Rapid Hydration of Mineral Drill Slurries for Drilled Shafts

Grip 2010

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Civil & Environmental Engineering

Problem Statement

The purpose of this study was to:

- Identify potential methods of rapidly hydrating mineral drilled slurry for drilled shaft construction.
- Develop a device for preparing small to mid-sized slurry volumes on the order of 2000 gallons.

Project Tasks

- Perform a literature search of present foreign and domestic mixing methods as well as pertinent parameters (e.g. available minerals, clay chemistry, equipment, field practice, possible admixtures).
- Perform lab and field testing of presently available and/or used methods of mixing slurry.

Project Tasks

- Modify and test new slurry mixing systems.
- Develop recommendations and/or guidelines for slurry mixing procedures.

Mineral Slurry Products

There are primarily two types of mineral slurry products applicable:

- Bentonite – All around usage
  - Pure Bentonite
  - High yield bentonite
- Attapulgite – Brackish / Saltwater usage

Outline

- Mineral Slurry Testing
- Mineral Slurry Mixing Systems
- Laboratory Testing and Results
- Advancements in Rapid Slurry Production
- Field Demonstration
- Conclusions

Mineral Slurry Testing

Mineral slurry, when maintained correctly,

- Is viscous enough to suspend small cuttings.
- Provides lateral pressure in excess of active earth pressure.
- Acts to eliminate groundwater intrusion.
- Provides stability, even with the motion of drilling tools.

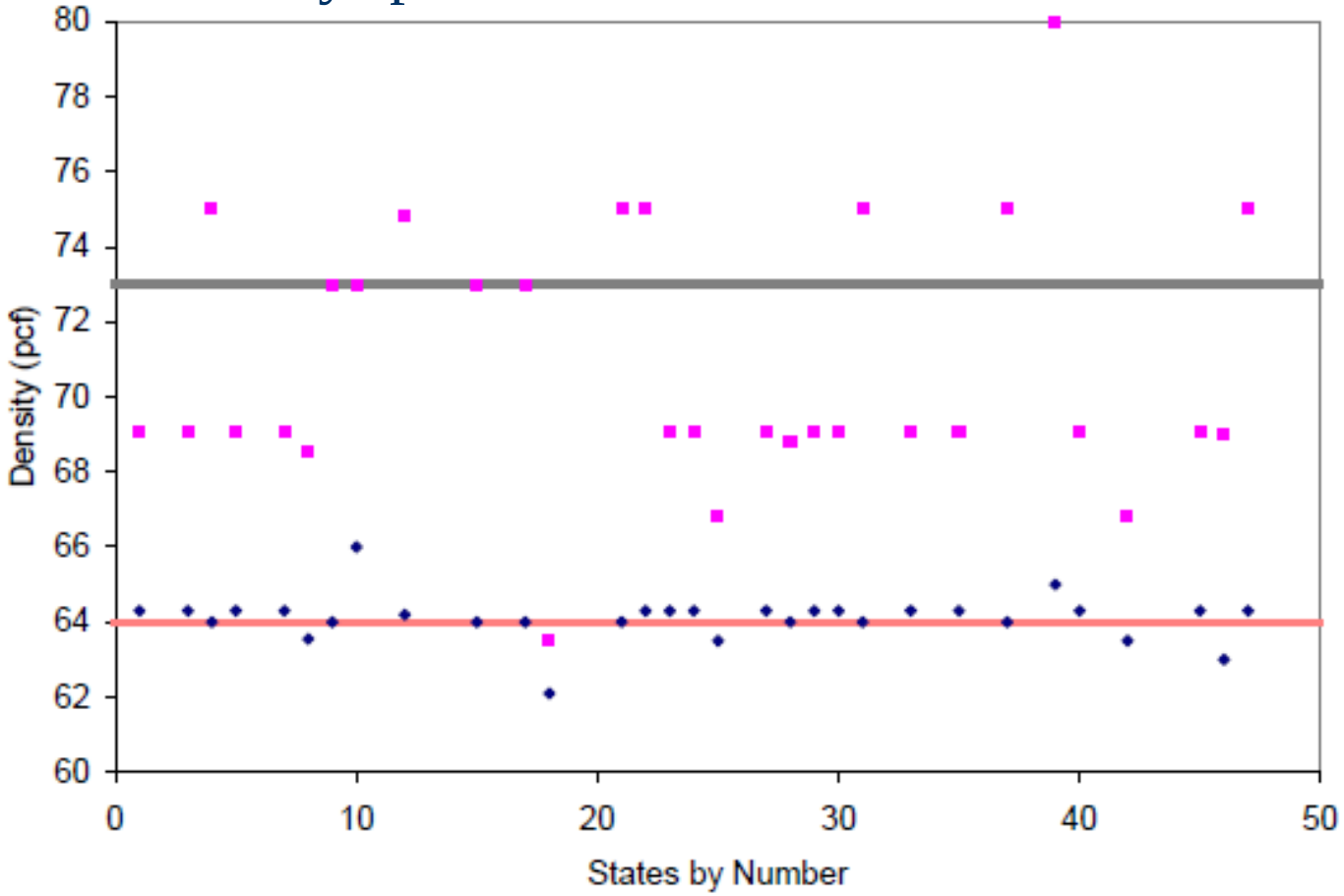
Mineral Slurry Testing

Why monitor slurry properties?

- Too heavy – slurries are not easily displaced during concreting.
- Too light – slurries do not supply sufficient lateral stress.
- Excessively viscous – concreting complications arise.
- Insufficiently viscous – slurries cannot suspend cuttings.

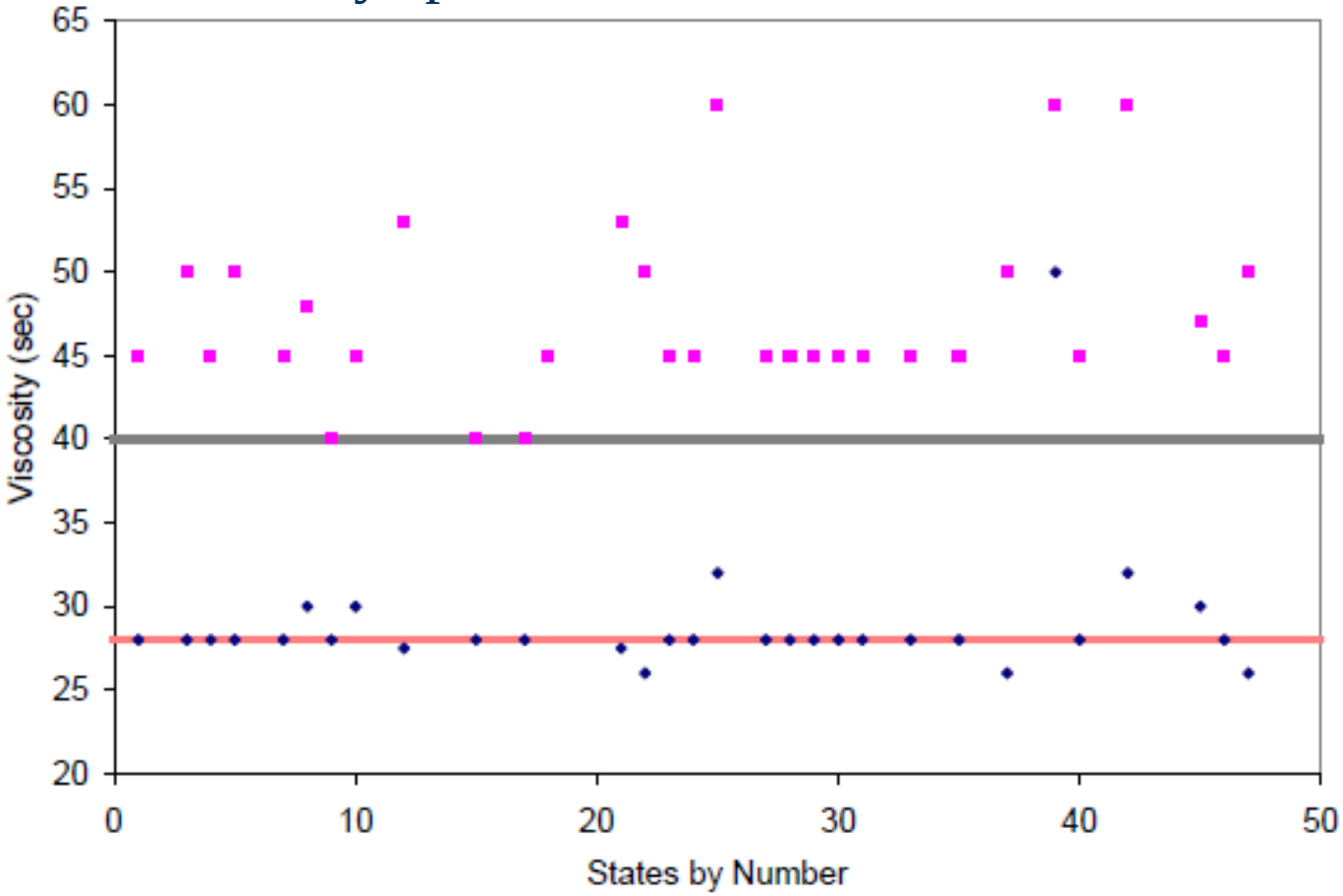
Mineral Slurry Testing

Density specifications for 41 of 50 states



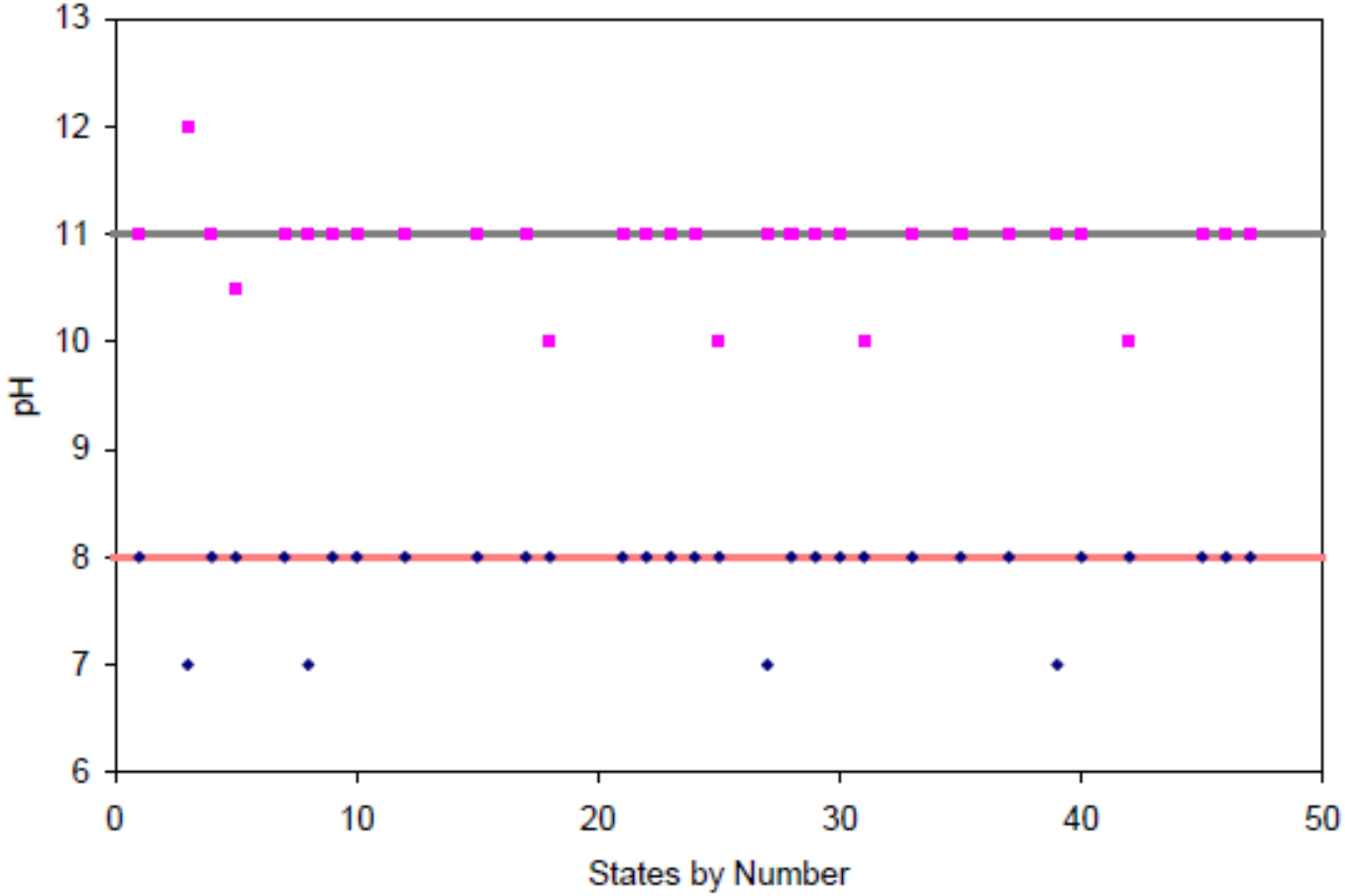
Mineral Slurry Testing

Viscosity specifications for 41 of 50 states



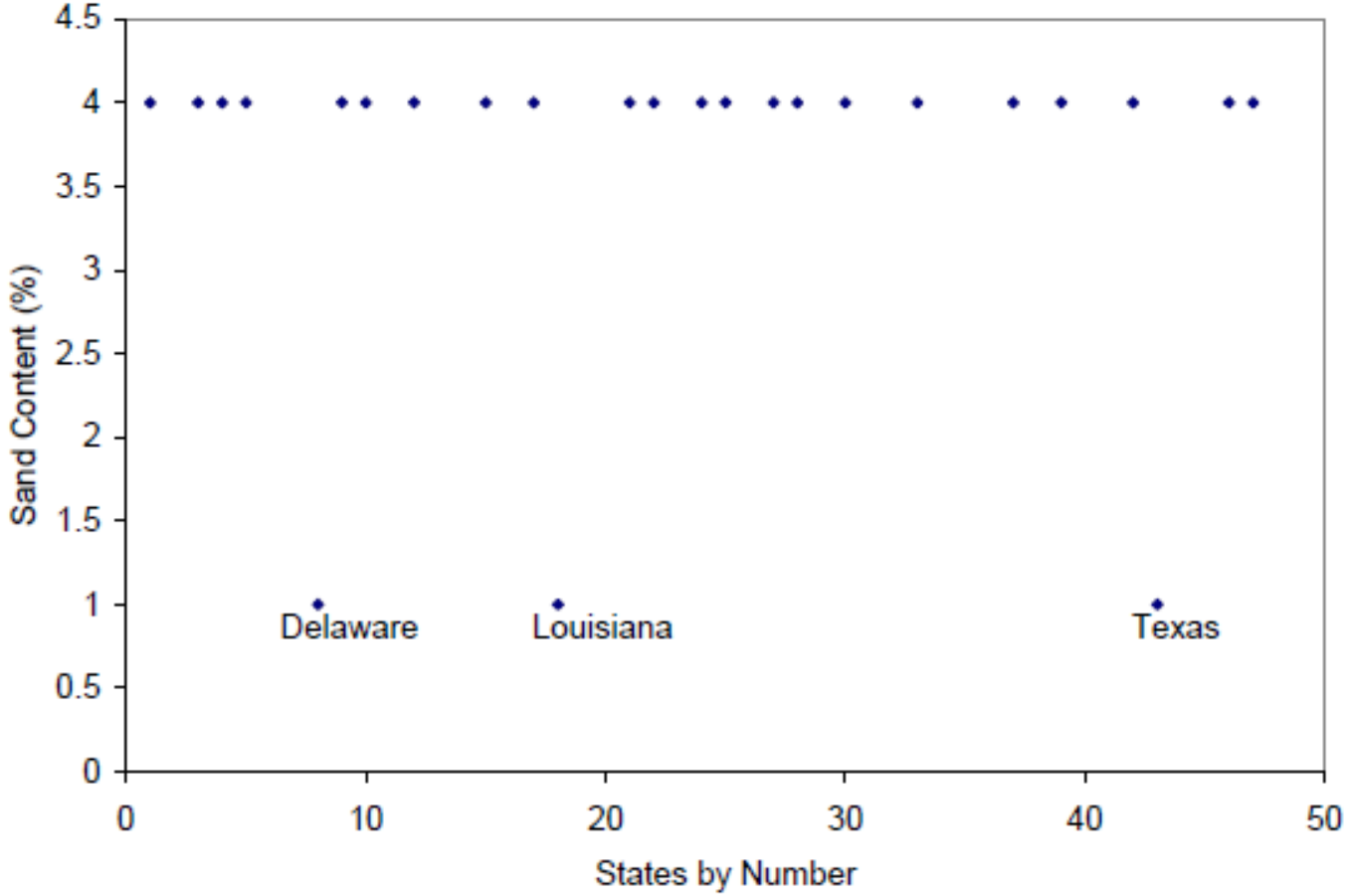
Mineral Slurry Testing

pH specifications for 41 of 50 states



Mineral Slurry Testing

Sand content specifications for 41 of 50 states



Mineral Slurry Mixing Systems

Conventional mixing and cleaning systems range from 2000 gallon trailer systems to 7000 gallon capacities. Common sized shafts require approximately 2000 gallons of slurry, depending on the water table and soil absorption.

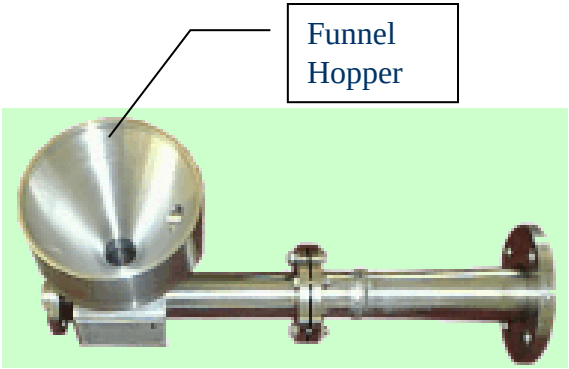
Mineral Slurry Mixing Systems

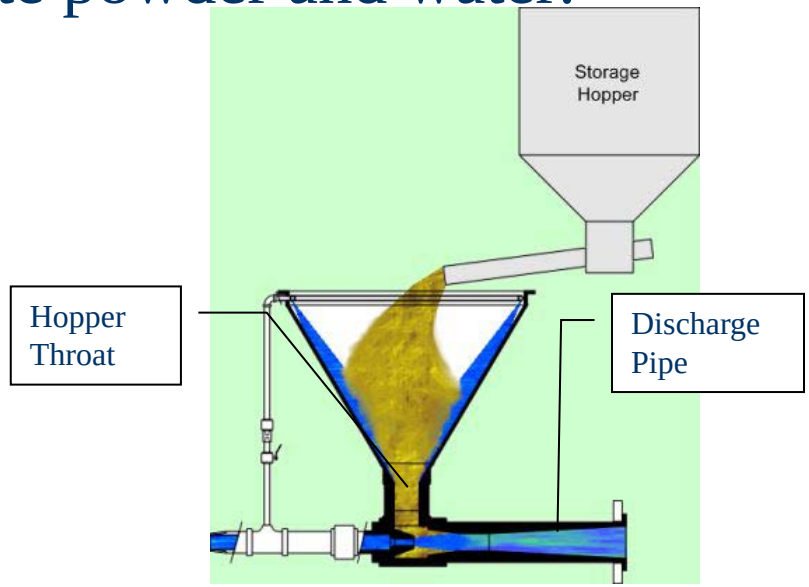
Conventional mixing systems typically consist of:

- A high pressure mud gun, otherwise known as a venturi hopper.
- A high shear, low pressure mixing tank.

Mineral Slurry Mixing Systems

- Venturi hoppers are the most common mud guns used in slurry mixing systems, and make use of Bernoulli's venturi principle.
- Designed for granular materials, to provide adequate contact between bentonite powder and water.





Mineral Slurry Mixing Systems

- Venturi hoppers suffer from two major issues, which plague most mixing operations:
  - The interface region of the mixer is prone to build-up of the sticky dry powder.
  - The feed rate of the powder in the hopper can overwhelm the mixing chamber. Feed rates are partially dependent on gravity and the cleanliness of the hopper.

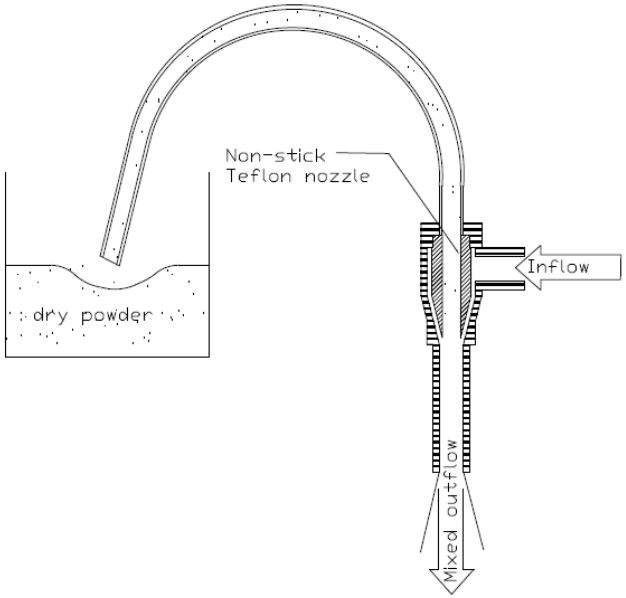
Mineral Slurry Mixing Systems

As systems get larger, they are more prone to clogging and producing “skinned over” powder balls.

Local contractor large scale mixing systems:

Mineral Slurry Mixing Systems

Eductor mixing systems also make use of Bernoulli's venturi principle; however, they feature significant differences from their hopper counterparts.



Mineral Slurry Mixing Systems

The major differences between the eductor mixing systems and hopper mixing systems include:

- Dry powder may never touch a wetted surface.
- Material mix rate is proportional to the water flow rate.
- The dry powder is completely enveloped in water at the water/bentonite interface region.
- The interface orifice is fabricated from non-stick Teflon.

Mineral Slurry Mixing Systems

Eductor Mixing Systems are commonly used in:

- Wastewater treatment plants to mix large quantities of poorly dispersing chemical additives with water.
- Food processing plants to mix sticky materials, such as guar gum, fine powdered sugars, etc.
- Possibly used to mix slurry for drilled shaft construction overseas.
- *Not* currently used in the U.S. for drilled shaft construction.

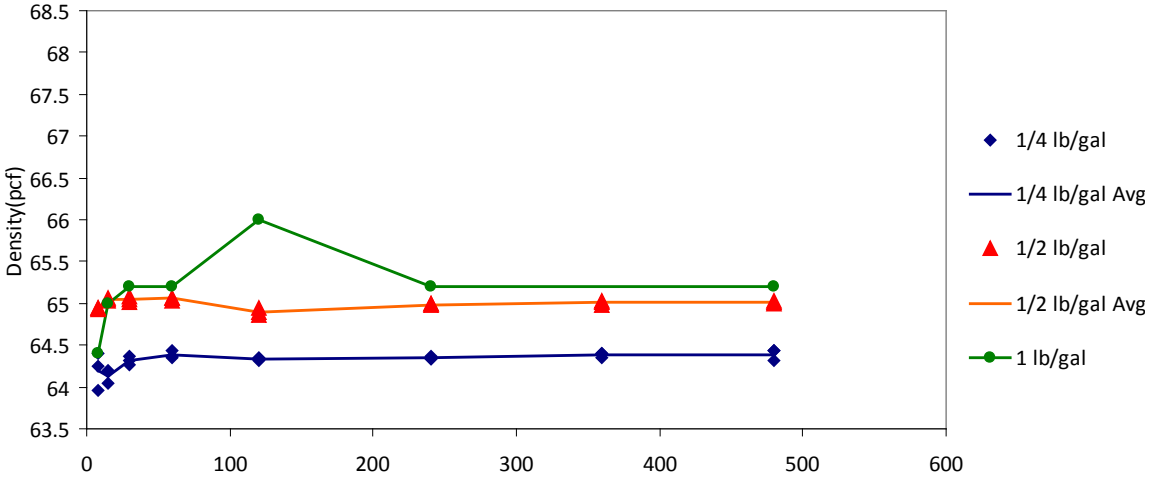
Laboratory Testing

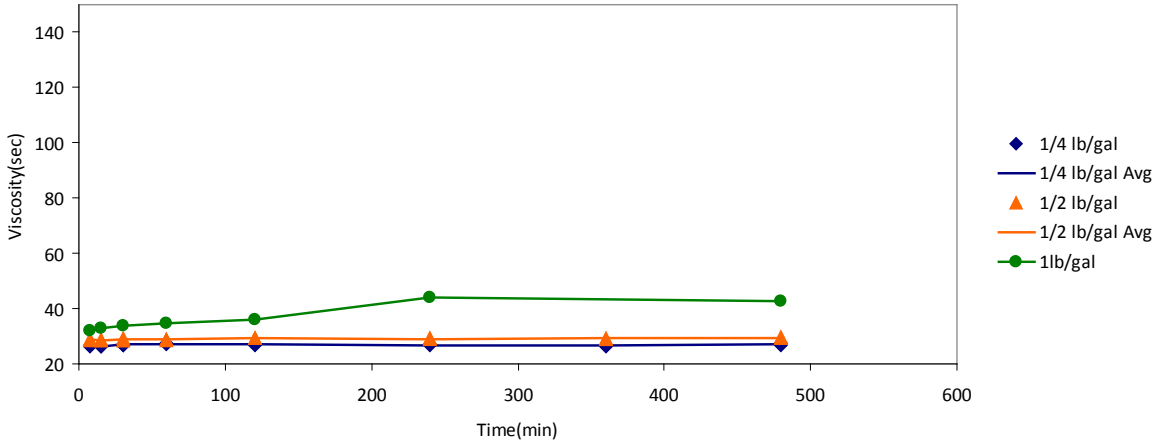
The initial test matrix featured several readily available mineral slurry products mixed at ratios of 0.25 lb/gal, 0.5 lb/gal, and 1 lb/gal (dry powder to water volume).

A venturi hopper was utlized for initial mixing as well.

Laboratory Test Results

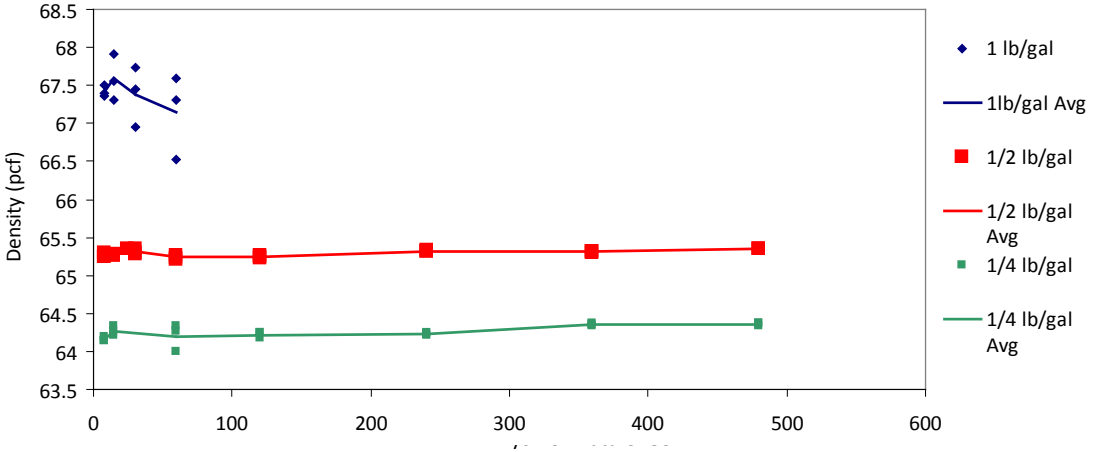
Pure Gold bentonite initial test results:

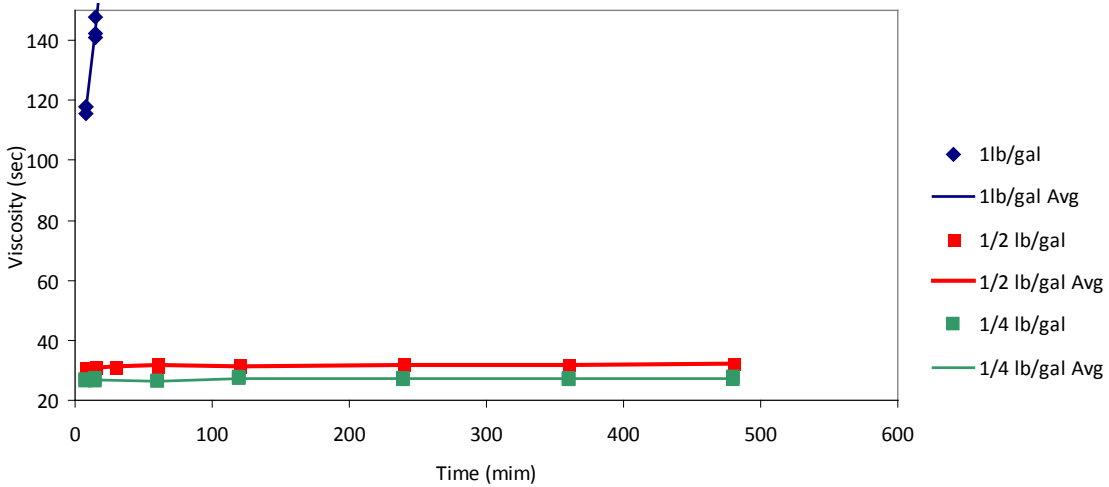




Laboratory Test Results

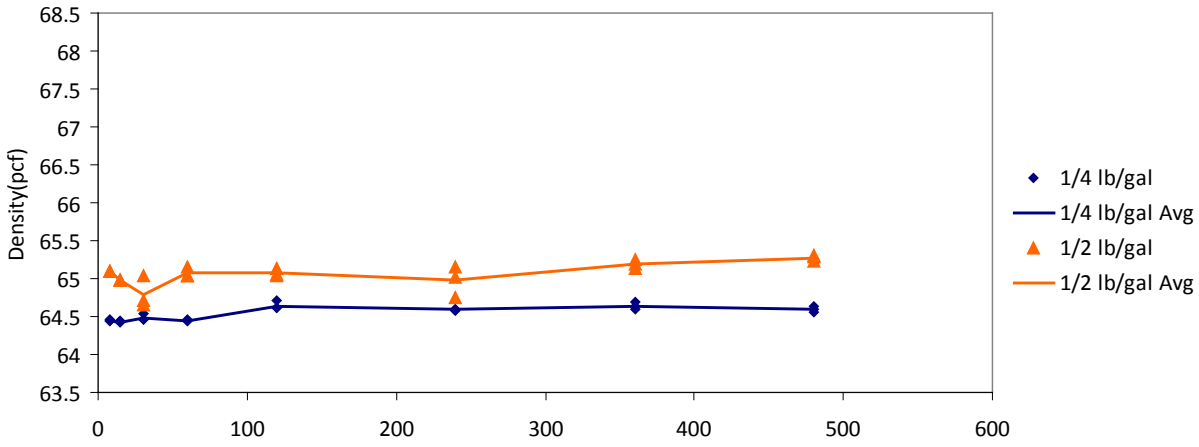
Wyo Ben Natural bentonite initial test results:

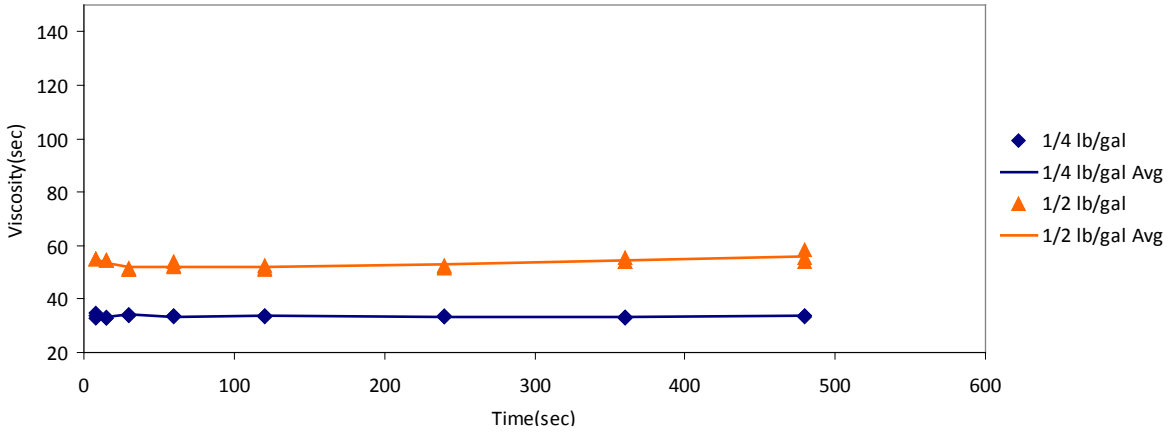




Laboratory Test Results

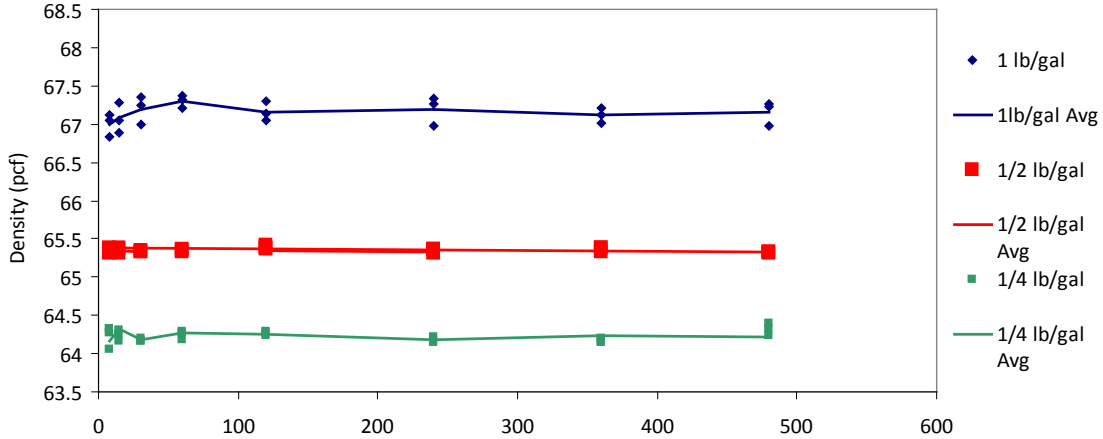
Super Gel X bentonite initial test results:

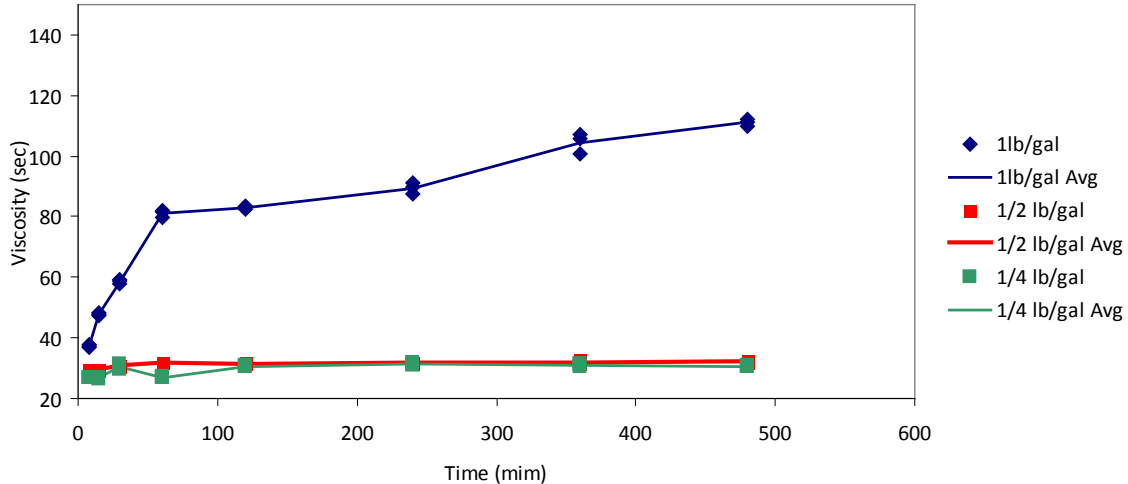




Laboratory Test Results

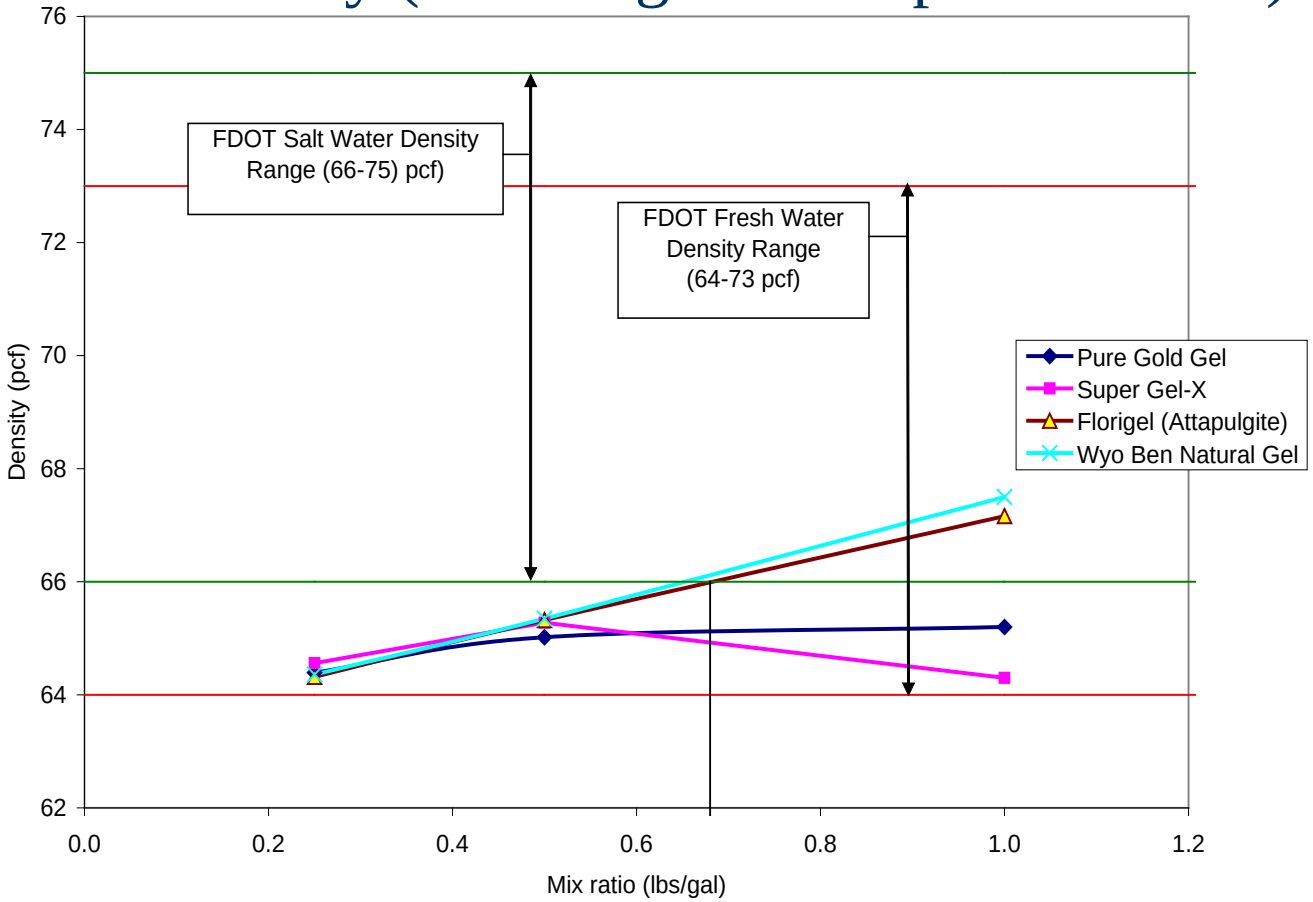
Florigel attapulgite initial test results:





Laboratory Test Results

Initial Test Summary (featuring FDOT specifications):



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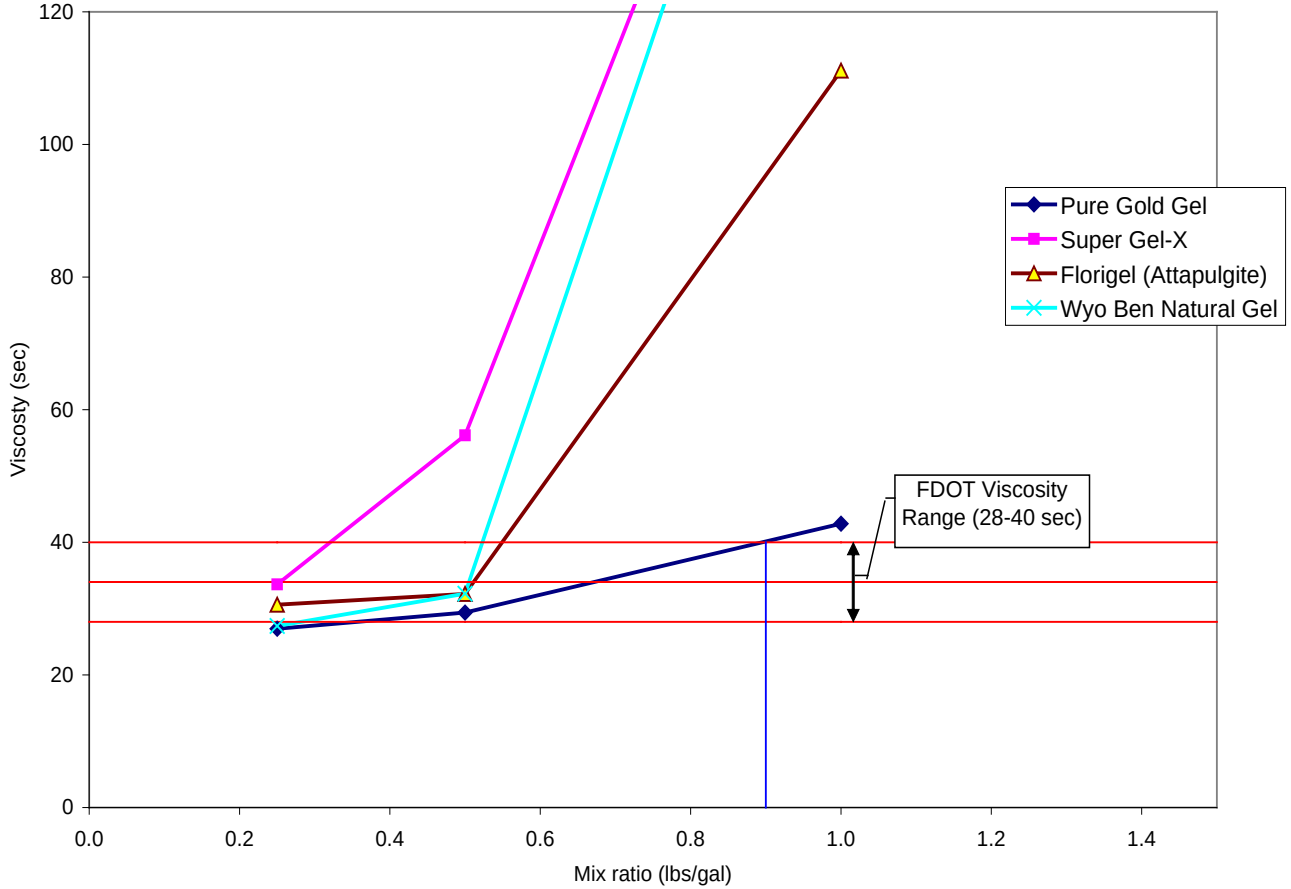


Laboratory Test Results

Initial Test Summary:

Product	Mix Ratio			Mixing Time (minutes)
	Viscosity (lb/gallon)	Density (lb/gallon)	Manufacturer Suggested	
Pure Gold	0.25-0.9	0.15 (min)	none	30
Wyo Ben Natural Gel	0.2-.05	0.15 (min)	none	15
Super Gel X	0.15-0.3	0.15-1.0	0.17	7.5-10
Florigel (attapulgite)	0.25-0.55	0.65 (max)	none	7.5-10

Laboratory Testing

To verify and better define slurry properties, further testing was conducted. Additionally another slurry product, Wyo Ben Extra High Yield, was added to the test matrix for testing.

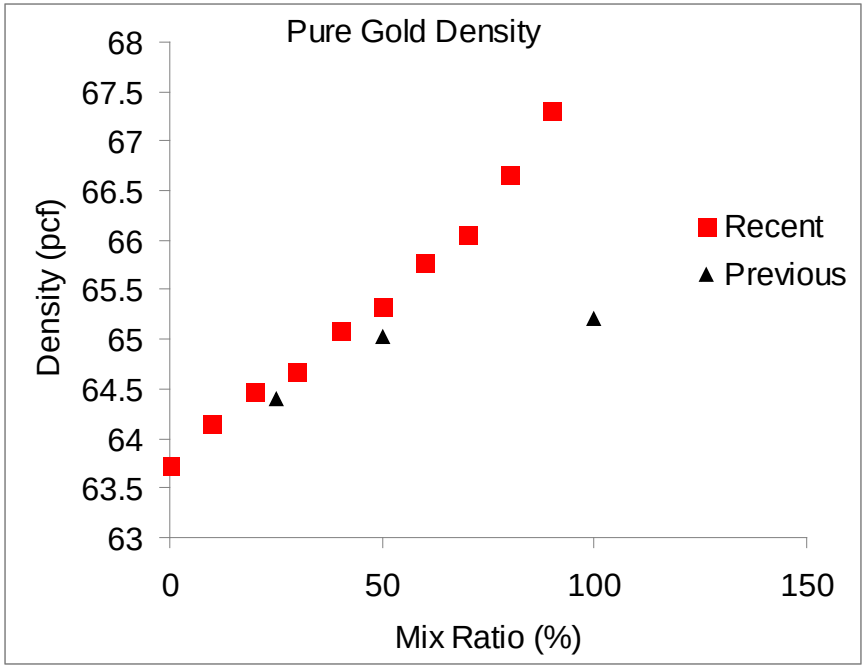
As before, a venturi hopper was utilized during the additional testing.

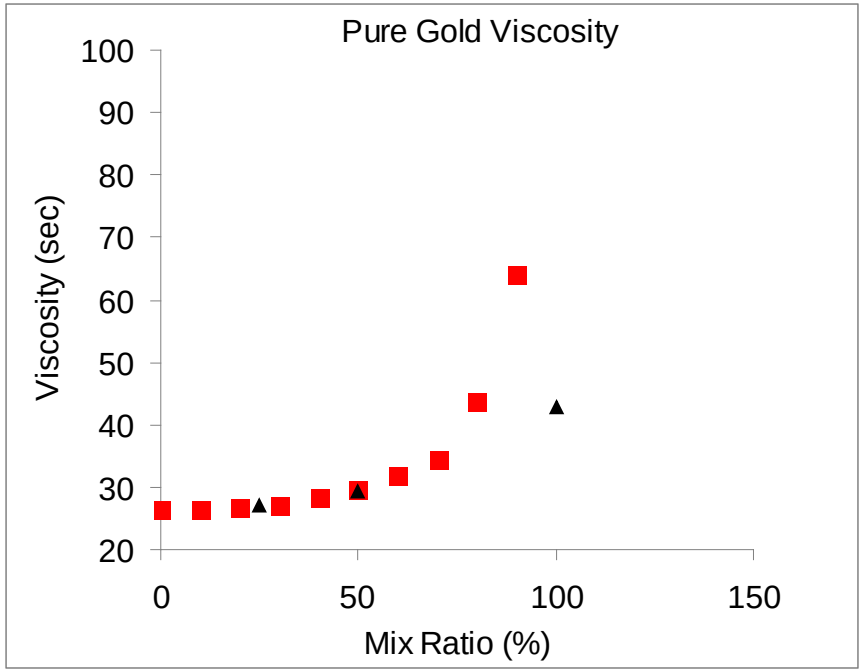
Tests consisted of:

- 100 gallons of potable water.
- Mix ratios from 0.1 lb/gal to 1.0 lb/gal, incremented by10%.
- Pumping rate of 60 GPM.
- Materials were recirculated for 30 minutes prior to testing.

Laboratory Test Results

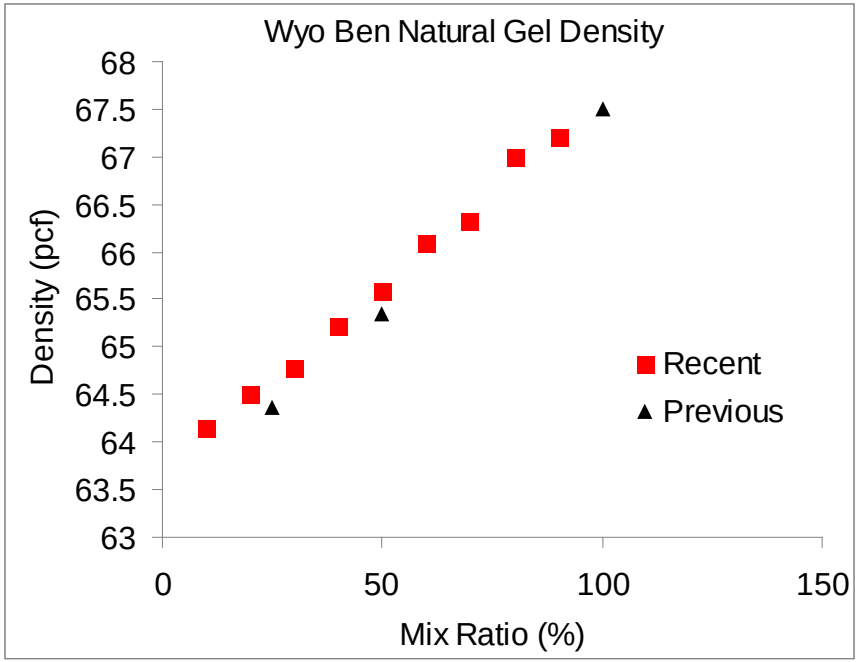
Pure Gold bentonite verification test results:

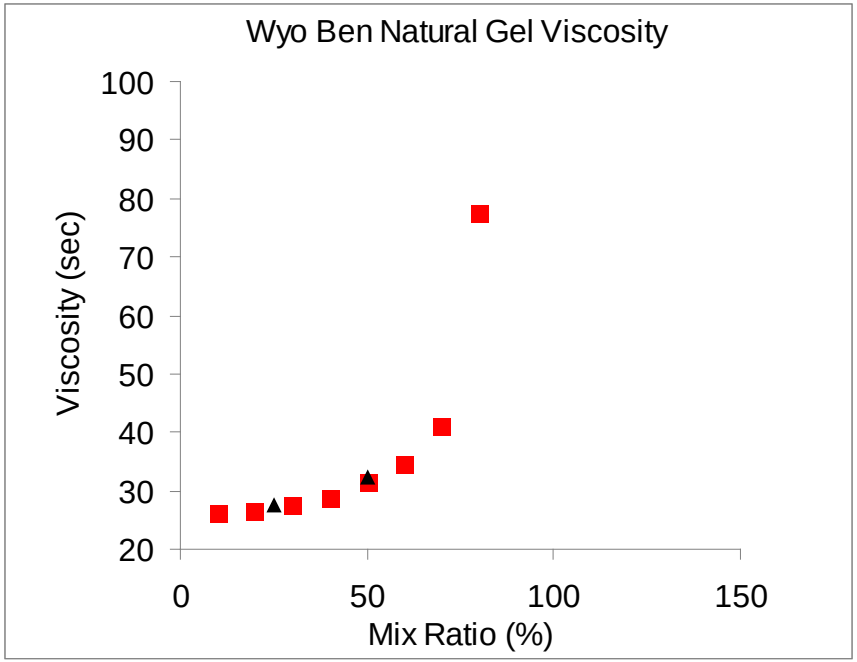




Laboratory Test Results

Wyo Ben Natural Gel bentonite verification test results:





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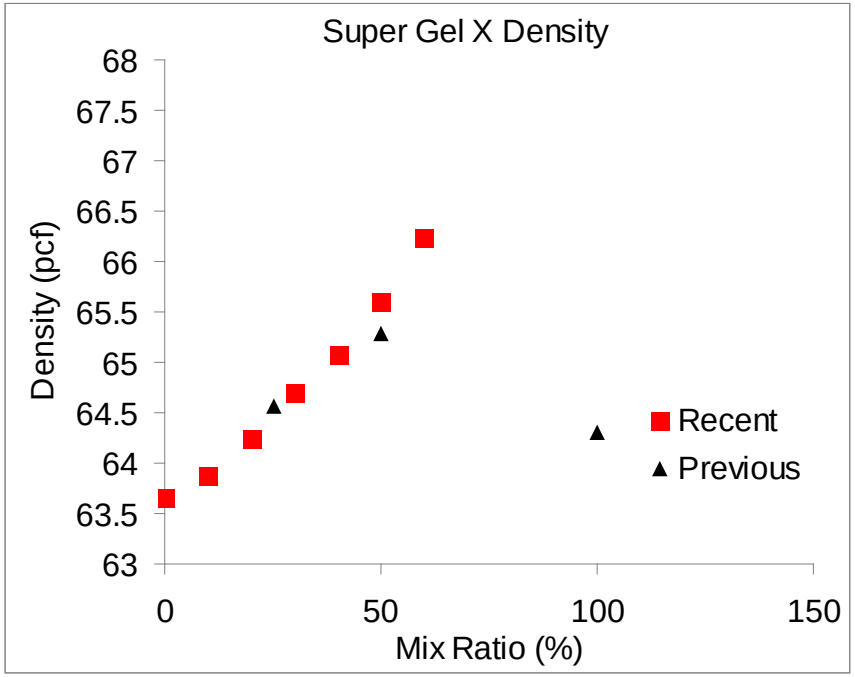

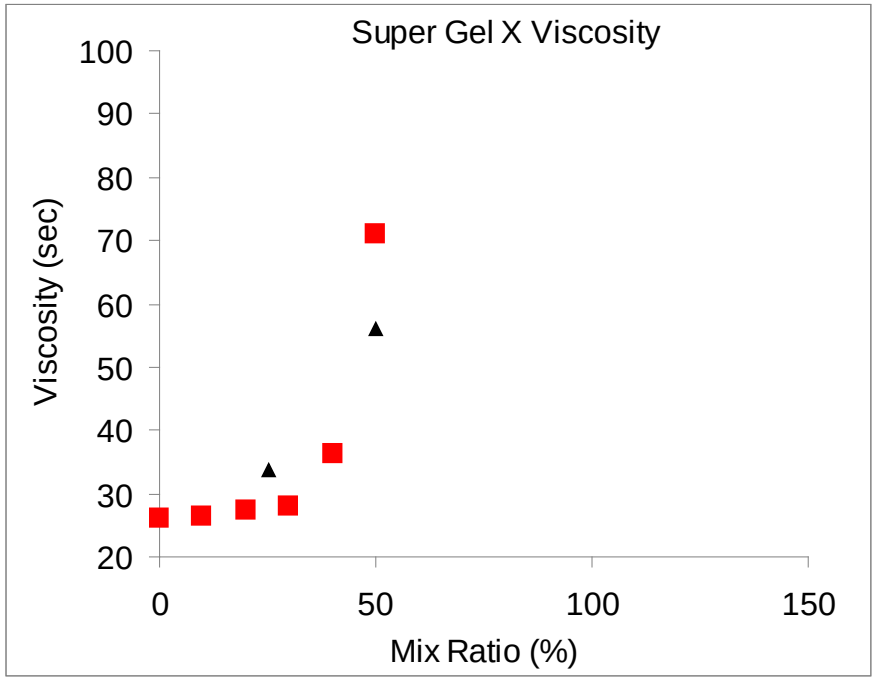

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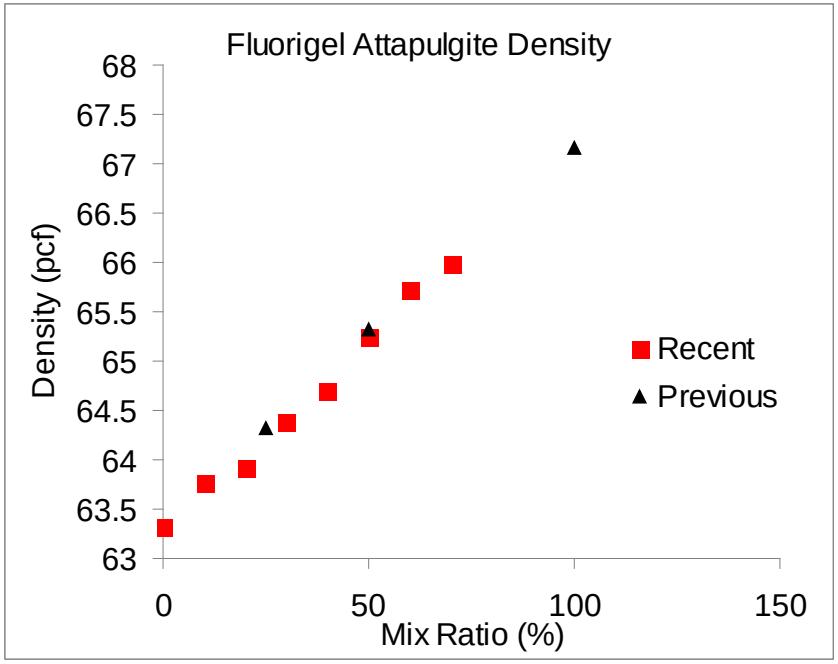
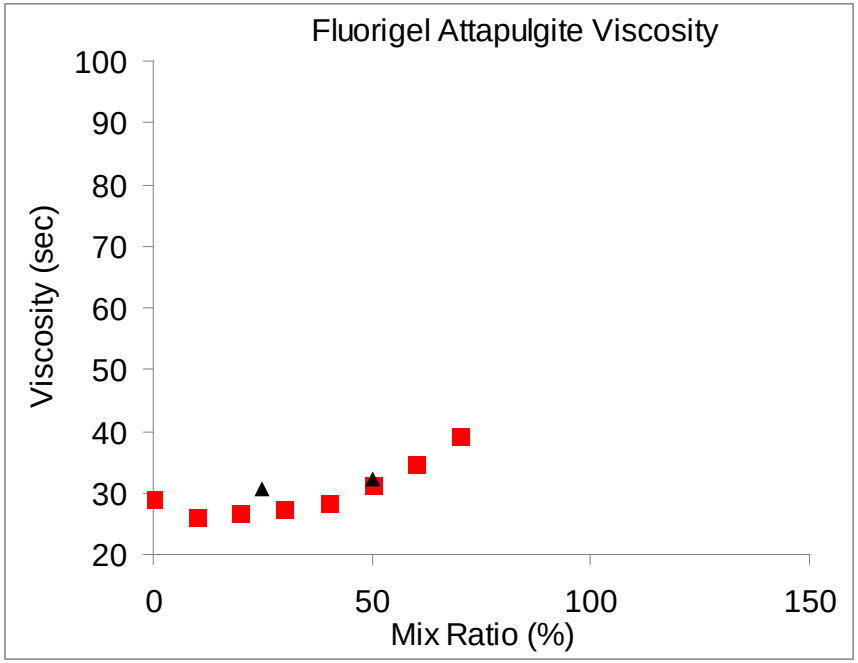
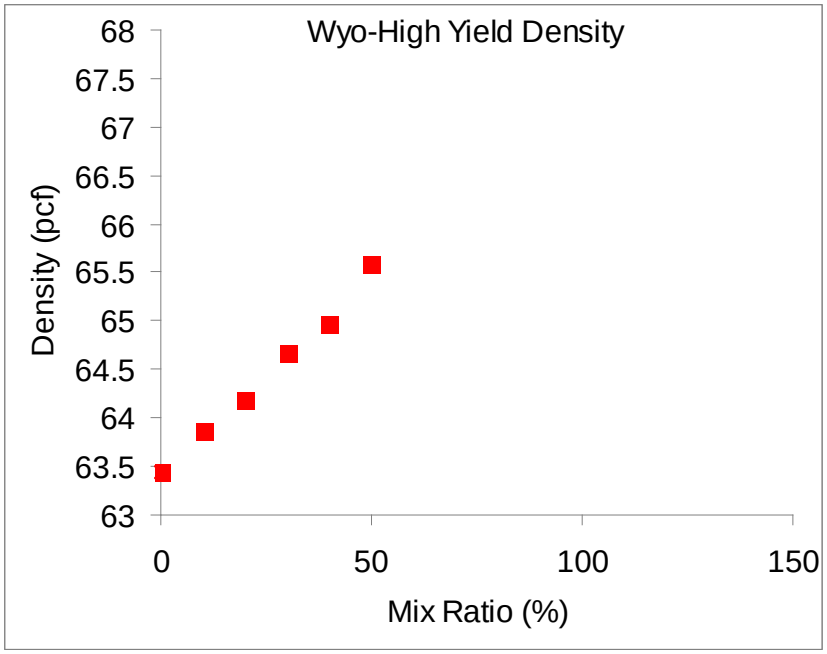
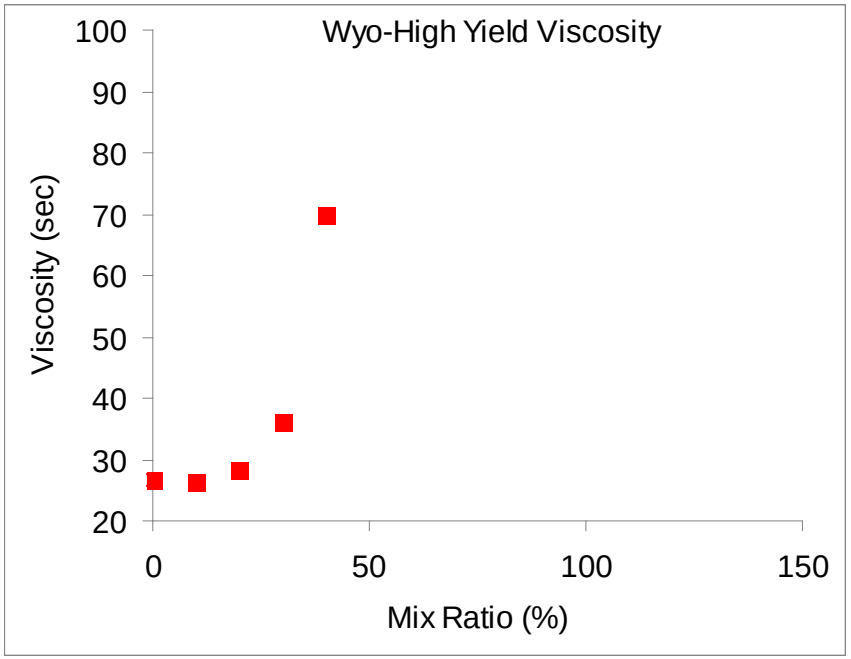




Laboratory Test Results

Wyo Ben High Yield bentonite verification test results:





Laboratory Testing

An effort to automate testing was made. In an attempt to correlate densities and Marsh viscosities to other properties, the mixing rig was outfitted with instruments to measure:

- Flow pressure (psi)
- Flow rate (GPM)
- Absolute viscosity (cPs)

Laboratory Testing

Automated Viscosity Measurements

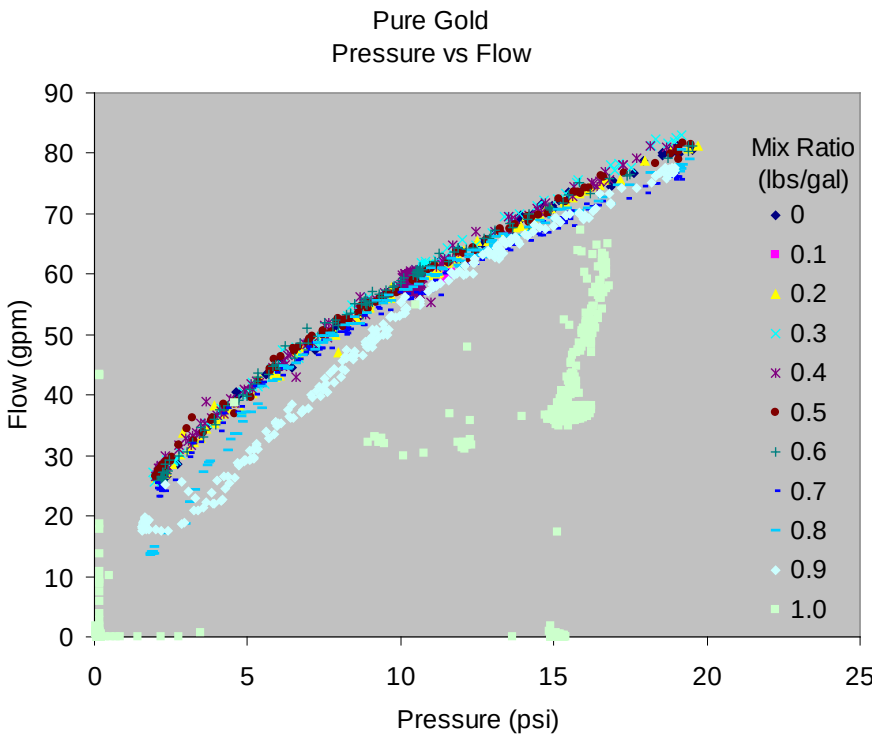
Although highly unpractical for field use, equipment capable of making automatic viscosity measurements is available, but quite expensive. These machines measure viscosity by:

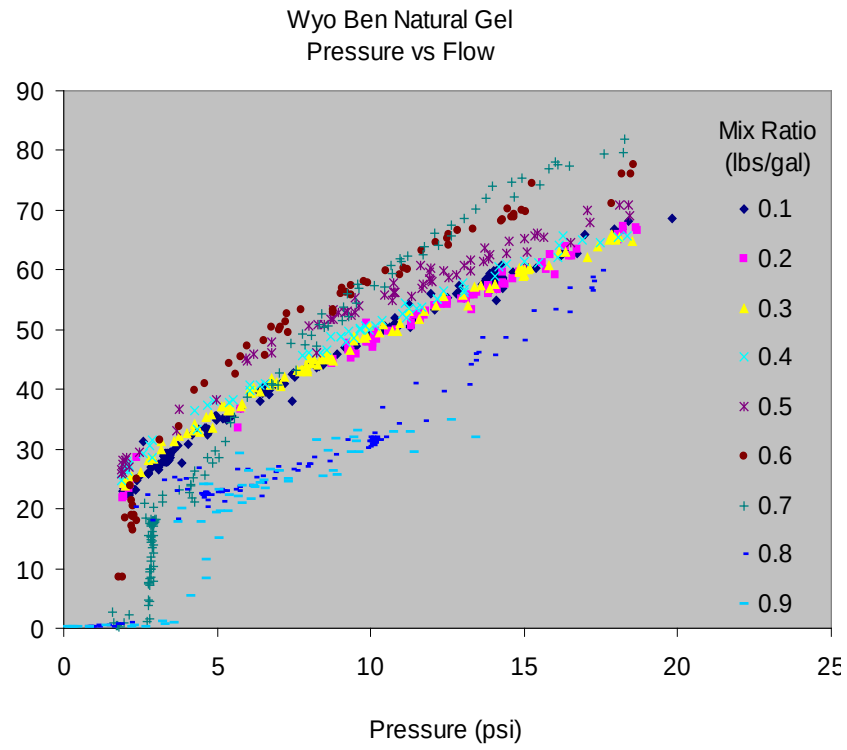
- Spinning a plate in fluid.
- Measuring drag on the plate.

These machines are very sensitive, and are easily disturbed by wind and vibrations.

Laboratory Test Results

Automated test results:





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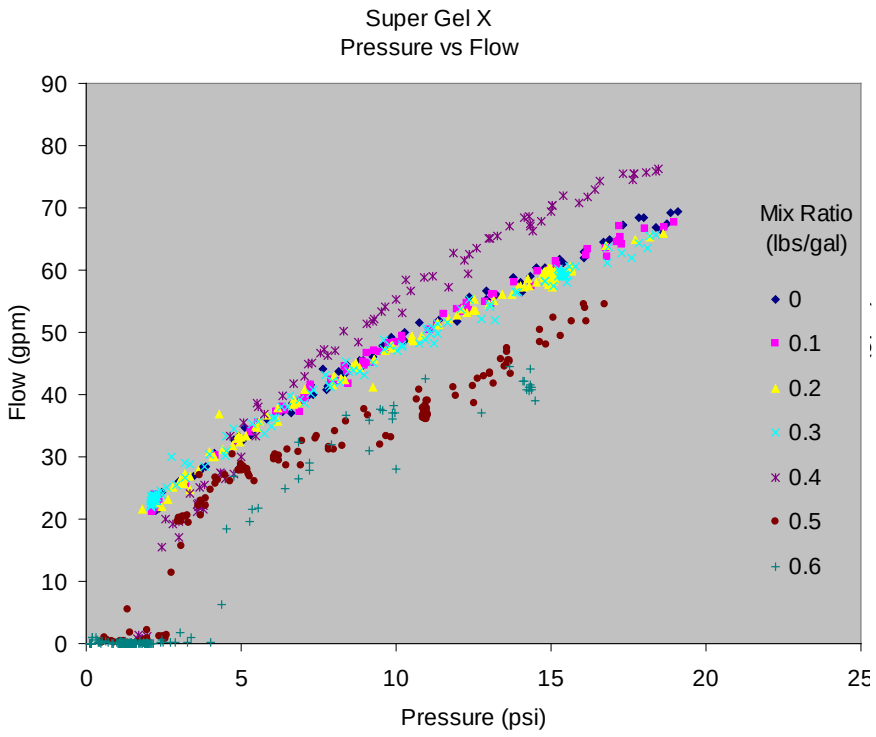

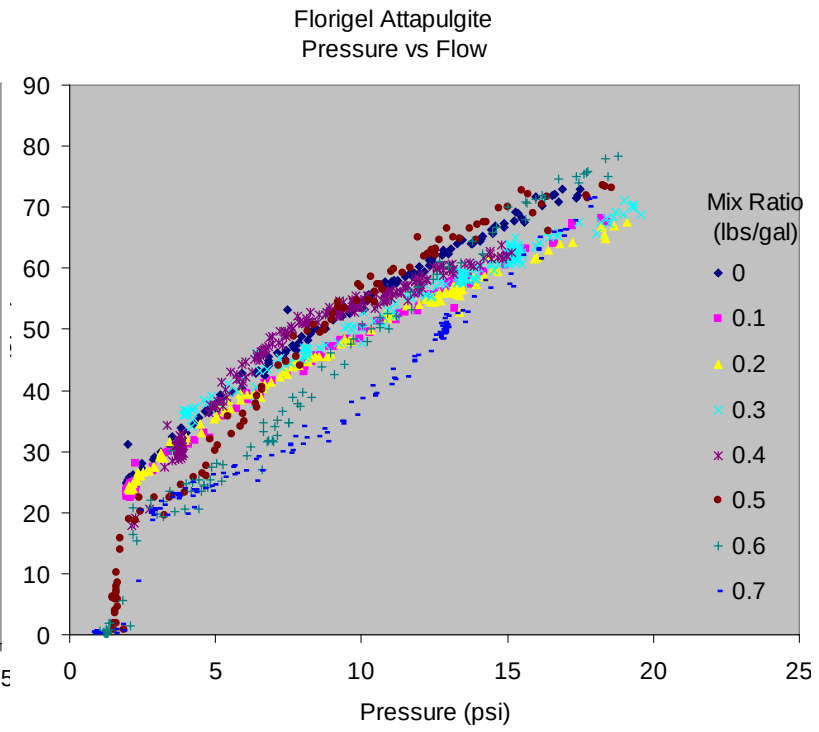

Laboratory Test Results

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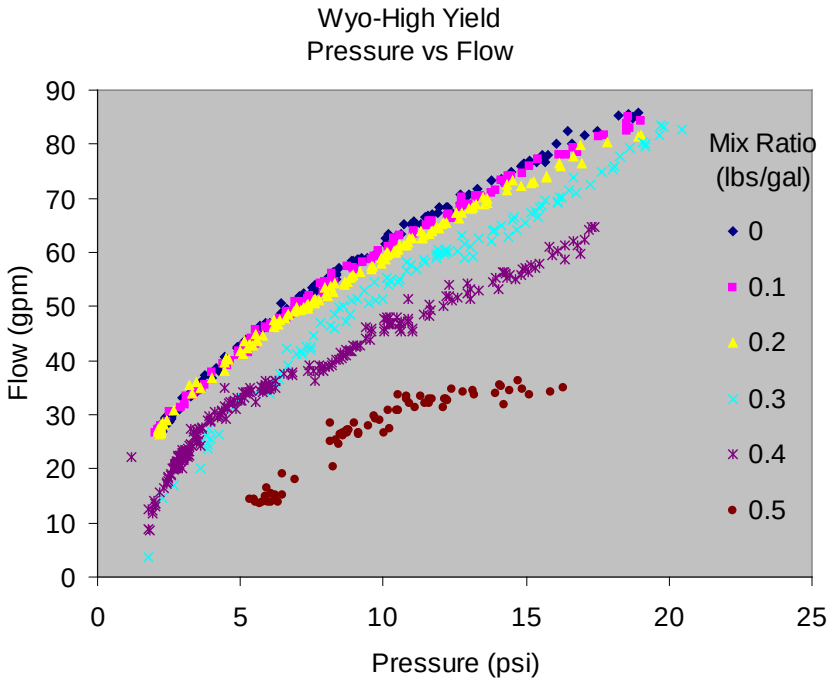


Laboratory Testing

Automated Slurry Testing Summary

Automated testing was plagued with problems, including:

- Wind and vibrational interference with viscometer.
- “Paddle-wheel” type flow meter yielded increasingly skewed results with increased slurry density.

Laboratory Testing

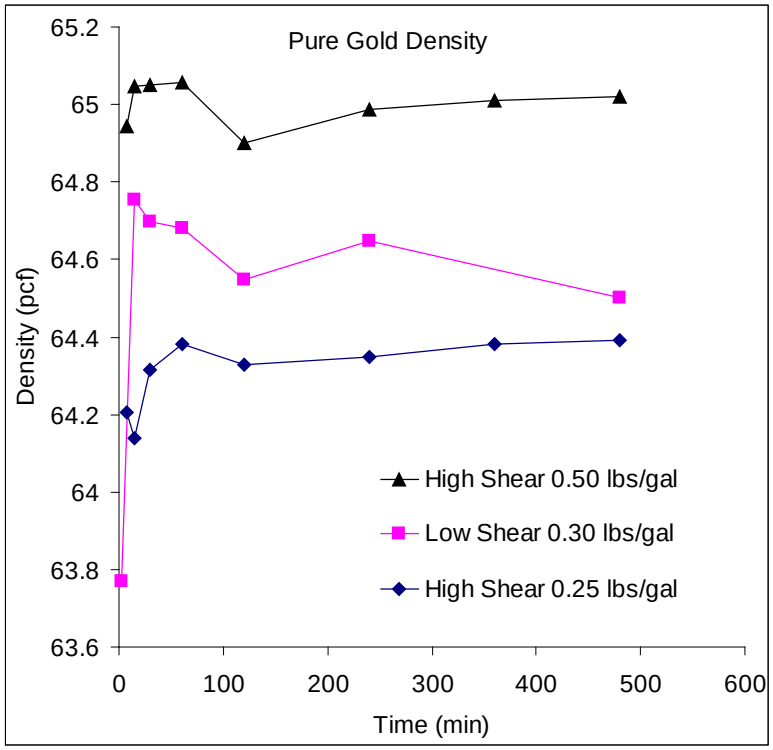
- Initially, mineral slurry mixing was performed with a high shear centrifugal pump.
- A low shear pump, incorporating a 3” diaphragm pump (5100 GPH max flow rate), was substituted for the high shear pump in additional testing.

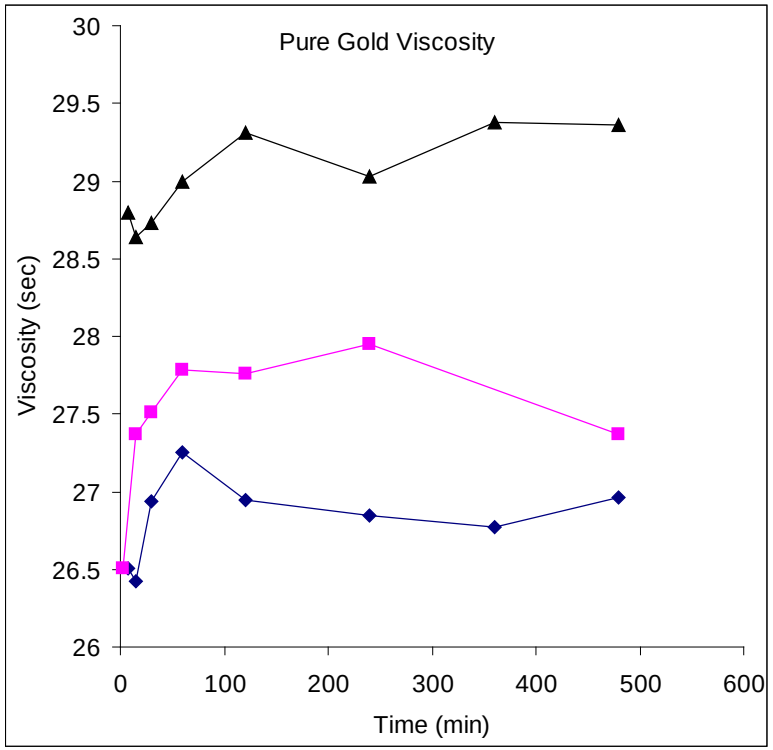
Laboratory Testing

Due to the limitations of the diaphragm pump, the mixing system was reconfigured, and a test matrix was developed for both high and low shear pumps on the reconfigured mixing rig.

Laboratory Test Results

High/Low shear test results





Laboratory Test Results

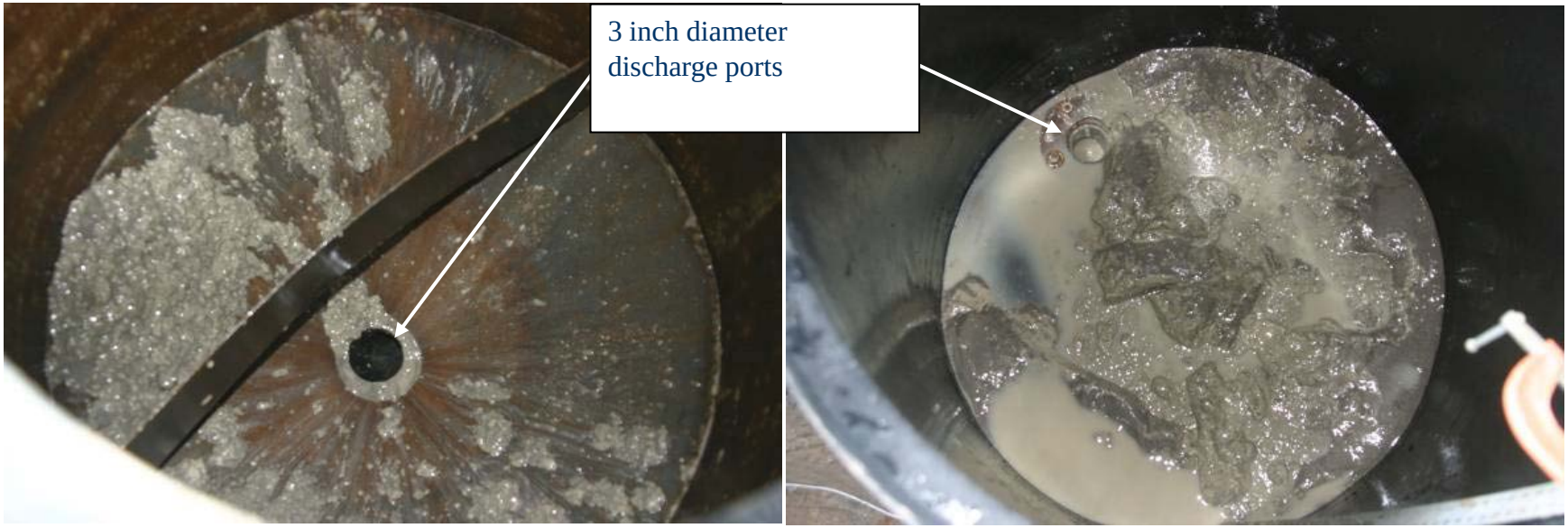
Unexpected results!

- No apparent effect of pump type observed.
- Low shear pump fell in line with previous test results based on mix ratio alone.
- Likely the result of the altered setup.
  - Mixing rigs disassembled to find cause of results.

Laboratory Test Results

A closer look…

- Flat-bottomed plastic tank with venturi hopper.
  - Allowed unmixed slurry powder to accumulate.
- Funnel-bottomed steel tank with powder simply dumped into top of tank.
  - Limited unmixed slurry powder accumulation.



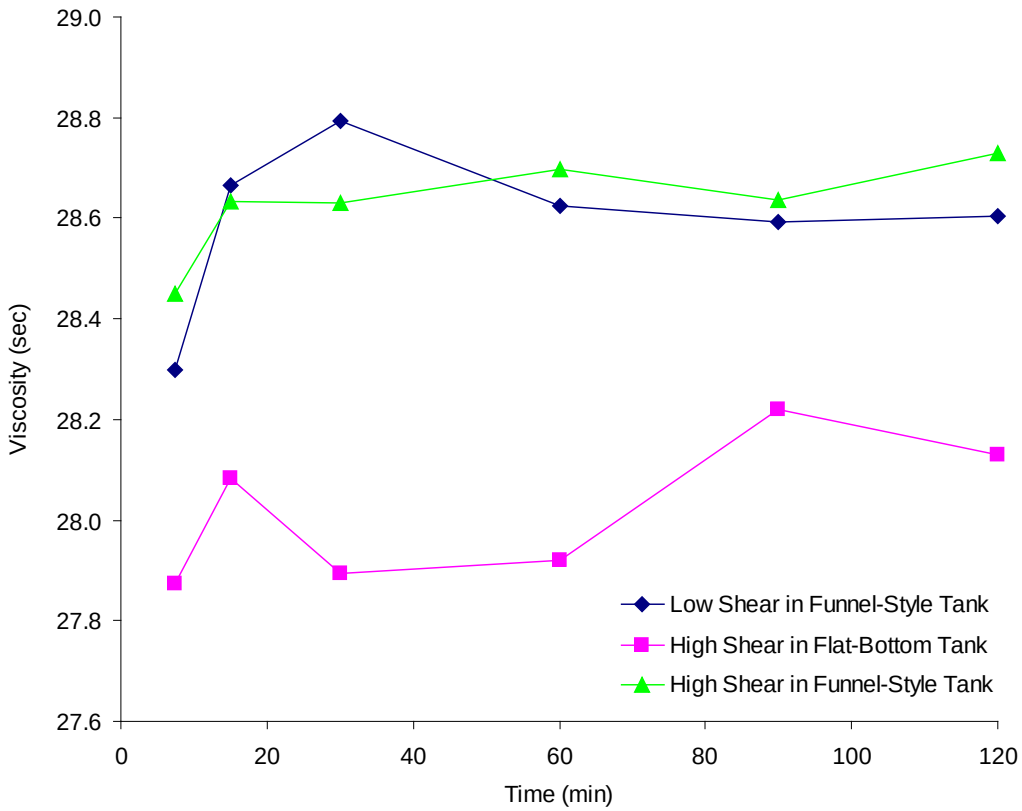
Laboratory Testing

Altered test setup:

- High shear pump plumbed with venturi hopper on funnel-bottomed tank

Laboratory Test Results

High shear pump plumbed with venturi hopper and funnel-bottomed tank.



Advancements in Rapid Slurry Production

Goals:

- Increase introduction rate of mineral powder.
- Eliminate hopper clogging/clumping.

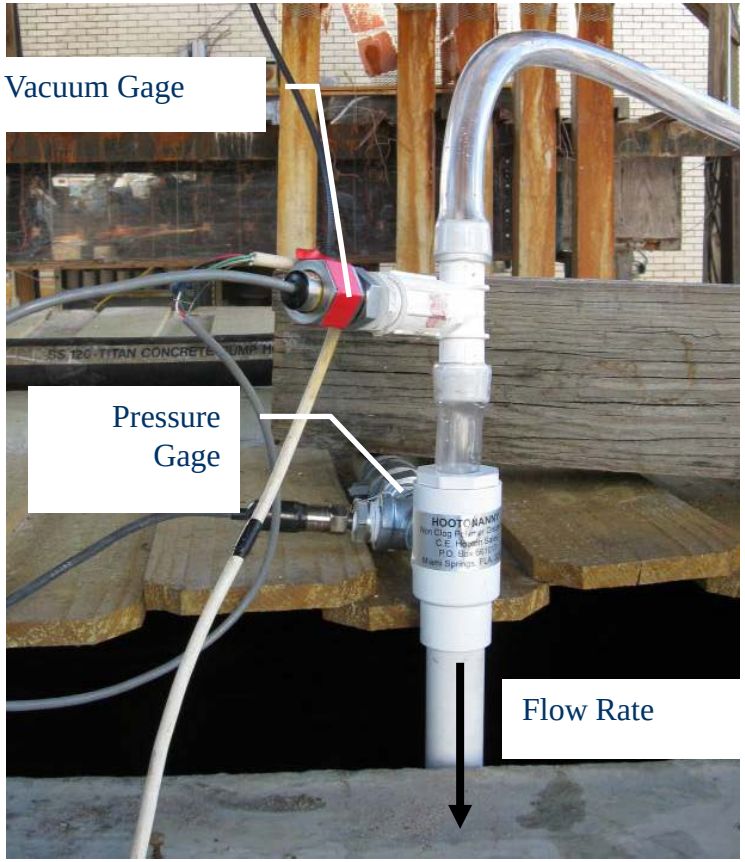
Solution:

- Teflon-lined eductors,

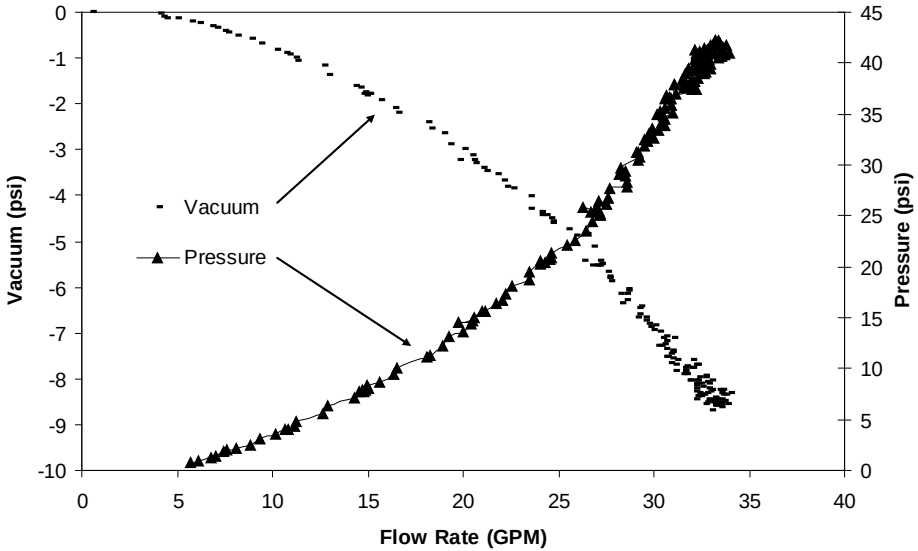
  widely known as the “Hootonany”.

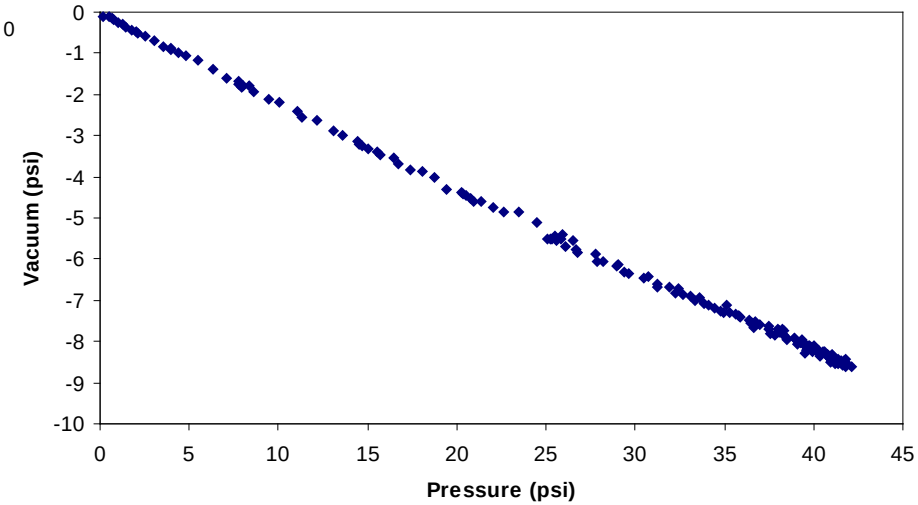
Advancements in Rapid Slurry Production

Initially, individual “Hootonanies” were evaluated.



Advancements in Rapid Slurry Production





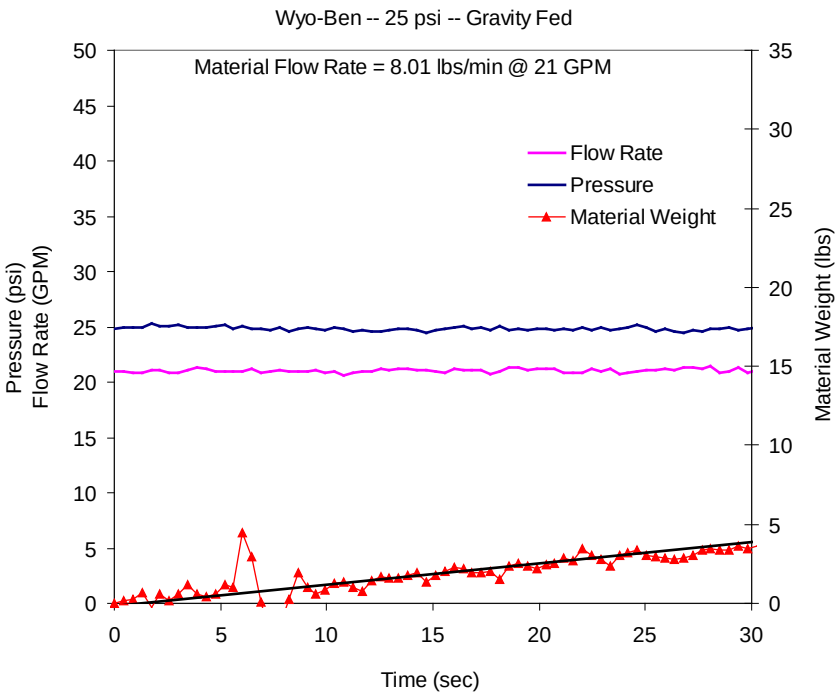
Advancements in Rapid Slurry Production

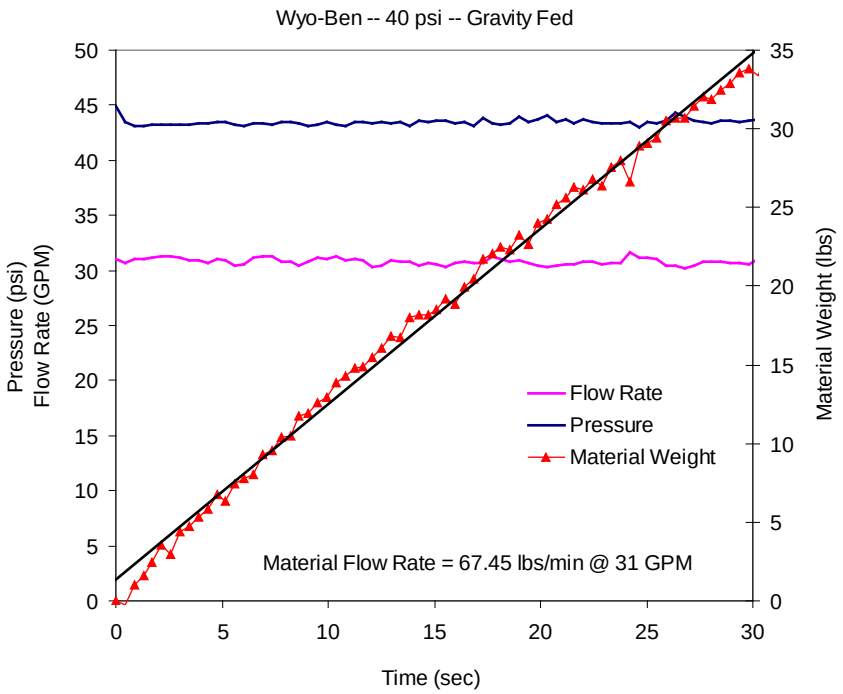
Some eductor suppliers offer additional components, such as large capacity funnels/hoppers and mounting hardware. To select the proper hardware, testing was done to determine the highest powder-introductory flow rates.

Pressure (psi)	Flow Rate (GPM)	Mix Ratio (lbs/gal)	Material	Test Type
25.25	21.08	0.43	Wyo Ben	Gravity Fed - Loose
43.46	30.79	2.19	Wyo Ben	Gravity Fed - Loose
44.74	29.70	0.32	Super Gel X	Vacuum – Wide Opening
46.14	29.13	0.79	Super Gel X	Gravity Fed - Loose
22.88	25.29	0.26	Super Gel X	Vacuum – Standard Opening
34.01	30.64	0.19	Super Gel X	Vacuum – Standard Opening
40.33	33.41	0.23	Super Gel X	Vacuum – Standard Opening
18.89	23.16	0.38	Super Gel X	Gravity Fed- Standard Opening
30.92	29.83	0.29	Super Gel X	Gravity Fed- Standard Opening
39.20	34.00	0.83	Super Gel X	Gravity Fed- Standard Opening

Advancements in Rapid Slurry Production

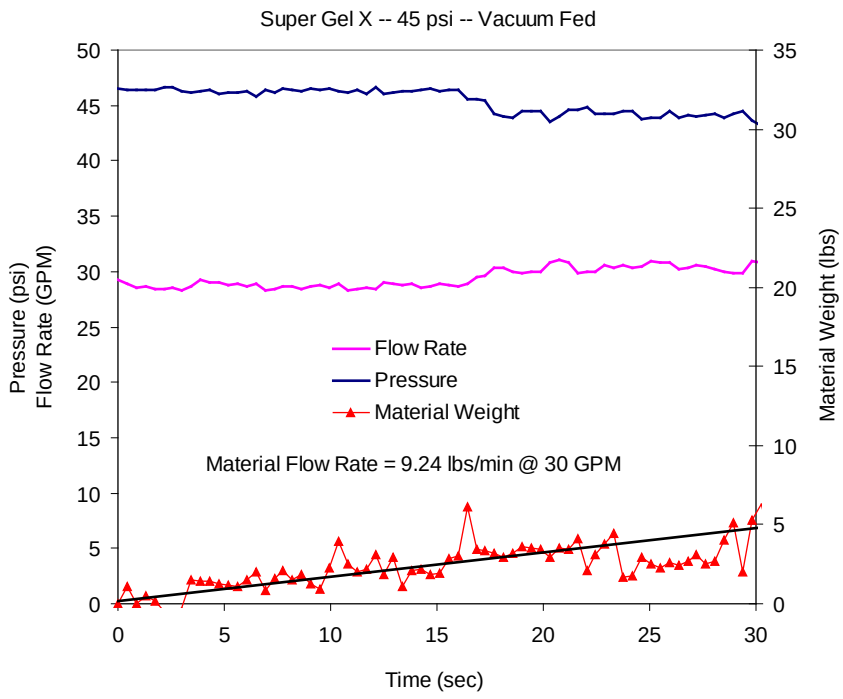
Feed Testing

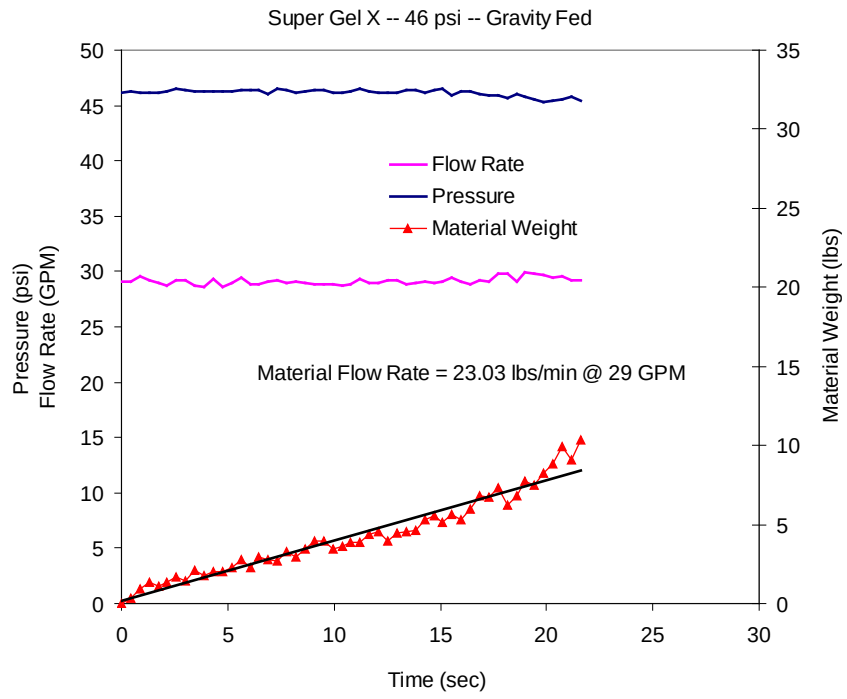




Advancements in Rapid Slurry Production

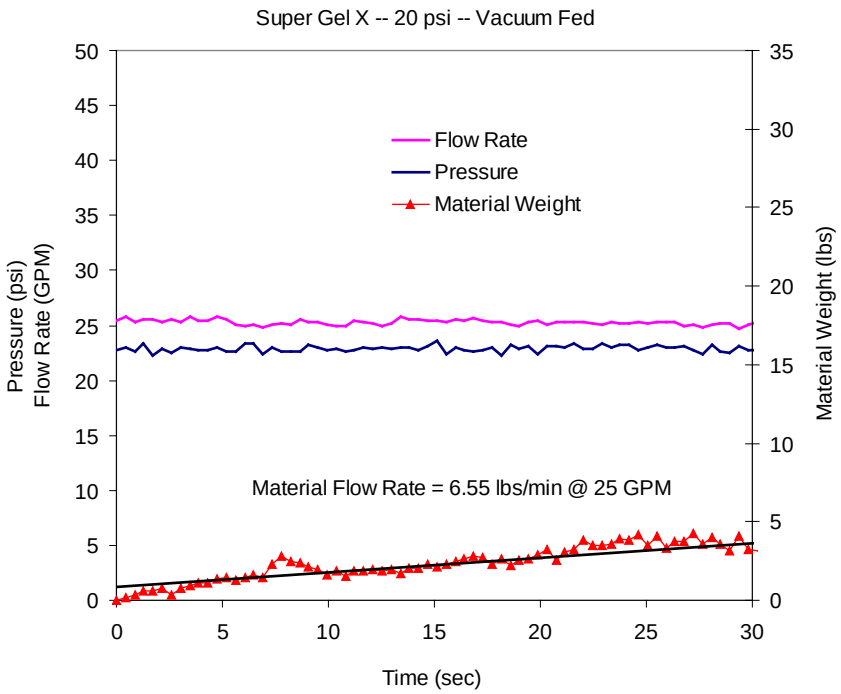
Feed Testing

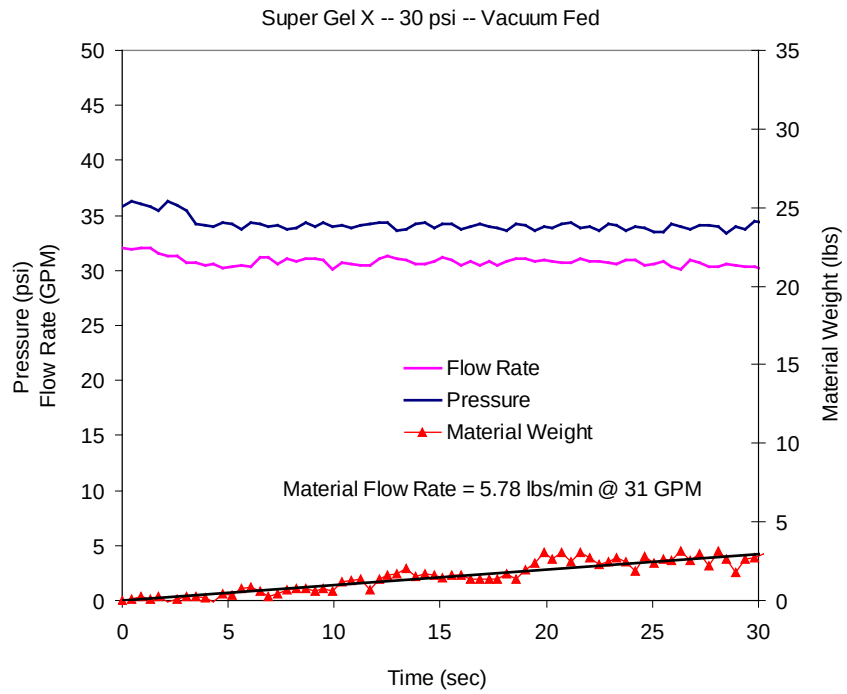




Advancements in Rapid Slurry Production

Feed Testing





Advancements in Rapid Slurry Production

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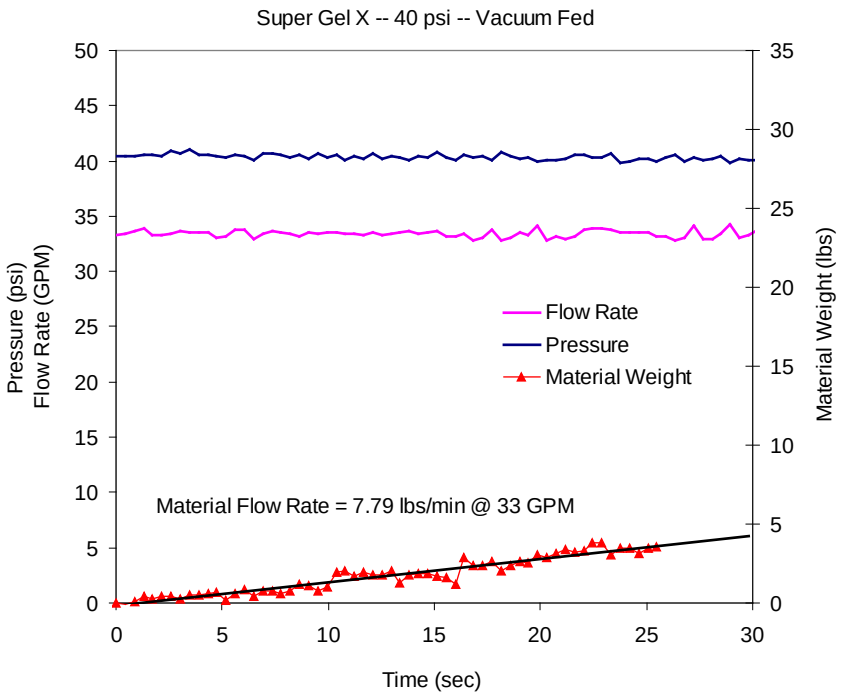
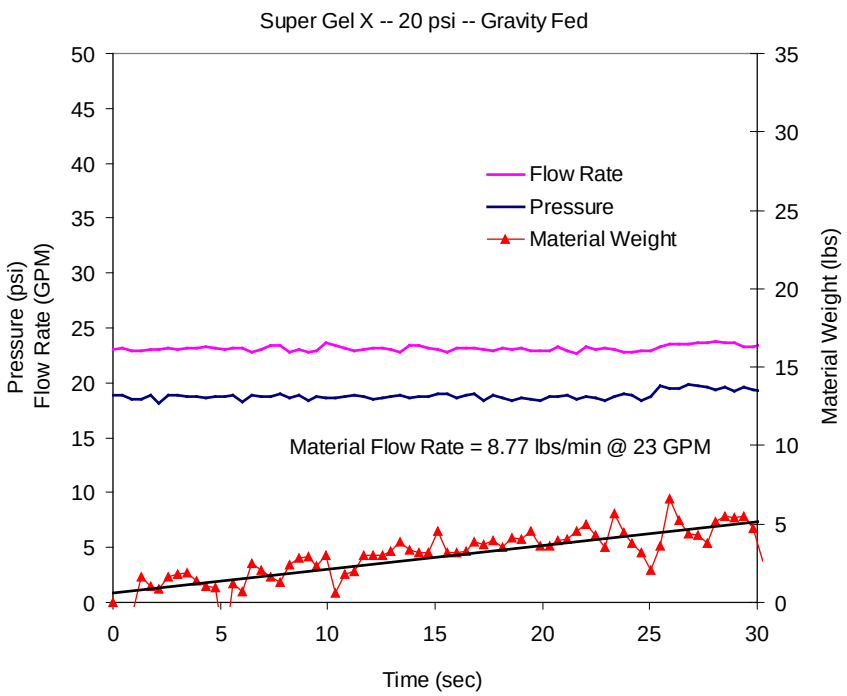
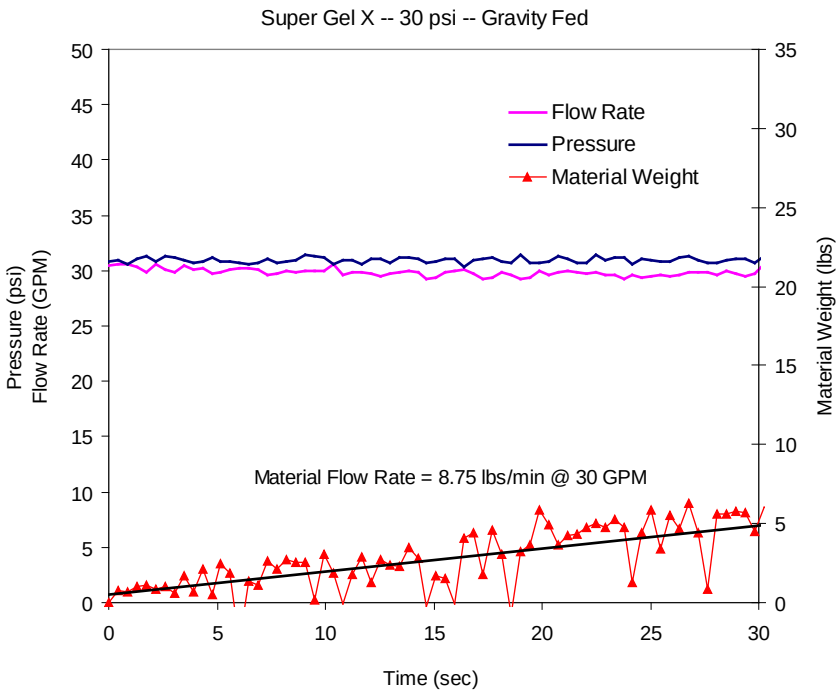
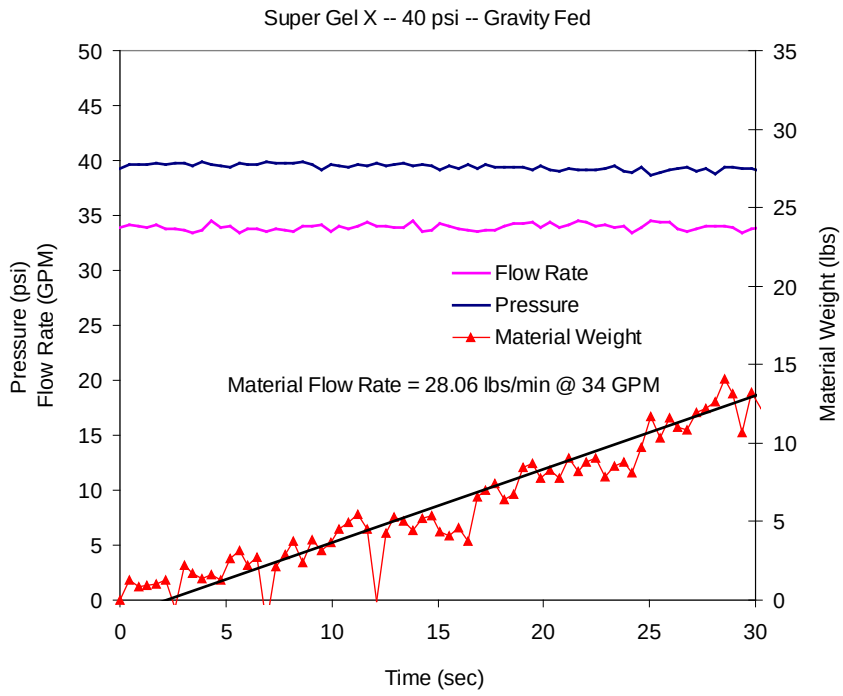




Advancements in Rapid Slurry Production

Feed Testing

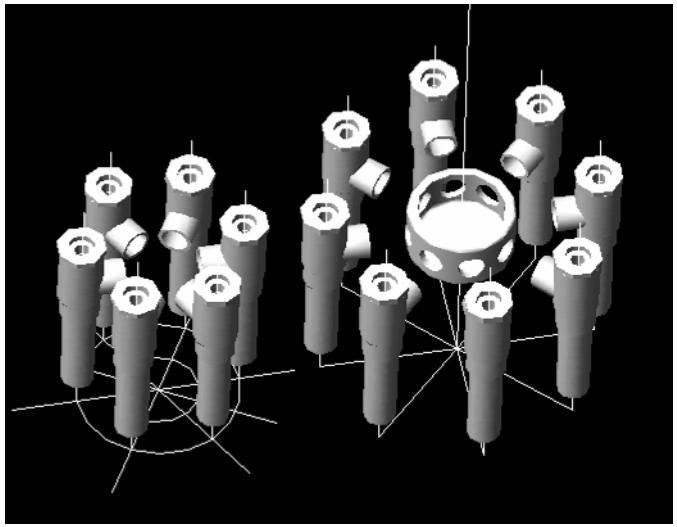




Advancements in Rapid Slurry Production

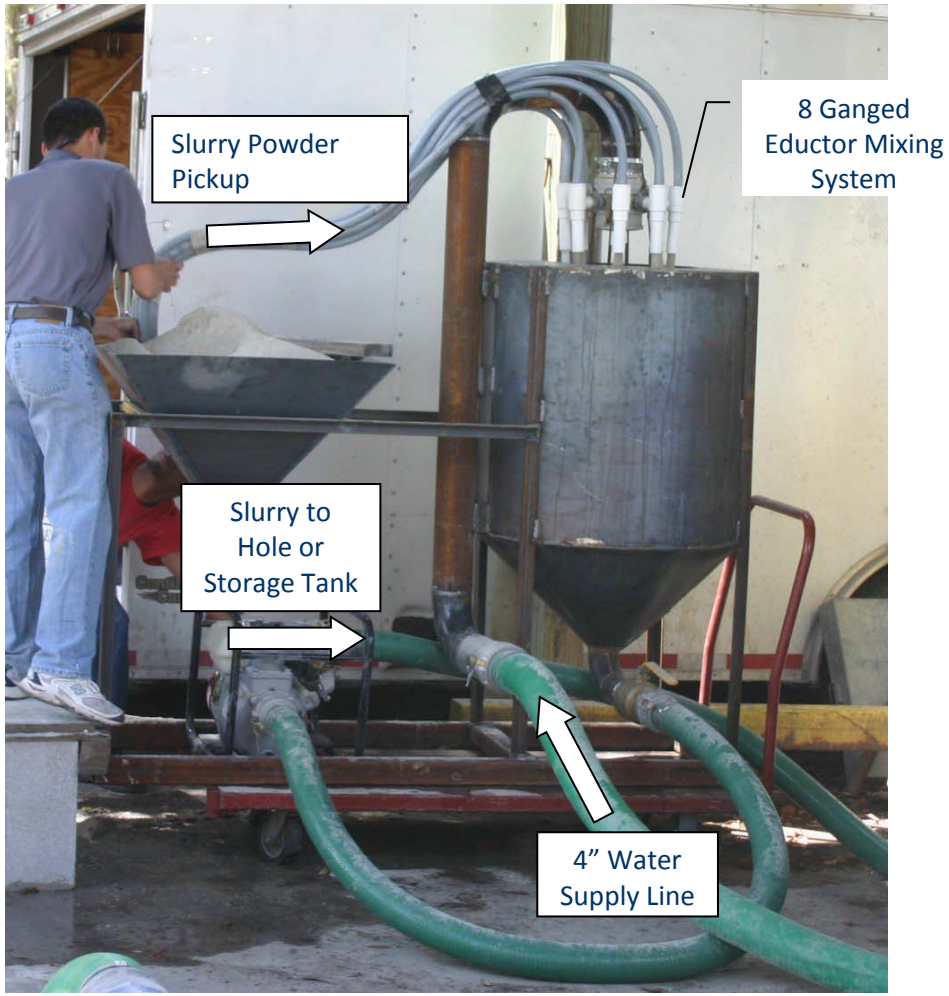
- "Hootonanies" mix slurry well without modification.
  - Mix at slow rate – 5-8 lbs/min, vacuum fed with standard opening.
    - Assuming 2-2.5 lbs of powder per ft^3 is required, it would take 1 "hootonany" up to 3 hours to produce 2000 gallons of slurry!
- To increase slurry production, a "multi gang eductor unit" was fabricated and plumbed inline with a pump capable of supplying 240 GPM while operating at 30 psi.

Concept Drawings



Advancements in Rapid Slurry Production

The “multi gang eductor unit” was placed on the funnel-bottomed hopper for testing.



Advancements in Rapid Slurry Production

Advancements in Rapid Slurry Production

- "Multi-gang eductor unit" testing
- Goal: Produce 1000 gallons of useable slurry.
  - 1000 gallons of potable water.
  - 300 lbs. of "Pure Gold" slurry powder.

Mixing Time (min)	Fluid Volume (gal)	Mix Ratio (lbs/gal)	Viscosity (sec)	Density (lb/ft^3)	pH
2.72	593.73	0.51	30.0	65.49	8
3.05	673.2	0.45	29.8	65.47	N/A

- Mix ratio higher than anticipated.
  - 0.45-0.51 lbs/gallon rather than 0.3 lbs/gallon.
- Solution:
  - Less vigorous vacuuming action.
  - Reduced number of eductors.

Field Demonstrations

- Two field demonstrations were carried out.
  - Small scale slurry mixing – exploratory type drilling.
  - Large scale slurry mixing – drilled shaft construction.

Field Demonstrations

- Small scale – exploratory drilling
- Rather than “sprinkling” bentonite over the water in the pan, an eductor was fitted to the pan.
- Powder was vacuumed up as the pan was filled, producing instantly useable slurry.

Field Demonstrations

- Large scale – drilled shaft construction
- Local contractor, R.W. Harris, agreed to test the multi-gang eductor unit on a large project, featuring 44 drilled shafts.
- Complications arose during training.
  - The eductors require debris free water, otherwise, clogging ensues.

Field Demonstrations

- Large scale – drilled shaft construction
- R.W. Harris personnel training – Powder vacuuming.

Field Demonstrations

- Large scale – drilled shaft construction
- R.W. Harris personnel training – Clogged eductor cleaning.
  - Remove set screw
  - Remove Teflon nozzle
  - Clean Teflon body

Field Demonstrations

- Large scale – drilled shaft construction
- R.W. Harris personnel training – Testing slurry viscosity
  - Immediately after mixing
  - Within excavation

Field Demonstrations

- Large scale – drilled shaft construction
- Recommendations for field use:
  - Only hydrants may be trusted as a water source.
  - Large surface-area inline screens should be used for feed water.
  - When reducing the number of eductors used, those remaining "offline" should be used as back-ups, only to be introduced if required.
  - Slurry quality may be tailored to fit desired attributes with an initial pilot volume, from which the correct number of eductors may be put online.

Field Demonstrations

- Large scale – drilled shaft construction
- Recommendations for field use:
  - Present system makes use of 4” pump to provide clean water. Water truck may be used to provide clean water as needed.
  - 3” pump on system may be used to transport slurry from tank to excavation as needed.
  - Holding tank may not be required if sufficient surface casing volume is provided to store additional slurry above that required to maintain sufficient head differential with existing groundwater table.

Conclusions

- High water table present in most of Florida.
  - Most drilled shaft excavations utilize slurry stabilization, avoiding expensive full-length temporary casings.
- The most widely accepted (possibly most effective) slurry type is bentonite mineral slurry.
  - Slurry formed by mixing dry bentonite powder with water.
  - Attapulgite powder is used in place of bentonite when saline conditions are present.
- Slurries require adequate mixing to ensure desired fluid properties arise from fully hydrated minerals.
  - Florida features performance driven specifications, allowing any means of production of mineral slurry to meet specifications.

Conclusions

- Five slurry products tested.
  - Two products – pure bentonite powders
    - Only products to truly meet FDOT specifications.
  - One product – high yield attapulgite
  - Two products – polymer modified bentonite products
    - Although called “High Yield Bentonite” and commonly used in practice, these do not truly meet FDOT specifications!
- Minimum viscosity and density may be met using mix ratio of 0.2 to 0.25 lbs of dry powder per gallon of water.
- When powder is introduced in a controlled fashion viable slurry may be produced using conventional centrifugal pumps in 15 to 30 minutes.

Conclusions

- Extended testing of slurry mixes, for up to 8 hours, showed little to no change in slurry properties.

Minimum Mix ratios and mix times for pure bentonite or attapulgite.

Product	Mix Ratio			Minimum Mixing Time
	Viscosity (lb/gal)	Density (lb/gal)	Manufacturer Suggested	Minutes
Pure Gold Gel	0.25-0.9	0.15 (min)	None	30
Wyo Ben Natural Gel	0.2-0.5	0.15 (min)	None	15
Florigel (Attapulgite)	0.25-0.55	0.65 (min)	None	7.5-10

Conclusions

- In practice:
  - Controlled inflow of bentonite into venturi hopper (as performed in this study) is not realistic.
  - Typically, the hopper is filled to capacity and agitated as necessary.
- The required amount of mineral typically could not be introduced while initially filling.
  - Target volume of slurry was reached and recirculated through the venturi hopper until the target mix ratio was achieved.

Conclusions

- Cost – effective and feasible solution for field use:
  - Use of non-clog, Teflon-lined eductors capable of drawing 0.3-0.5 lbs of powder per gallon of incoming water.
- Two trial batches, targeting 300 lbs of powder in 1000 gallons of water were prepared at a rate of 220 GPM.
  - Mixes resulted in mix ratios of 0.45 – 0.51 lbs/gal
  - Mixes resulted in viscosities of 29.8 sec – 30 sec
  - Mixes resulted in densities of 65.47 pcf – 65.49 pcf
- Trial batches fell within FDOT specifications
  - Viscosity: 28 – 40 seconds
  - Density: 64 – 73 lb/ft^3

Conclusions

- Initial contact between water and dry powder while using eductors produces very little sediment and no clumping.
- If vacuuming is too vigorous on the multi-gang eductor unit, one or more eductor units may be excluded from mixing to produce desired slurry characteristics.

Thank you