4.371 [ft/s]	V_{top} = 0 [ft/s]	V_v = 4.371 [ft/s]
W_{in} = 0.005208 [ft]	x = 0	y_b = 0.5
z_{in} = 0 [ft]	z_{out} = -7 [ft]	z_{top} = 0 [ft]
z_v = 26.14 [ft]		

DFMEA

Description of component, subsystem, or function	Symptom (what?)	Effect (so what)	Failure mode (why?)	Probability of failure	Severity of effect	Risk priority	Remedial action
Suction Path	Flow rate is decreased	Suction is decreased	Suction getting clogged with sediment	2	3	6	Use pump to add pressure to lines
Slip Ring	Resists rotation	Slower rotation speed/ no rotation	Friction in slip ring	2	2	4	Add lubrication
Axle	Gears don't line up	No rotation	Supports on axle fail	3	4	12	Add more supports
Suction Sweeper	Reduced sediment removal	Uneven suction	Deflection	1	2	2	Sand down male connection
Gears	Uneven rotation	Focused areas of suction	Gear tooth breaking	1	3	3	Create stronger gears
Slip Ring	Leaking sediment	Sediment resuspend ed	Inadequate seal	2	2	4	Create part that fits with lip seals

Risk Matrix		Very Probable	Probable	Occasional	Remote	Improbable
		5	4	3	2	1
Catastrophic	4	20	16	12	8	4
Critical	3	15	12	9	6	3
Marginal	2	10	8	6	4	2
Negligible	1	5	4	3	2	1

Severity of Effect	
Catastrophic	The failure causes substantial damage to the product itself or related items (including people), requiring repair.
Critical	The failure causes significant damage to the product itself or related items, requiring repair.
Marginal	The failure causes some damage to the product itself or related items, potentially requiring repair.
Negligible	The failure causes no significant damage.

Probability of Failure	
Very Probable	Every time
Probable	Most times
Occasional	Observed multiple times during the project.
Remote	Might be possible during the project.
Improbable	Maybe observed once during the project or predicted to happen after hand off.

Arduino Code

```
#include <Stepper.h>

const int stepsPerRevolution = 200;  // change this to fit the number of steps per revolution
                                     // for your motor

// initialize the stepper library on pins 8 through 11:
Stepper myStepper(stepsPerRevolution, 2,4,7,8);

void setup() {
  // set the speed at 60 rpm:
  myStepper.setSpeed(250);
  // initialize the serial port:
  Serial.begin(9600);
int a = 0;
}
void loop() {
  // step one revolution  in one direction:
int a = analogRead(A1);
if (a==0){
  delay(1000);
}
else if (a!=0){
  //   Serial.println("clockwise");
  Serial.println("clockwise");
  myStepper.step(66*stepsPerRevolution);

  Serial.println("clockwise");
  myStepper.step(66*stepsPerRevolution);

    Serial.println("clockwise");
  myStepper.step(66*stepsPerRevolution);
  delay(500);

  // step one revolution in the other direction:
  Serial.println("counterclockwise");
  myStepper.step(66*-stepsPerRevolution);

  Serial.println("counterclockwise");
  myStepper.step(66*-stepsPerRevolution);

  Serial.println("counterclockwise");
  myStepper.step(66*-stepsPerRevolution);
  delay(500);
}
}
```

Stepper Motor

Electrical Specification

Manufacturer Part Number	8HS15-0604S-PG64
Motor Type	Bipolar Stepper
Step Angle	0.028°
Holding Torque	0.9Nm
Rated Current/phase	0.6A
Phase Resistance	10ohms
Recommended Voltage	12V
Inductance	5.5mH±20%(1KHz)

Gearbox Specifications

Gearbox Type	Planetary
Gear Ratio	64:1
Efficiency	73%
Backlash at No-load	<=1°
Max.Permissible Torque	0.9Nm(127.5oz-in)
Moment Permissible Torque	2Nm(283oz-in)
Shaft Maximum Axial Load	5N
Shaft Maximum Radial Load	25N

Physical Specifications

Frame Size	22 x 22mm
Motor Length	38mm
Gearbox Length	30.95mm
Shaft Diameter	Φ6mm
Shaft Length	15mm
D-cut Length	9mm
Number of Leads	4
Lead Length	300mm
Weight	130g

Connection

Wire Color	Black	Green	Red	Blue
Board Connector	A	C	B	D