Non-Toxic Soil Thickeners for Reducing Mudslide Intensity

A Senior Project
Presented To
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In Partial Fulfillment
Of the Requirements for Degree
Bachelor of Science

By
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Background

Mudslides occur primarily when heavy rainfall saturates the soil to the point that the soil behaves like a liquid and begins flowing rapidly downhill. Nature's primary defense mechanism against this phenomenon is plant roots, which serve to draw excess water out of the soil as well as physically hold it in place. However, wildfires can burn up every plant on a hillside very quickly and leave large amounts of soil prone to flowing. This is what occurred in Santa Barbara in January 2018 when the Thomas fires ravaged the entire county. A hillside in Montecito was stripped of all plant matter, and unusually heavy rains caused a mudslide. This mudslide killed 23 people and caused around 300 million dollars of damage[1].

While the United States Geological Survey (USGS) offers several recommendations for reinforcing hill sides and blocking flow once it happens, they do not offer any suggestions for increasing the amount of water soil can hold before beginning to flow. The purpose of this project is to identify a readily available, non-toxic thickening agent that can be applied to soil in order to increase the soil's viscosity when heavily saturated with water. This increase in viscosity would then theoretically slow down mudslides, allowing time for people to evacuate and potentially causing less property damage.

If an effective thickening agent could be found and thoroughly tested, the potential impact could be enormous. The USGS estimates that 25-50 people are killed annually by mudslides in the United States, and this number balloons to hundreds around the world killed each year by mudslides. Additionally, 1-2 billion dollars are spent annually to fix property damage caused by mudslides in this country[2].

Hypothesis

Research into food thickeners as mud thickener candidates led to the identification of gum tragacanth, which is known to have excellent food thickening properties. These food thickening properties include a large increase in viscosity in solution at low concentrations, acid stability, and salt stability. These properties are believed to be desirable in a mud thickening application, where the acid and salt stability will render the compound more durable in the environment. Additionally, gum tragacanth does not need to be heated to increase the viscosity of a solution[3].

We also believe dental cements can also act as mud thickeners, increasing mud viscosity at high water contents. Dental cements offer a great deal of promise, as they require large amounts of water to bind together and harden. We envision that small particles of hardened cement will form throughout the soil, trapping a large amount of water in place and keeping the soil from behaving as a liquid.

Background and Literature Search

This project was intended to be a continuation of senior project work done last year by a group consisting of two Materials Engineering students and a Soil Science student. Their report was crucial in identifying a range of food thickeners that could be capable of performing in the mud thickening application. All thickeners that were chosen both this year and last year are biocompatible, to alleviate some toxicity concerns. The food thickeners all belong to a class of compounds known as colloids. Since water is the fluid being thickened, these compounds are more accurately referred to as hydrocolloids. Hydrocolloids are essentially long chain polymers that can become entangled at high enough concentrations, trapping water molecules in place[4].

Especially important was the identification by last year's group of students of guar gum as a mud thickening candidate (Figure 1). Guar gum is a naturally occurring long chain polysaccharide that is produced by grinding the endosperm of the *Cyamopsis Tetragonolobus* legume. Guar gum sees a significant amount of use as a thickener in foods that are not meant to be cooked, since its thickening effect is not triggered by high heat. Additionally, it is also added to fracking fluid to increase the fluid's viscosity and allow it to more effectively carry sand into fractured rock[5].

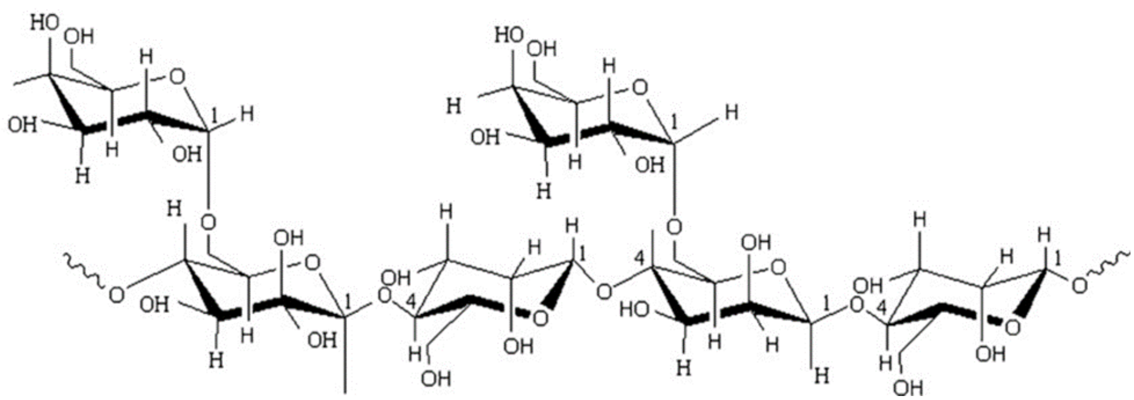

Figure 1. Mer structure of guar gum. Strong hydrogen bonding leads to good secondary bond formation with water. Figure is from [5].

Whey protein was also identified as a potential thickening agent by the previous year's group. Whey protein is a collection of globular proteins isolated from milk whey. Milk whey in its raw form contains roughly 20% by volume whey protein, the remainder being casein proteins. Milk whey is further refined into whey protein concentrate with a required minimum protein concentration of 34% by volume[6]. Whey protein has outstanding food thickening properties but can only achieve peak viscosities with the application of temperatures above 30ºC[7]. These temperatures are concerningly high for our proposed application but could be feasible in some warmer areas of the world. This concern can also be assuaged by simply using larger concentrations of whey protein.

There are no obvious toxicity concerns with whey protein, but the concentrations that may be required to see a significant increase in mud viscosity may pose issues to the ecosystems of the hillsides on a macro scale. Large additions of foreign substances can dramatically alter the soil chemistry of the surrounding area, potentially causing harm to native plants that have adapted to growing in a certain soil type. Additionally, with concentrations up to 19wt%, the logistics of employing this relatively large amount of whey protein in the environment is potentially very difficult.

Initial research this year led to the selection of gum tragacanth as another food thickener for testing (Figure 2). Gum tragacanth has been in use for thousands of years, but due to troubled diplomatic relations between the countries in which it is grown and the United States, its use in this country has declined significantly over the last several decades. It is gathered from the exudate of the *Astragalus* bush in small amounts. Most of these bushes are grown in Iran, Syria and Turkey. The compound most responsible for its thickening effect is a polysaccharide known as tragacanthin which is capable of forming a colloid with water. The bulk of the exudate, roughly 60%-70%, is a compound called bassorin. Bassorin swells in contact with water, forming gel particles[8].

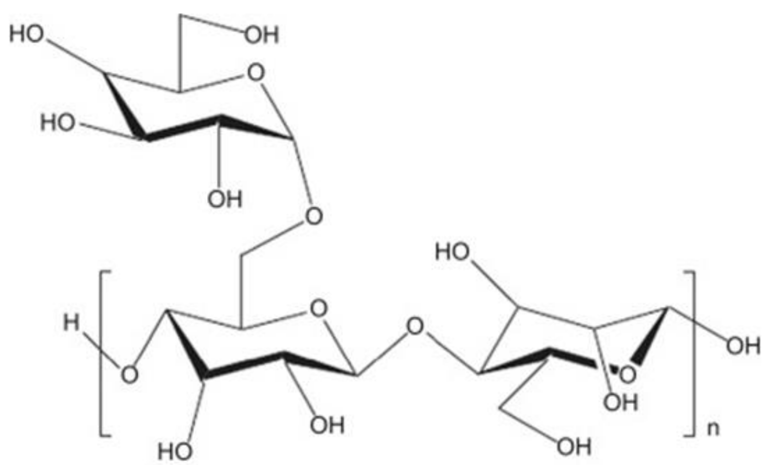

Figure 2. Mer structure of Gum tragacanth. Strong polarity and high hydrogen bonding leads to strong secondary bonding between molecule and water. Figure is from [8].

In addition to food thickeners, dental cements were also investigated as potential mud thickeners. Dental cements do come with potentially serious environmental hazards because the acids required for the curing reaction could potentially acidify the soil. They are, however, capable of trapping large quantities of water as they set. Two different cements were identified: glass-ionomer dental cements (GIDC) and Zinc-phosphate cements.

Glass-ionomer dental cements (GIDC) require three essential components to be functional: a polymeric acid, a basic glass, and water. In an ideal clinical setting, the acid (with the water as a solvent) reacts with the glass to form a hard, durable salt. The water then becomes incorporated into this salt. This reaction typically occurs in less than three minutes and can occur at room temperature. GIDC's have not been investigated for use as a thickening agent. For mud thickening purposes, various concentrations of the polymeric acid and glass will be investigated in the soil samples. Ideally, small amounts of dispersed salt will form, depleting water from the soil and increasing its viscosity[9].

Zinc phosphate is one of the most common cement materials used today. The cement sets in an acid-base reaction, where zinc oxide and a small amount of magnesium react with aqueous phosphoric acid. A lack of water during the reaction will lengthen the setting time, which may be useful if the compound is to be implanted into soil. Much like the glass-ionomer dental cement, the zinc/magnesium oxides will be added to the soil with solid phosphoric acid powder so that the acid will dissolve into the water present in the soil and commence the reaction[10].

A soil thickener could not ethically be placed on a hillside if there were concerns about potential toxicity to the environment. As it is difficult to directly measure the toxicity of the candidate thickening agents, proxy testing must be employed. The first and most basic indicator of a lack of toxicity was that all thickener candidates chosen for testing were not harmful to the human body. Food thickeners are regularly consumed by humans and dental cements spend decades in human bodies without issue.

Materials and Methods

Soil Collection

For the purposes of this project, approximately 25 gallons of soil was collected from a hill behind the Fremont dormitory on the Cal Poly campus. According to the United Soil Classification System, this soil is of the Fat Clay type. The area where samples were taken has a history of mudslides, most recently in 2016. To test the water content of the soil, 5 samples of approximately 100 g each were weighed, then desiccated in a 110^{o}C oven for 24 hours before being weighed again to determine how much water was lost. This revealed that the soil has a standard water content of approximately 12.9% by mass. The soil was stored in sealed 5-gallon buckets in the Soil Science Department labs.

Viscometer Testing

For a thickener to be successful, it must accomplish two things: it must offer a significant increase in mud viscosity versus an un-treated mud sample, and it must be non-toxic to the environment. To test viscosity, a Baoshishan NDJ-1™ rotary viscometer was employed that rotates a small circular metal barrel in the mud and measures its resistance to rotation (Figure 3). Samples tested consisted of approximately 250 g of mud. This device allows for a quantitative measurement of viscosity that can be easily compared across all soil samples, both treated and untreated. The device measures the resistance to rotational motion and reports this value in Newtons as an Alpha value. To account for the surface area of the barrel (Figure 4) and the speed at which the barrel is rotated, a constant K value is also provided for each combination of barrel size and rpm (revolutions per minute) with which the machine can operate. Alpha and K are then multiplied which gives a viscosity value in mPa-s.

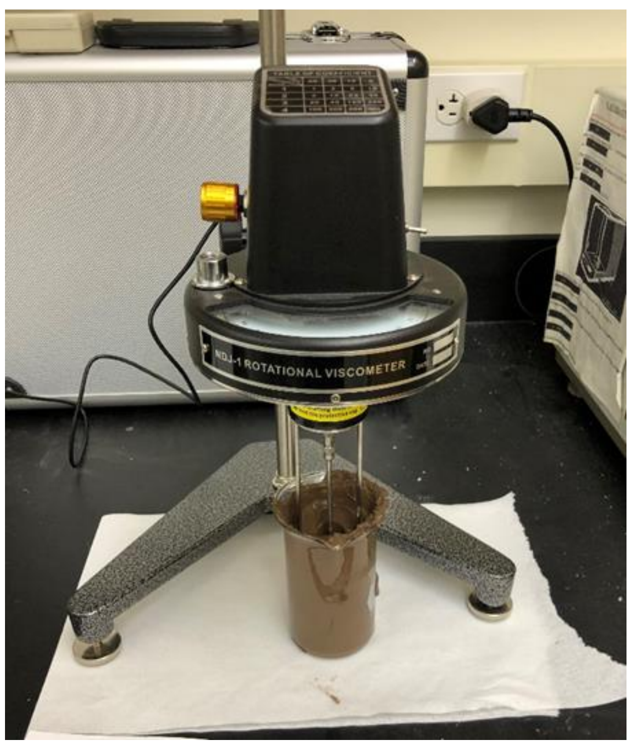

Figure 3. Viscometer used for initial viscosity testing

Figure 4. Barrels used by the viscometer, labeled by number.
Barrels are approximately 5” long. Barrels 3 and 4 were used, with
diameters of approximately 1 cm and 2 mm respectively.

The operating instructions for the viscometer recommend allowing the barrel to rotate until the Alpha value indicated on the dial stops fluctuating, which is typically around 30 rotations. The rotational velocity of the machine and the barrel surface area should be chosen based off the expected viscosity of the sample. A slower rotational velocity and a smaller barrel size should be chosen for high viscosity samples. For the untreated mud samples, barrel 3 was used at speeds of 60 rpm and 30 rpm. For guar gum testing, barrel 4 was used at 60 rpm and for gum tragacanth testing barrel 4 was used at 30 rpm and 12 rpm. Multiple speeds were used to ensure that the final viscosity value was consistent under different testing parameters. Guar gum was not able to be tested at multiple speeds because lowering the speed resulted in an alpha value that was outside the range that was deemed reliable in the operating manual (between 30 N and 90 N).

The water content at which soil begins to behave like a liquid was found last year to be 32% by mass. To ensure that the mud samples behaved fully as a liquid, the soil was weighed, and enough water was added to bring the added water content to 40% by mass. This is in addition to the 12.9% water content that was in the soil when it was removed from the hill behind the Fremont dorm. After all water additions, the total water content in the mud was 52.9% by mass. Since the water content can change as the water evaporates, samples were not tested more than 4 hours after being mixed with water.

After the control samples were tested, testing of guar gum and gum tragacanth as thickening agents was carried out by weighing each thickener on a scale capable of measuring to the milligram precision before adding them to the control samples and thoroughly mixing them into the soil by hand. Testing was performed on guar gum primarily as a reference sample and to assess reproducibility, to ensure results gathered this year were like those gathered last year. Several tests failed because the added thickener increased the viscosity to the point that the sample no longer behaved like a liquid and could not be tested. After multiple failed tests, 0.5 wt% of both gum tragacanth and guar gum were eventually identified as upper concentration limits for testing. These thickeners were measured with respect to the mass of the added water.

While the data reported by the viscometer was illuminating and useful, the ultimate goal of this project is to identify a soil thickener that can be used on a hillside. Therefore it was pertinent to develop a testing method that can compare the treated and untreated soil viscosities they flow down a hill. We were unable to find any readily available testing methods to accomplish this, so one was designed and fabricated.

Apparatus for Slope Testing

The designed testing system took the form of two plexiglass boxes, connected in the center by two hinges (Figure 5). This system had a total length of around five feet and was around two feet in width. The height of the 0.22" thick walls allowed for a soil depth of up to 6", which is around 100 lbs. of mud. Due to mixing limitations and the sheer weight of the mud, tests were performed with around 50 lbs. of mud. A 1" high bar of plexiglass ran across the fill side of the testing system, so that the mud is forced to flow over it. This is critical so that the mud that is touching the plexiglass base of the box is blocked and does not flow. The flow of the surface mud will then be measured as it flows over itself and not due to it sliding over the smooth plexiglass surface. This was done to more accurately replicate conditions found on a hillside. To record the tests, a 1ft. bar of plexiglass jutted out from the side of the fill box to which a GoPro™ camera was attached that could film the tests as they happen. Taped lines one inch apart along the side of the fill box were used as reference marks to track the speed of the flow (Figure 6).

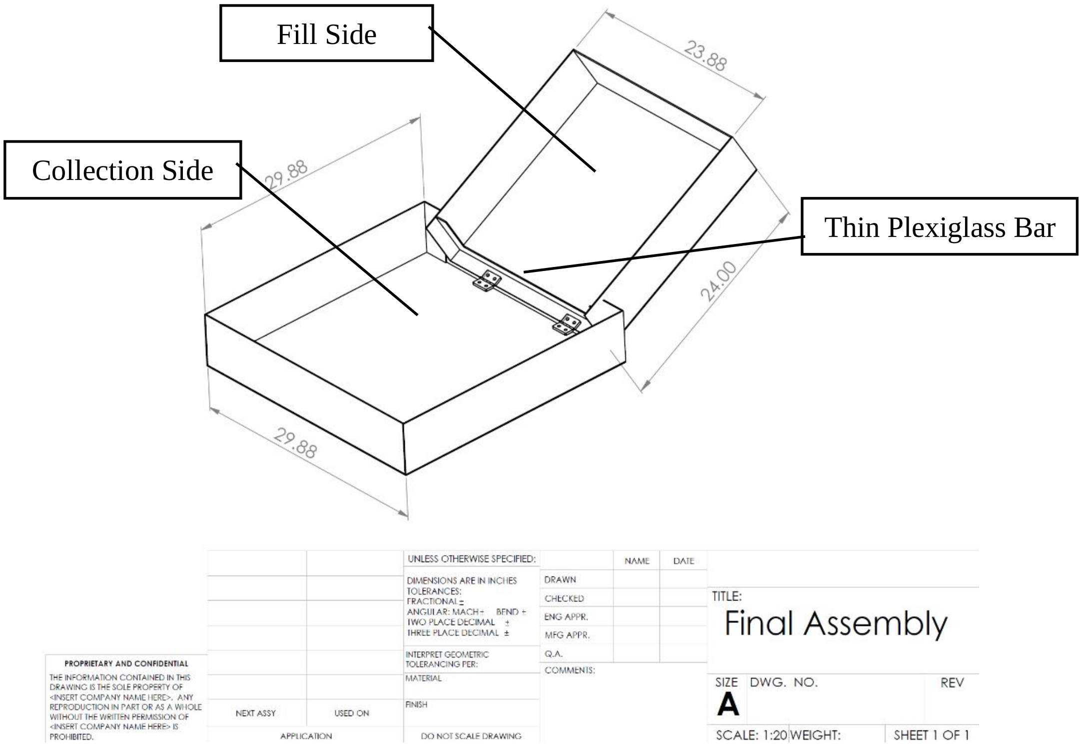

Figure 5. SolidWorks drawing of testing box assembly. The fill side is on the right, the collection side is on the left.


Figure 6. Completed testing box with attached GoPro camera.

Toxicity Testing

The proxy for toxicity testing of candidate thickening agents was to test their effects on plant life. In this case, ryegrass was grown in 4” diameter plastic pots containing 30 ryegrass seeds and approximately 300 g of soil mixed with one thickening agent per pot (Figure 7). Each food thickener was tested in 10 total pots, of which 5 pots had 0.5 wt% thickener and 5 pots contained 5 wt% thickener. The thickener concentrations were measured with respect to soil mass. Additionally, 5 pots with untreated soil were used as a control. It was intended that each dental cement would also have been tested in an identical manner to the food thickeners. The ryegrass in the pots mixed with dental cements was to be grown for the same total amount of time as the ryegrass planted in soil mixed with food thickeners. The ryegrass in these pots of soil was to be grown in the same greenhouse, with the same amount of sunlight and water. At the end of 40 days of growing, the number and length of the ryegrass blades in each pot was to be measured. The blades of ryegrass would then be harvested and the sugar content of the ryegrass (in degrees Brix) was to be measured with a Brix refractometer as an indicator of overall plant health. Additionally, the ryegrass was to be desiccated in a 110°F oven for 24 hours and then weighed to measure its dry mass as an overall indicator of plant health. If any ryegrass grown in treated soil produced statistically less sugar or grew less than the untreated control samples, that thickening agent would have been eliminated from consideration as a non-toxic mud thickener.

Figure 7. Ryegrass pots in Cal Poly greenhouse.

Results and Discussion

Due to public health restrictions from the COVID-19 pandemic, the Cal Poly campus was closed shortly after the conclusion of the Winter 2020 quarter and multiple issues with the testing apparatus went unresolved. Unfortunately, the size of the box meant that the mud layer was too thin to have adequate flow over the thin plexiglass bar, which invalidated any testing that was done. Additionally, it was found that the joints of the acrylic pieces should have been fastened with mechanical fasteners instead of the acrylic welding compound that was used. Flexure caused by the weight of the mud caused a significant degree of cracking at the joints because they could not bend at the welded joint. This testing method still holds a lot of promise as a useful method for testing soil thickeners, but a significant amount of refinement will be required.

Additionally, ryegrass plants had just been placed in the Cal Poly greenhouse to begin their 40-day growing period when the campus was shut down. Viscometer testing was performed on most of the food thickeners and was not completed on the dental cements.

Immediately noticeable was that gum tragacanth is a highly effective thickener (Tables I and II). Even at small quantities (0.5 wt% with respect to water weight), the viscosity of the mud increased by nearly 10X with respect to untreated soil samples. Guar gum also proved to be a good thickening agent, with an increase in viscosity of almost 4X with an addition of 0.25 wt% of guar gum to the soil (Tables III and IV). At concentrations of as low as 1 wt% guar gum, the soil became too viscous to effectively test with the available viscometer.

Table I. Untreated Control Sample, Prior To Gum Tragacanth Testing

Untreated @ 40% Added Water (2/29/20)			
	K	Alpha	Viscosity (mPa s)
Trial 1	20	72.4	1448
Trial 2	40	47.2	1888
Trial 3	20	66.1	1322
Trial 4	40	52.5	2100
Trial 5	20	67.8	1356
Trial 6	40	51.4	2056
Trial 7	20	68.2	1364
Trial 8	40	51.6	2064
Trial 9	20	68.2	1364
Trial 10	40	53.6	2144
STDDEV		8.90	346.57
		Average (K=20)	1370.80
		Average (K=40)	2050.40
		Overall Average	1710.60

Table II. Gum Tragacanth Treated Sample

0.5wt% Gum Tragacanth @ 40% Added Water (2/29/20)			
	K	**Alpha**	**Viscosity (mPa s)**
Trial 1	200	60.3	12060
Trial 2	500	36	18000
Trial 3	200	71.1	14220
Trial 4	500	50.6	25300
Trial 5	200	64.6	12920
Trial 6	500	50.5	25250
Trial 7	200	66.4	13280
Trial 8	500	38.1	19050
Trial 9	200	63.6	12720
Trial 10	500	37.2	18600
STDDEV		12.54	4748.20
		Average (K=200)	13040.00
		Average (K=500)	21240.00
		Overall Average	17140.00

Table III. Untreated Control Sample, Prior to Guar Gum Testing

Untreated @ 40% Added Water (2/28/20)			
	K	**Alpha**	**Viscosity (mPa s)**
Trial 1	20	40.8	816
Trial 2	40	34	1360
Trial 3	20	43.4	868
Trial 4	40	37.5	1500
Trial 5	20	49.6	992
Trial 6	40	36.3	1452
Trial 7	20	44.4	888
Trial 8	40	35	1400
Trial 9	20	43.9	878
Trial 10	40	35.9	1436
STDDEV		4.86	275.67
		Average (K=20)	888.40
		Average (K=40)	1429.60
		Overall Average	1159.00

Table IV. Guar Gum Treated Sample

0.25wt% Guar Gum @ 40% Added Water (2/28/20)			
	K	**Alpha**	**Viscosity (mPa s)**
Trial 1	100	35.4	3540
Trial 2	100	35.6	3560
Trial 3	100	36.7	3670
Trial 4	100	40.4	4040
Trial 5	100	43.2	4320
Trial 6	100	32.5	3250
Trial 7	100	48.6	4860
Trial 8	100	45.1	4510
Trial 9	100	66	6600
Trial 10	100	58.6	5860
STDDEV		10.31	1030.90
		Overall Average	4421.00

Immediately apparent is the significant difference in viscosities between the untreated samples. Fat clay has a natural tendency to clump together into large lumps, and while every effort was made to break up these lumps, they are impossible to entirely remove. These lumps can influence the measured viscosity, which is why a new untreated control sample was tested prior to testing each thickener. The increase in the viscosity between the untreated control and the treated sample tested on the same day is the critical data to examine.

Gum tragacanth seems to show the most promise out of all the food thickeners considered, because it has proven itself to be highly effective at low concentrations. While whey protein was not tested using this viscometer, work done last year showed a relatively high concentration was necessary to see any benefit. As concentrations increase, the overall cost of implementation increases, and detrimental environmental effects become more likely.

Because both guar gum and gum tragacanth offer viscosity increases that are similar to each other at low concentrations, the bulk cost of the powder becomes important when deciding between them. Prices were taken from Bulkapothecary.com in May of 2020 and are the lowest possible prices after bulk discounts (Table V)

Table V. Costs of Tested Food Thickeners

Cost Comparison	
Thickener	**Price ($/kg)**
Gum Tragacanth	43.54
Guar Gum	5.15
Whey Protein	9.35

While gum tragacanth offers a greater thickening effect than the other food thickeners tested, its high cost may render it unfeasible in application. Since the only dental cements that are available today are of medical grade, they are orders of magnitude more expensive than the food thickeners. Bulk prices for the reagents used in dental cements were not available.

Future Work

The primary focus of future work should be the refinement of the testing box apparatus. The testing box holds a great deal of promise, as it allows the user to closely mimic real-world conditions. The current iteration of the box was too large and clumsy to effectively produce consistent results and began to break down during limited testing due to fabrication error. This box is currently the bottleneck in an overall testing system that could evaluate many potential thickening agents. Since testing with the viscometer is significantly quicker than using the testing box, treated soil samples could be tested with the viscometer, and the thickener candidates could either be eliminated or moved forward for further consideration depending on their measured viscosity. From there, thickener candidates could be further narrowed down using the testing box apparatus. The thickener candidates that show significant improvement over an untreated control mud sample in both tests would then undergo rigorous environmental testing.

The environmental testing component of this project is another aspect that could be significantly improved. While use of ryegrass as a proxy in toxicity testing is a critical component of a thorough screening process, there are many more aspects of an ecosystem that must be considered before deciding if a particular thickener is safe to apply. Effects of the thickening agents on the native plants and animals must be evaluated before application, as well as risk of water contamination. This may require an extended controlled test in the field.

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