

In-line Sludge Dewatering

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Keon Research

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Contents

Introduction	3
System Design	3
Hoses	4
Inner Hose	4
Outer Hose	5
Vacuum	5
Connections	6
Traps	7
Controls and meters	8
Testing	9
Total Solids	9
Small 1-pump test	10
Material and Sludge Characterization	10
Small 2-pump test	12
Medium 2-pump test	14
Pump Setting Variables	14
Variable TS	14
Multiple Consecutive Tests	16
Prolonged Test	17
Conclusion and Recommendations	19

Introduction

This paper summarizes the work done to show a proof of concept for an in-line sludge dewatering system. First, the design of the system is described, including the selection of materials, devices, and simulated sludge used to test this concept. The different materials and processes considered for each element are described in the System Design section. Once the system was finalized, the performance of the system in removing sludge was carried out and results are described in the Testing section. Finally, based on what was learned during this study, we recommend the next steps in development to take this system closer to an MVP design.

System Design

The basic system for dewatering sludge is outlined below. The components can be divided into: hoses, vacuums, traps, controls and meters. Iterations of each of these components have been made throughout the development process in order to make a functional and then optimized system.

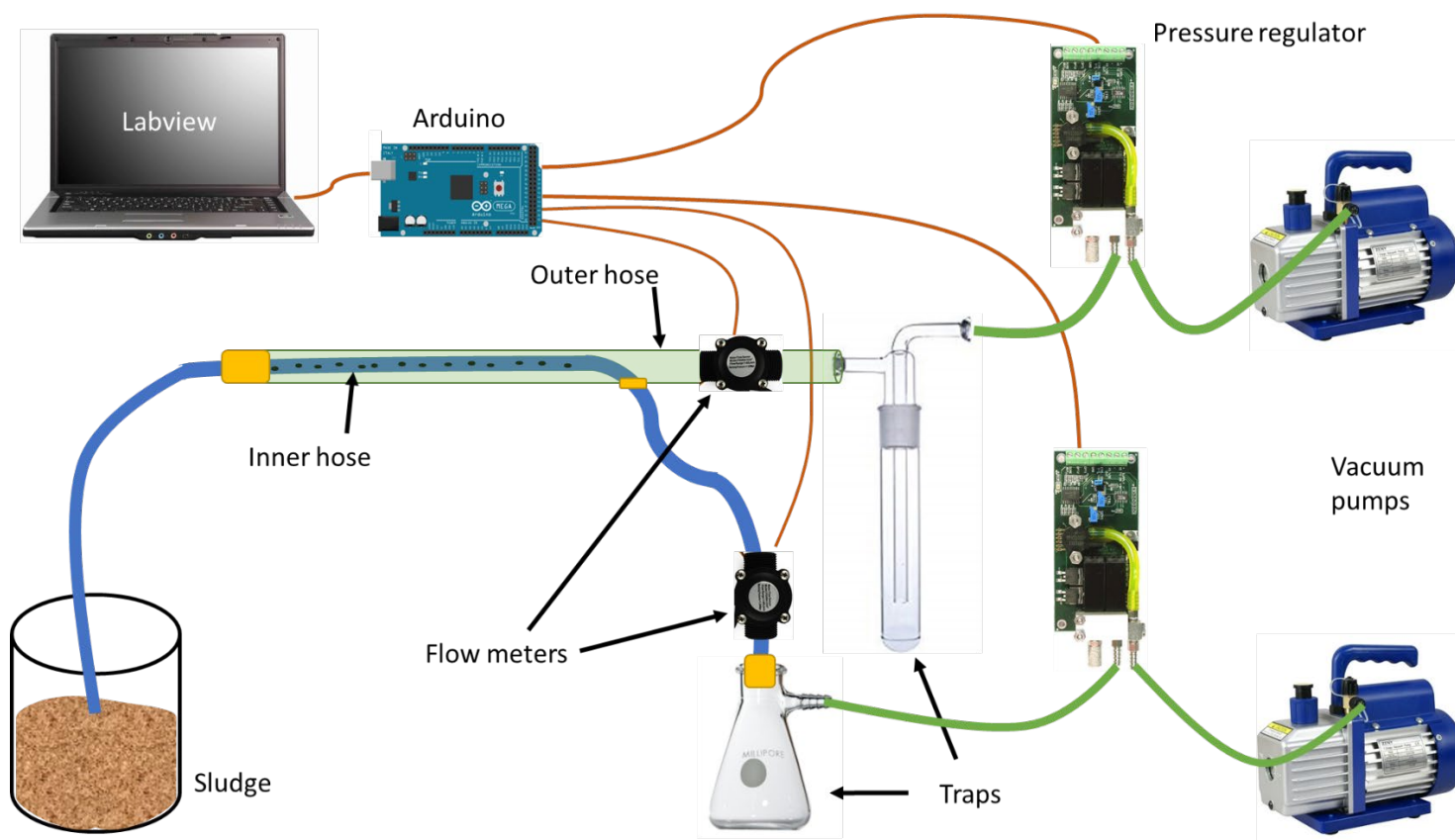


Figure 1. Diagram of sludge dewatering system.

Hoses

Inner Hose

The system relies on nested hoses, which are designated as the inner and outer hoses. The sludge travels through the inner hose, allowing for water to be removed from the sludge through its walls. The pores of the inner hose need to be large enough that water can be pulled through, but small enough that solids remain largely contained in the hose. Potential materials that have been investigated are geotextile, sintered rubber (a.k.a "soaker hose"), perforated vinyl tubing, and covered perforated vinyl tubing. Some initial testing was done by passing some test sludge through a section of the inner hose placed in a Buchner funnel. More rigorous testing was done using a small, static system as described in [Small 1-pump test](#).

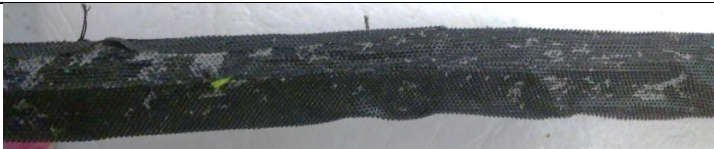
Material	Picture	Notes	Results
Geotextile		Comes as sheet, is wrapped 1x around wire cage and sewed	1 layer of geotextile pores are too large for sludge
Sintered rubber		Often used as landscaping soaker hose	Water flows easily through, not liquid collected with sludge
Perforated vinyl tubing		Perforations made using Dremel bit	Pores are too large for sludge
Covered perforated vinyl tubing		Perforated vinyl tubing covered with 2 layers of geotextile	Pores too large for sludge, may be useful for other test mixtures

Table 1. Summary of inner hose materials.

As summarized in the table above, the sintered rubber hose was not porous enough to pass any liquid through when particulates were present. The geotextile performed at the opposite end of the spectrum and passed all liquid through, in addition to sludge particles. While the perforated vinyl tube covered with

geotextile also proved to be too porous, this design presented the opportunity to try other synthetic fabrics as the covering.

Using a small test using the 0.25 RV HP vacuum (see testing section for details), we tried: nylon, woven polyester (PE), 100% polyester interfacing (100PE), and 60%polyester/40% viscose interfacing (60PE). Ultimately, a perforated vinyl tube wrapped with 2 layers of woven PE was chosen and used for most testing.

Outer Hose

The outer hose needs to be rigid enough to withstand the vacuum necessary to pull the water through the pores in the inner hose. The prime candidate for the outer hose is a thick walled reinforced vinyl tubing, pictured below. The vinyl has the benefits of being flexible, and the transparency of the tube is helpful for monitoring the dewatering process. We have noticed that in combination with a stronger vacuum (see vacuum systems section) the vinyl hose begins to collapse. A PVC pipe can be used for the outer hose to create a rigid system, but flexibility and transparency are lost. All tests of the system were done using the reinforced vinyl hose pictured below.



Figure 2. Vinyl tubing used for outer hose.

Vacuum

Vacuum pumps need to be able to move sludge through the inner hose in addition to pulling water from the inner hose to the outer hose. Vacuum pumps available are: (2) 0.25 horsepower rotary vane pumps (0.25 HP RV), (1) 0.5 horsepower rotary vane pump (0.5 HP RV), and (1) shop vac. The rotary vane pumps are preferred because they can be used in line with the vacuum regulator whereas the shop vac requires a more indirect connection.

The 0.5 HP RV pump has only been tried on the outer hose. This pump has the ability to collapse the vinyl outer hose.

Instead of vacuum, a sump pump or peristaltic pump device could be used to pull up the sludge and push it through the inner hose, although this method has not been thoroughly tested.

The 0.25 HP RV pumps have sufficient power to pull the sludge through the inner hose. A difference in vacuum power using a pair of these pumps is achieved by using the vacuum regulators as described below. All tests as described in the testing section were performed using the 0.25 HP RV pumps unless otherwise noted.

Connections

Construction of this system requires joining the inner and outer hoses to a common inlet, then splitting the outlet so they can be pumped independently and volumes of fluid collected in the inner versus outer hoses can be measured. This set-up uses some non-standard plumbing. We designed and 3D printed (in ABS polymer) several connectors to meet these needs. The connector shown in Figure 3A joins the hoses at the inlet of the device. The outer hose is hose-clamped to the outside and the smaller connector fits snugly into the inner hose. The connector shown in Figure 3B splits the two hoses at the end of the device. Outer hoses can be secured to either end of this connector with hose-clamps. The inner hose fits through the opening in the side of connector B and then connects to its own trap.

During our testing we discovered that it is important to ensure a good seal, especially where the inner hose leaves the connector. An inadequate seal results in the outer hose becoming depressurized first, meaning the dewatering efficiency drops drastically if the seal leaks. Our first attempts using a combination of parafilm and electrical tape were adequate but not consistent. A final solution was achieved using a heat-activated adhesive glue lined marine shrink tube wire sleeving. This allowed for a robust seal and repeatable results.

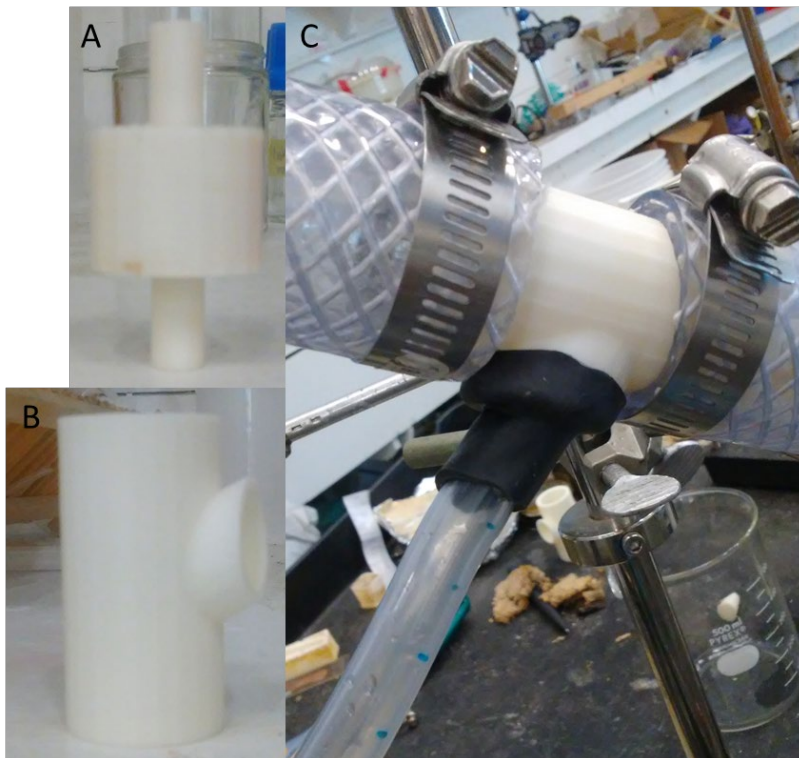


Figure 3. A) and B) show the two connectors made specifically for this set-up. C) shows the shrink wrap securing the gap between the inner tube and the connector.

Traps

A trap is installed between the hoses and the pumps. These protect the pumps from the sludge and also allow us to collect and measure the sludge and water collected. A first set of traps were constructed using 5 gallon paint buckets and modifying the lids to attach hose barb fittings (Figure 4B). The plastic buckets did not hold up to the vacuum pulled by the 0.25 HP RV pumps and began to buckle in a manner of seconds. Next, steel 5 gallon buckets were used with the same lids (Figure 4A). These buckets can withstand the vacuum of the 0.25 HP RV pumps but not the 0.5 HP RV pump (Figure 4C).

To allow for strong vacuum to be pulled, laboratory glassware traps have shown greater success. These include vacuum flasks as well as a more traditional vacuum trap. Glassware works well for a smaller test system, but a system to reinforce the larger traps will be needed when larger volumes are used. The large volume test described in this document used a double lined bucket trap for the inner vacuum and a 4L Nalgene vacuum flask for the outer vacuum.



Figure 4. A) Steel 5 gal trap. B) Plastic 5 gal trap. C) Steel trap after being used with 0.5 HP RV pump.

Controls and meters

The primary control in the system is the vacuum regulator. We use a digital vacuum regulator (Model# 487-001-6) made by LJ Engineering. The regulator takes a 0-5V analog input to control the vacuum output. The regulator also outputs as 0-5V analog signal which can be converted to a pressure at the output. A system was designed using the regulator and an Arduino Mega2650 board in combination with a LabView program to actively control the vacuum of the 0.25 HP RV pump. The system is diagrammed below.

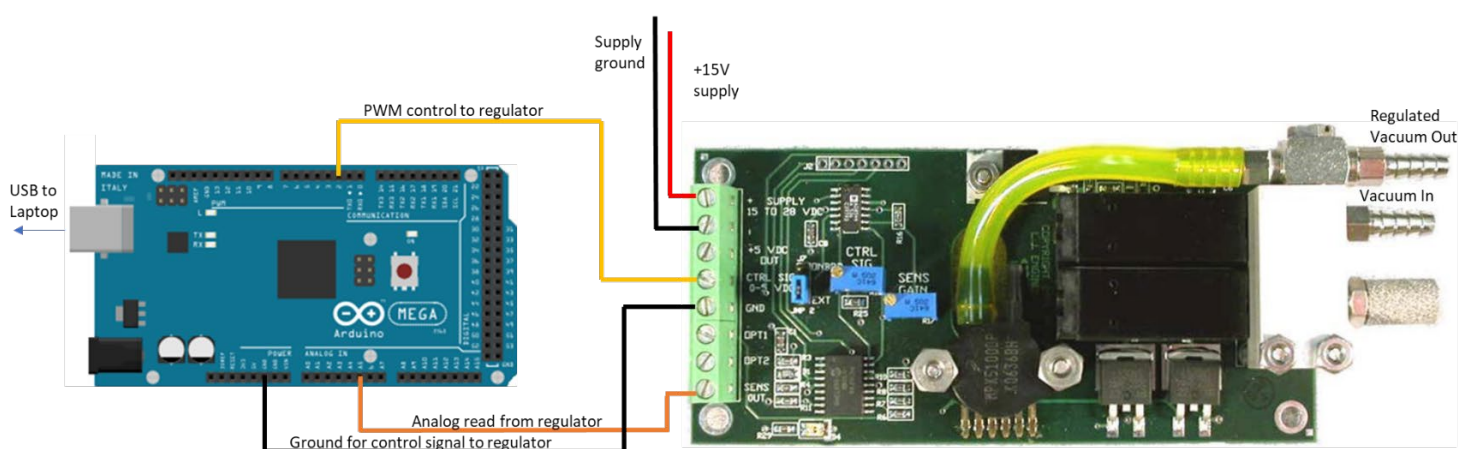


Figure 5. Wiring diagram of Arduino to vacuum regulator and computer.

Using the LINX tool published by National Instruments, LabView interfaces with the Arduino board to output a pulse width modulation (PWM) control to the regulator. PWM control is the Arduino's approximation of an analog output since it is not equipped for digital-to-analog conversion. The Arduino can do analog-to-digital conversion, so the analog output from the regulator to read the pressure can read by the Arduino and sent to the LabView program. Two separate LabView programs (VIs) were made to either provide steady control or modulating control of the vacuum.

The vacuum regulator also includes an onboard 5V source which can be controlled using a potentiometer as opposed to through the Arduino board. The potentiometer configuration was used when the vacuum regulator was set to fully open but unmodulated throughout the experiment.

Flow meters can be installed between the hoses and the traps. The flow meters have Hall flow sensors which output a 5V pulse for every 2 mL of fluid passed through the meter. Arduino is used to read the digital output from the flow meter and a LabView program (VI) is written to take to convert the digital signal from the Arduino into a flow rate that can be plotted vs time and output as an Excel file (Figure 6).

During our experiments, the flow from the hoses into the traps occurred at a flow rate below the sensitivity of these meters. Instead the flow into the device was measured by starting with a known volume and using a stopwatch.

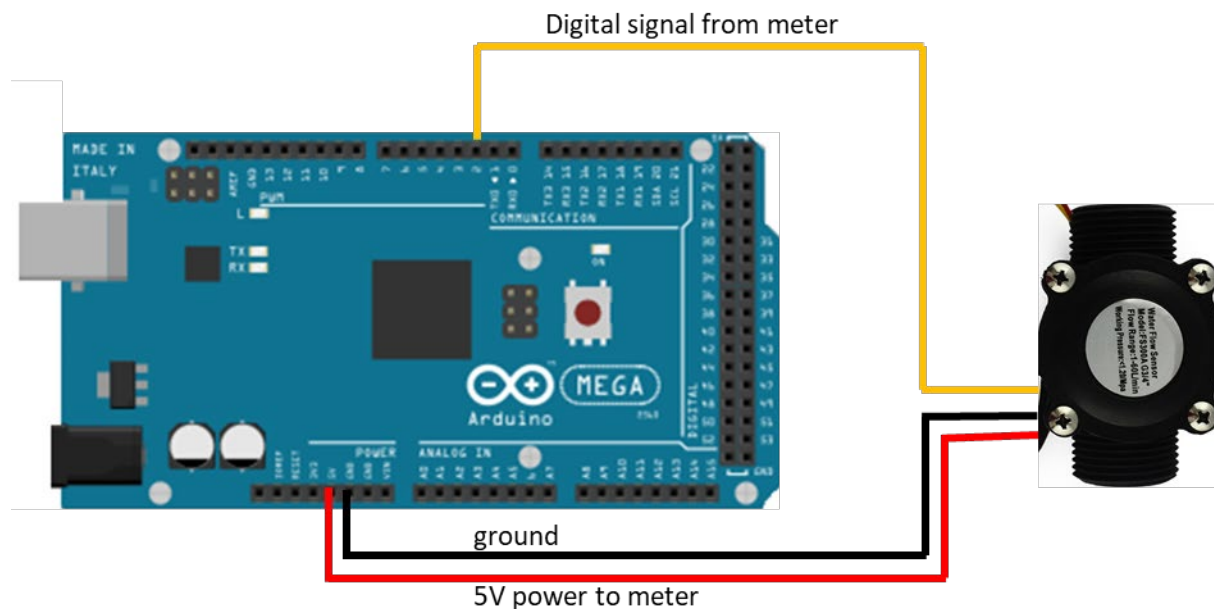


Figure 6. Wiring diagram of Arduino board to flow meter.

Testing

Total Solids

It is useful to have measure of the total solids (TS) of both the starting stock sludge simulants and the effluents from the system. TS is measured by filtering a known volume of the sludge or effluent through a pre-weighed filter paper. The filter paper is then allowed to dry overnight and difference between the new dry weight and pre-weight is the total grams of solid per the known starting volume. This number is represented as a percent value in g/mL.

Small 1-pump test

In order to test the suitability of different materials for the inner hose, a small test using the 0.25 HP RV pump was performed. In this test, approximately 1 foot of the inner hose was plugged at one end and loaded with 30 mL of test sludge through the open end. Vacuum was then pulled on the outer hose through a small glass trap. The volume and TSS in the effluent was measured. Two different simulants were tested. A recipe based on what was published by University of KwaZulu-Natal (UK) was prepared using 4 times the normal amount of water resulting in a solution that started with 2.3% TS. A recipe using just diluted miso paste was recommended by partners at Duke University and this was also tested. This recipe uses a stock prepared with 50% miso paste by weight in water giving a solution with 12% TS. This solution was diluted by different amounts to obtain simulants with desired starting TS.

Material	Sludge	TS (% g/mL)	dTS* (% g/mL)	Volume Collected (mL)
Nylon	2.3% UK recipe	1.3	1	11
Woven PE	2.3% UK recipe	1.3	1	9
100PS	2.3% UK recipe	0.5	1.8	5
60PS	2.3% UK recipe	0.8	1.5	11
Nylon	5.3% miso	n/a	n/a	0
Woven PE	5.3% miso	1.8	3.5	2.5
100PE	5.3% miso	n/a	n/a	0
60PE	5.3% miso	0.73%	4.6%	4
Nylon	1.6 % miso	n/a	n/a	0
Chiffon	1.6 % miso	0.68%	.92%	11
100PE	1.6 % miso	.38%	1.2%	6
60PE	1.6 % miso	.43%	1.2%	7.5

Table 2. TS and recovered volumes from small 1-pump test. * dTS = (Sludge TS) – (TS measured from outer hose)

Based on these results, there appears to be a balance between volume collected and the decrease in TS. The nylon proved to be entirely too tightly woven for using with the miso sludge. The 60 PS material resulted in the largest changes in TS but may allow a smaller volume collected. Based on balancing between these two features, we chose woven PE as the best material for going forward. Also, based on the desired simplicity, we chose diluted miso paste solution as the simulated sludge for all experiments moving forward.

We also looked at different number of layers of material around the inner hose. As expected, the decrease in TS increases as more layers added, but this can also begin to slow the volume collected. We chose 2 layers as the optimal coverage for the woven PE. Subsequent experiments were all done using the miso sludge and an inner hose covered with 2 layers of woven PE.

Material and Sludge Characterization

A light microscope was used to characterize the chosen inner hose material and sludge. Figure 7 shows a 100x image of the woven PE material. The size was calibrated using the grid of a hemocytometer and the

pores of the woven PE are judged to be approximately 1 mm. The figure below also shows how doubling the woven PE layer effectively decreases the pore size of the material.

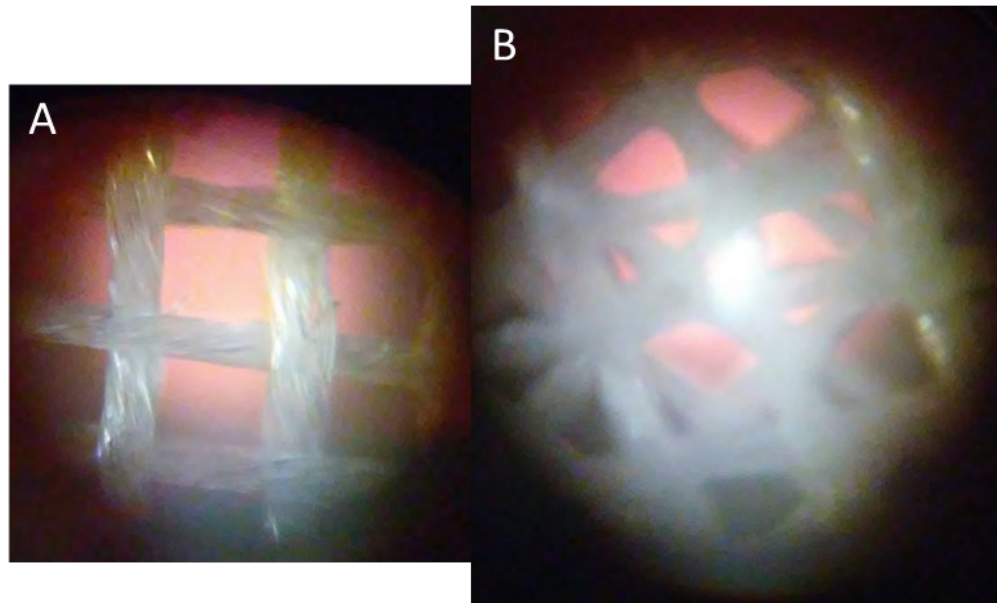


Figure 7. 100x light microscope images of one layer of woven PE (A) and two layers of woven PE (B).

A light microscope was also used to characterize the size of solids in the miso. Using a hemocytometer for scale, a sample of 2% miso was imaged using a 100x lens and shown in Figure 8. In this image, larger particles on the order of 0.25 mm – 0.5 mm are visible as well as many out of focus particles which are much smaller. Based on the size of sludge particles and woven PE mesh pores, it is apparent that two layers of will greatly improve the separation of solids. Additionally, the presence of very small particles indicates that there is a limit where adding more layers of woven PE will not result in a much larger pay-off in separation of solids.

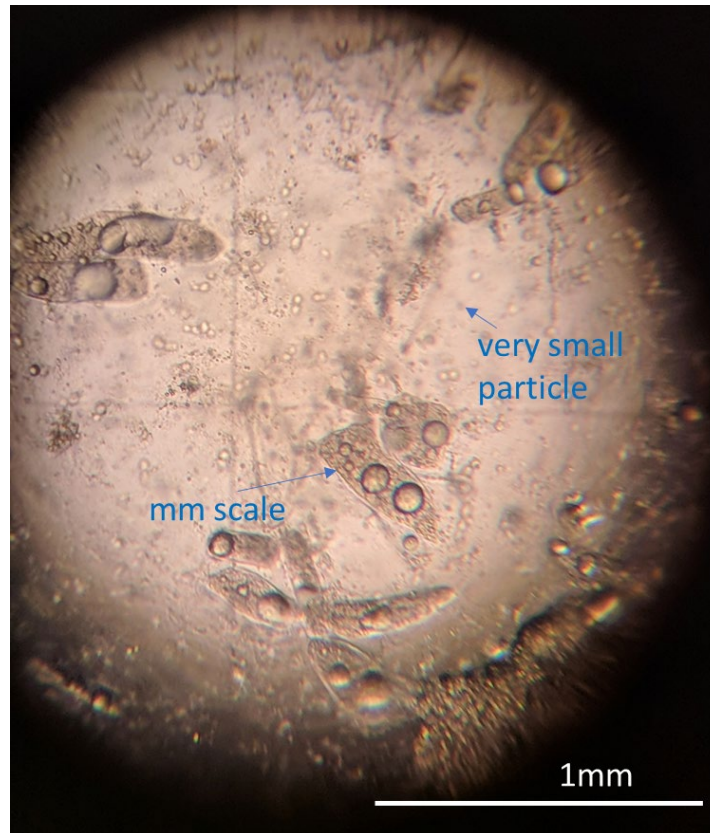


Figure 8. 100x light microscope image of 2% miso sludge.

Small 2-pump test

Using the same 1-foot test system, a connector was added so that both the inner hose and outer hose can be connected to pumps and controls. Tests were performed using the woven PE wrapped hose and a ~2% miso sludge. The setup used for this set of experiments was the same as Figure 1 minus the flow meters.

In this first set of tests, we started by modulating the pumps using out of phase square waves. The hope was that this would best allow isolation of the vacuum pulling the sludge through the system and the vacuum pulling the water out of the system, thus maximizing dewatering. The two 0.25 HP RV pumps were controlled using the LJ engineering regulators and LabView program. The function generator in LabView allows for control of: amplitude, duty cycle, frequency, and phase. For most tests the amplitude was set to 1 (corresponding to regulator fully open), the frequency set to 0.005 Hz, and the phase of the two pumps were set at 180 degrees from each other. For each test, 100 mL of 2% miso sludge was passed through the system, and the volume of liquid collected in the trap for the outer hose was measured. Results of these tests using the woven PE wrapped perforated inner tube are shown in Table 3 below.

Inner Duty Cycle	Outer Duty Cycle	Notes	Volume Collected
50	50		3 mL
2	100		0 mL
10	10		0 mL
25	25		Some, < 3 mL
100	2		0 mL
50	50	Amplitude of inner set to 0.5	0 mL

Table 3. Regulator settings and subsequent volume collected in the outer hose from small 2-pump test.

The results indicate that the power of the pumps is greatly decreased when passed through regulators, even when it is set to fully open. We went from collecting 37% of the liquid used in the outer hose of the static system to collecting at most 3%. To illustrate the decrease in vacuum power due to the regulators, we looked at the time to filter 300 mL of water through a filter paper when pulling with vacuum alone or vacuum through a fully open regulator. We saw that the vacuum through the regulator took about 20 times longer to pull the same amount of water than the same pump without the regulator.

Another 2 pump test was performed using the same inner/outer house setup, but the regulator was used on the inner tube only, while the outer tube was connected directly to its pump. The analog control of the regulator was set to a constant value using the Arduino board and a LabView program. The volume collected was recorded and the average of two trials is in Table 4. The best result occurred with the inner tube dampened by the regulator, but still set to its fully open setting.

Inner Regulator Setting	Volume Collected
1	10 mL
0.5	8 mL
0.25	5.8 mL

Table 4. Static inner vacuum regulator settings and resulting volumes collected in the outer tube.

Medium 2-pump test

Pump Setting Variables

We tested to see how the system scaled between 1 ft and 5 ft of tubing. A 5 ft long version of the test system was constructed again using the woven PE wrapped porous vinyl hose and two 0.25 HP RV pumps. We hypothesized that since the length of time of the sludge in the tube is the limiting factor for being able to pull out water, a longer hose will be able to pull out more water. We tested both the condition of the inner pump dampened with the regulator set to fully open (setting of 1) and a full power outer pump. Another test condition featured both pumps regulated using an out of phase square wave. These tests were performed using 300 mL of 2% miso sludge. Flow rate was also measured in these tests by timing how long it took to pass the full 300 mL through the system. Results are an average of two tests. Recovery fraction is given by the volume recovered from the outer hose divided by the total volume pumped through the system.

Condition	1 ft Recovery Frac.	5 ft Recovery Frac.	Flow Rate (L/min)
Square Wave 2 Regulators	.03	.03	1.0
Inner Regulated Only	.10	.40	3.2

Table 5. Recovery fractions from 1 ft and 5 ft tests as well as the flow rate as measured in the 5 ft test.

In the small test system, we observed that the best recovery is achieved with only the inner pump regulated. Our experiments show this holds true in the 5 ft scaled up system. We also observed that when the regulator is on both pumps, no advantage is gained by having a longer system. This indicates that at a flow rate of 1 L/min, the outer hose pump has sufficient time to act on the inner hose and remove fluid.

TS was measured on the sludge collected from the inner hose trap and outer hose trap in the system where only the inner tube is regulated. As expected, The TS in the inner hose trap increased from 2.1 % to 2.4% and the TS in the outer trap decreased from 2.1% to 1.2%. The decrease in TSS in the liquid recovered from the outer trap is comparable to the experiments done in the 1-pump test. This indicated that the amount of TS removed is only a function of the inner tube material and not of the flow rates through the system.

Variable TS

We wanted to test how different concentrations of sludge would work in this system. For these tests, we kept the best performing options from our explorations of materials and pump settings. We used the woven PE wrapped tube with the two 0.25 HP RV pumps. Only the inner pump was regulated, using the regulator set statically to its fully open position. All tests on the 5 ft system were done using 300 mL of test sludge.

Figure 9 below shows the trends in the flow rate and recovery fraction as we varied the starting TS of the miso sludge. As expected, both the recovery fraction and flow rate decrease as the % TS in the starting

sludge increases. The dependence of flow rate on starting sludge TS is much closer to being linear than the recovery fraction. It is promising that even at a little over 8% TS, the system is still capable of recovering about one-fifth of the water present.

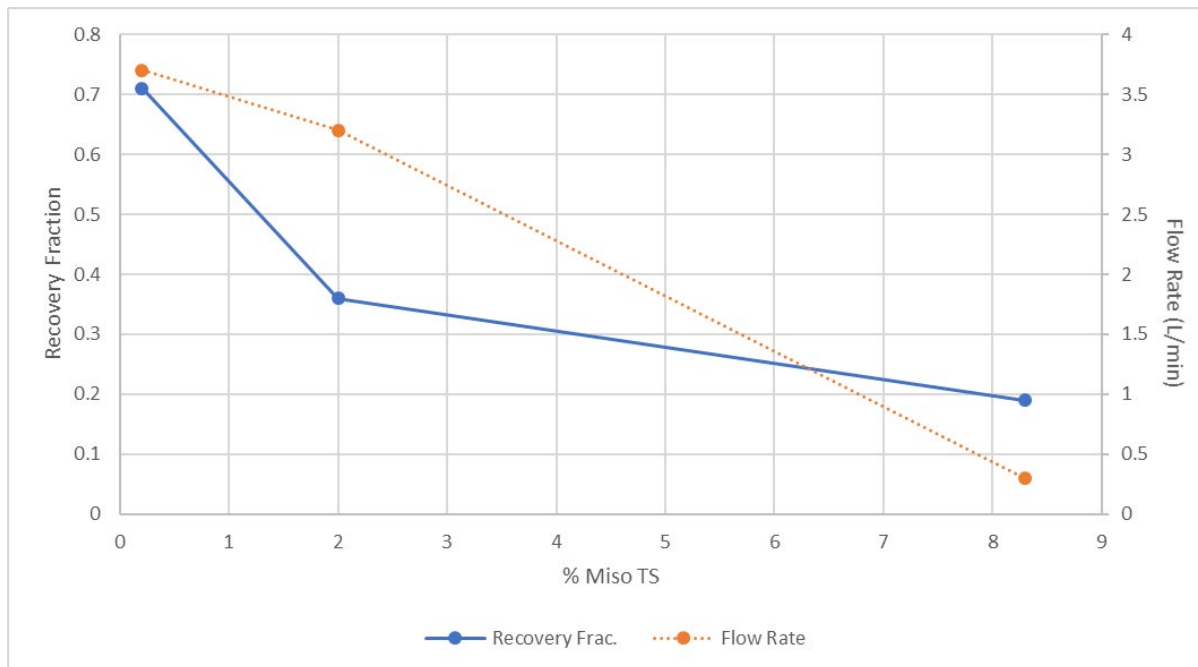


Figure 9. Plot showing the recovery fraction (left axis, blue line) and flow rate (right axis, orange line) as a function of the starting %TSS from the miso paste. The system configuration was kept the same for all tests and only the starting %TSS in the simulated sludge was changed.

Table 6 below summarizes the change in TS when filtered through the 2-layer woven PE wrapped tube. This table combines the data from the static tests described in the previous section and the 2-pump tests using the 5-ft hose. Since the sludge was not flowing through the inner hose in the static tests, these do not have data for %TS from the inner hose. Above 1% starting TS, the percent decrease achieved using the woven PE fabric does not have a strong dependence on the starting TS. At the 0.3% level, the change appears to be outside our limit of detection. At the highest starting TS, we see that the % TS recovered in the inner trap does not account for the drop in TS in the outer. This could indicate that much of the TS at this level is being trapped in the fabric. Anecdotally, we observed much heavier fouling after just one trial when using the 8.3% starting TS.

Starting %TS	%TS Inner	%TS Outer	% Decrease
0.33	0.32	0.31	6
1.6	n/a	.68	57
2.1	2.4	1.2	43
5.3	n/a	1.8	66
8.3	8.9	2.8	66

Table 6. Compilation of TS measurements from medium 2-pump test and small 1-pump test.

Multiple Consecutive Tests

Previous tests using this 5 foot system have been done using 300 mL of sludge at a time and doing at most 2 consecutive tests before cleaning the inner hose to prevent fouling. Multiple consecutive tests gave information about the fouling behavior of the system. We continued to use 300 mL increments, measuring the flow rate and removing the collected sludge from the traps and inner and outer hoses in between. The inner hose was not removed or cleaned between any of the measurements. We also collected samples from the inner and outer hose traps from the final run for testing TS.

The results from this test are plotted in Figure 10. We performed 10 tests using 300 mL for a total of 3 L of 2% miso sludge passed through the system for a total of 1 minute and 15 seconds. Looking at the recovery fraction, we do see a drop in recovery fraction occurring in two stages over the 3 L passed through the system, which may be evidence of fouling. The first drop off occurred after the very first run of 300 mL, after which a steady state with a recovery fraction of approximately 0.25 was achieved for the next 1.9 L. After a total of 2.4 L had passed through the system, the recovery fraction began to drop off again, reaching a value 0.1. by the end of 3 L.

Flow rate is also plotted on the figure below. The flow rate did start out higher during the first 600 mL, but then achieved a steady state, fluctuating around 2.2 L/min. This indicates that the flow rate is only slightly affected by the fouling of the membrane.

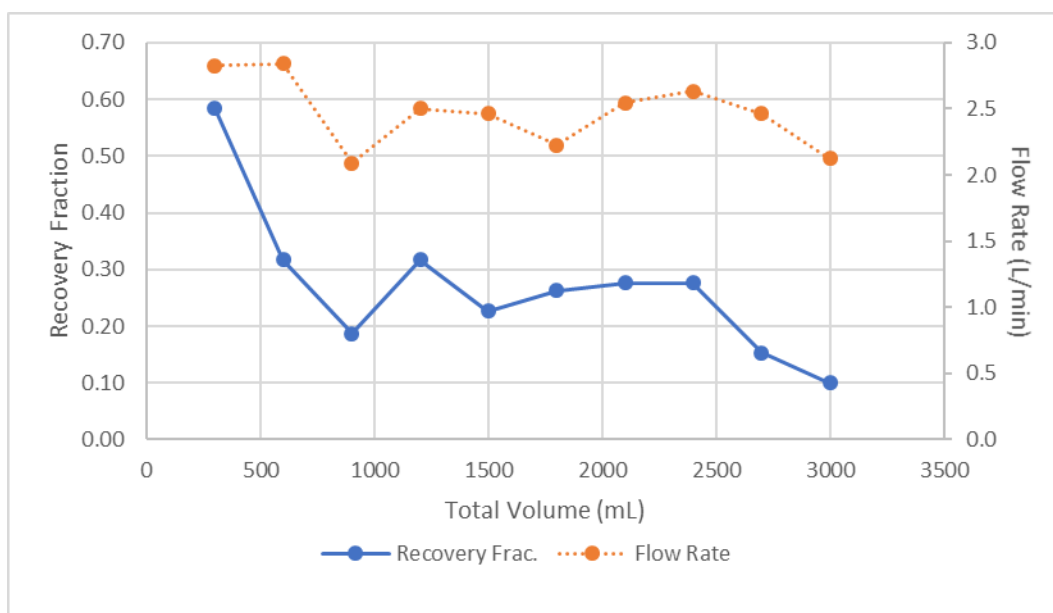


Figure 10. Recovery fraction (left axis) and flow rate (right axis) measured during many consecutive tests with 300 mL of sludge.

As another measure of performance after the multiple tests, we looked at the TS of the sludge recovered from the inner and outer hoses. Our starting sludge for this test was 2.1% and the sludge recovered from the inner hose had increased to 2.3% while the sludge recovered from the outer hose had decreased to 0.8%. The percentage decrease is within the range expected for this material. The difference in the decrease at the outer hose and increase in the inner is slightly larger than is expected for the 2.1% starting sludge, which could also be indicative of increased fouling.

Prolonged Test

The system was also tested for its performance for running over extended periods of time continuously (at least 1 minute). This necessitated changing the traps from the glassware used in the previous trials, to larger vessels capable of holding multiple liters of miso sludge. The first trial used the modified 5 gallon buckets as described in the trap section above. The trap for the outer hose needed to be specially reinforced using an internal wooden scaffolding to account for the larger vacuum pull on the trap. However, using the bucket traps resulted in zero recovery of fluid into the outer hose. We hypothesize that this is because the bucket traps do not give a good seal and are effectively buffering both of the vacuums (inner and outer) equally.

To remediate this, we purchased a better sealed, large trap to use on the outer vacuum (a 4L polypropylene vacuum bottle). A plastic bucket was still used on the inner vacuum, which was buffered using the fully open, static regulator. This resulted in measuring a non-zero recovery fraction, although this recovery fraction was only 0.02, still much less than the shorter experiments using the glass traps. We also repeated the run, but modulated the inner vacuum regulator using a square wave with a duty

cycle of 50% and frequency of 0.005 Hz (modulated). This resulted in a slightly slower flow rate and a slightly smaller recovery fraction of 0.01.

Inner Vacuum	Starting Volume	Sludge	Volume in Outer Hose	Recovery Fraction
Static	4500 mL		90 mL	0.02
Modulated	4500 mL		60 mL	0.01

Table 7. Volumes measured during prolonged test with two different inner vacuum conditions

The flow rates of the two trials are shown in Figure 11. We measured time intervals at 0.5 L, 1.5L, 2.5L, and 4.5 L. The full 4.5 L run took a total of 1 min and 45 seconds with a static inner vacuum and 2 minutes and 4 seconds for the modulated vacuum. Looking at the changes in flow rate over time, there are fluctuations, but no trends to indicate that fouling is slowing the system. The decrease in recovery fraction is at first concerning but this decrease is due to the change in traps and connections made to the vacuum system and not to a fundamental problem in using the system for large volumes of liquid. Based on the experiences with changing traps and having any loose vacuum connection in the system, these can drastically affect the recovery fraction. We believe that switching out the remaining bucket trap with a bottle will bring the recovery fraction back to what was observed using glass traps and smaller vacuums.

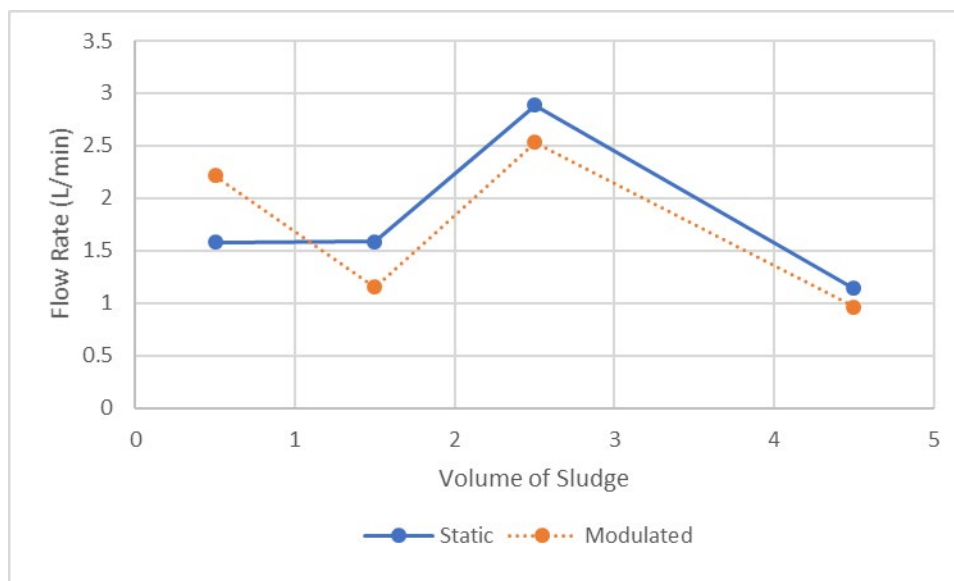


Figure 11. Flow rates of the system at intervals throughout the prolonged test.

Conclusion and Recommendations

This initial work has demonstrated the feasibility of the in-line dewatering system for being able to reduce the volume of sludge by removing water from the solid material as it passes through the system. The differential vacuum serves to both move sludge from inlet to outlet and pull some liquid containing reduced TS from an inner filter hose to an outer hose. A recovery fraction of up to 0.6 was observed using this system and TS was decreased by about 60%. We believe this result serves as a proof of concept and warrants further development that will result in the following research outcomes.

The key risk identified with this approach remains the possibility of the inner hose fouling, which we have confidence can be overcome using differential pressure and/or backflow regimes. The next step in the validation of this technology, therefore, is to make improvements to the test system to determine whether any fouling of the system can be mitigated through these approaches. This entails:

1. **Improve efficiency the system.** This includes replacing the following elements of the system.
 - a. **Regulators:** Regulators should be chosen so that the full range of vacuum power can be changed, rather than the step down that we experienced with the current system. Based on our measurements with the smaller regulators, the square wave appears to be the optimal waveform for modulating the flow of sludge. A square wave could be accomplished using a pair of electrically controlled solenoids being open and closed using and Arduino/LabView control.
 - b. **Pumps:** The 0.25 HP RV pumps proved to be sufficient for a proof of concept study, but they did not stand up well to the operating conditions of pumping fluids. Any small amount of water vapor in the pump eventually heats and corrodes the system causing rust. Further experiments should be done to hopefully find an oil-free pump system that provides sufficient vacuum. A shop vac system which is fan based, with at least a 6 horse power motor may be sufficient.
 - c. **Traps:** Large traps, specially designed for vacuum, which would be accomplished by adapting large (eg 32 Gallon) shop vacs allow for longer runs to determine fouling rates.
2. **Improve inner hose.** The material choice should provide the best filtering capability with only a single layer. Having a material which can be heat sealed will also make construction of a durable inner hose. Consultation with a geotextile manufacturer for material selection will help provide insight into manufacture and design elements for improving the inner hose.
3. **Address Fouling.** Accomplishing outcome #1 and #2 will allow for us to determine if fouling rates scale with the length of the system. Further reduction in fouling can be addressed in two ways:
 - a. Modulation of the vacuum in waves which will be possible based on the modification suggested in #1a
 - b. Design of the inner hose, including the selection of materials as outline in #2. This can also include modification of how the material is attached to the inner hose and the ultimate structure of the inner hose.

The learnings obtained from this initial project will accelerate the ability to construct an improved test system, which we propose scaling to a 15ft length for more realistic testing conditions. This will likely take 8 weeks to construct at a cost of \$26,000. The testing phase will take an additional 6 weeks at a cost of \$22,000. This includes the cost of all materials and labor, as well as any additional costs for outside consultants needed.

The outcome of this next phase will demonstrate improvements to the system, for both the control and efficiency of dewatering, as well as addressing what we believe to be the key risk for further development, the potential for the inner hose to foul. If successful this data will inform further product development efforts.