Supplemental Sediment Handling Characterization Report

Glass Furnace Technology

May 30, 2003

Prepared for:

Wisconsin Department of Natural Resources

MINERGY™
A WISCONSIN ENERGY CORPORATION

Table of Contents

1.0 INTRODUCTION

Minergy Corporation respectfully submits this document to the Wisconsin Department of Natural Resources (the "Department") to report on supplemental testing and characterization of sediment. The activities associated in this report are in conjunction with the Glass Aggregate Feasibility Study (the "Study") under the agreement between Minergy and the Department dated September 21, 2000, (State of Wisconsin purchase order numbers NMJ00001936 and NMB00000488).

1.1 Background

The purpose of the Study is to evaluate the economic and technical feasibility of melting PCB contaminated river sediments in a glass furnace. The Glass Furnace Technology (GFT) was developed by Minergy. Minergy originally developed vitrification technologies to process wastewater sludge into glass aggregate that could be sold as a commercial product. The technology was evaluated during a U.S. Environmental Protection Agency Superfund Innovative Technology Evaluation (SITE) Program demonstration at the Minergy facility in Winneconne, Wisconsin, in August 2001. The SITE program evaluated the technology's ability to treat sediment containing PCBs and mercury. Because the GFT process requires the river sediment to be greater than 90 percent solids prior to loading into the melter, the SITE program also evaluated a bench-scale dryer technology as a secondary activity. The sediment for this evaluation was dredged from the Lower Fox River, dewatered, and filter pressed.

1.2 Rationale for the Study

The GFT process is capable of treating PCB-contaminated sediment containing other organic and inorganic contaminants. Contaminated sediment is a relatively common problem throughout the Great Lakes Basin, with sediment removal generally being the most preferred remediation method. Currently, the public, particularly on a local scale, is reluctant to accept placing PCB- and mercury-contaminated sediments in landfills. The public has also expressed a desire to further explore remediation technologies that reduce the contaminant exposure pathway. The GFT potentially can help address the problem of landfilling contaminated dredge materials.

Providing environmentally acceptable and cost-effective disposal of contaminated sediment would allow for more effective and publicly acceptable cleanups.

1.3 Beneficial Features of GFT

The GFT process has many beneficial features for treatment of dredged sediment. The primary feature of the GFT is that the system is designed to create a high quality glass from the mineral component of the sediment. The glass making process uses high temperatures (2600-2900 degrees F) to melt the minerals contained in the sediment. These high temperatures result in very high destruction efficiency of PCBs and other organic contaminants. The GFT process avoids landfilling of sediment, as the glass product is readily sold to construction companies. Because the final product is glass, it is very inert and does not leach into the environment.

The GFT process is beneficial in comparison with other treatment or vitrification systems. An incinerator would require large quantities of fuel for treatment of low-organic-content sediment, such as the sediment used in this Study, and would generate large amounts of ash which require landfilling. Unlike other vitrification technologies, GFT is designed to melt materials using very little auxiliary fuel. Other vitrification systems typically require very high electric or natural gas consumption. GFT is based on commercial glass-making technology which operates in a more energy efficient manner.

1.4 EPA SITE Evaluation

The primary objectives of the SITE demonstration were:

P1. To determine the treatment efficiency (TE) of PCBs in dredged-and-dewatered river sediment when processed in the Minergy GFT.

P2. To determine whether the GFT glass aggregate product meets the criteria for beneficial reuse under relevant federal and state regulations.

In addition, the following secondary objectives were intended to provide additional information that will be useful in evaluating the technology.

S1. Determine the unit cost of operating the GFT on dredged-and-dewatered river sediment.

S2. Quantify the organic and inorganic contaminant losses resulting from the drying process.

S3. Characterize organic and inorganic constituents in all GFT process input and output streams.

The technology was evaluated during two sampling events: (1) an event associated with the bench-scale dryer, conducted January 24 to 28, 2001; and (2) an event associated with the melter, conducted August 14 to 17, 2001. The bench-scale dryer evaluation involved sampling and analysis of sediments prior to and after drying, as well as sampling and analysis of effluent gas and condensate water generated in the drying process. The melter evaluation involved sampling and analysis of sediment prior to melting, glass aggregate product generated, quench water, and furnace exhaust. System operating conditions were monitored during both events.

1.5 Further Refinement of Results

The purpose of the Study was to evaluate the economic and technical feasibility of melting PCB contaminated river sediments in a glass furnace (with the focus on accomplishing the EPA SITE Program Objectives). The decision was made to defer the refinement of the characterizations until after completion of the EPA SITE data acquisition. The decision to defer the refinement was logical because such work would not be necessary if the GFT process was technically or economically infeasible. However, the demonstration results were very successful, as can be seen in the results issued by EPA SITE, and Minergy's demonstration reports to the Department. The GFT provided excellent PCB destruction, created a non-leachable glass product, and performed with energy efficiencies that make the use of the system competitive with (or in many cases, less expensive than) other disposal options.

The Work Scope contained in this report includes the refinement of sediment handling characteristics in various material handling systems, and further development of the applicable regulatory process. These issues were identified during the Study during the phases of dryer demonstration, melter demonstration, and unit cost calculation.

1.6 Applicability of Work Scope Results

Many disposal alternatives, including a sediment melter, will find the results of this Work Scope useful because both wet and dry river sediment offer unique material handling challenges. Proper selection of material handling equipment is essential for accurate cost estimates and safe and reliable operation of any project that will handle dredged sediment. The equipment for which the sediment will be characterized is generally commercially available and not unique to a melter application.

1.7 Summary of Systems Under Study

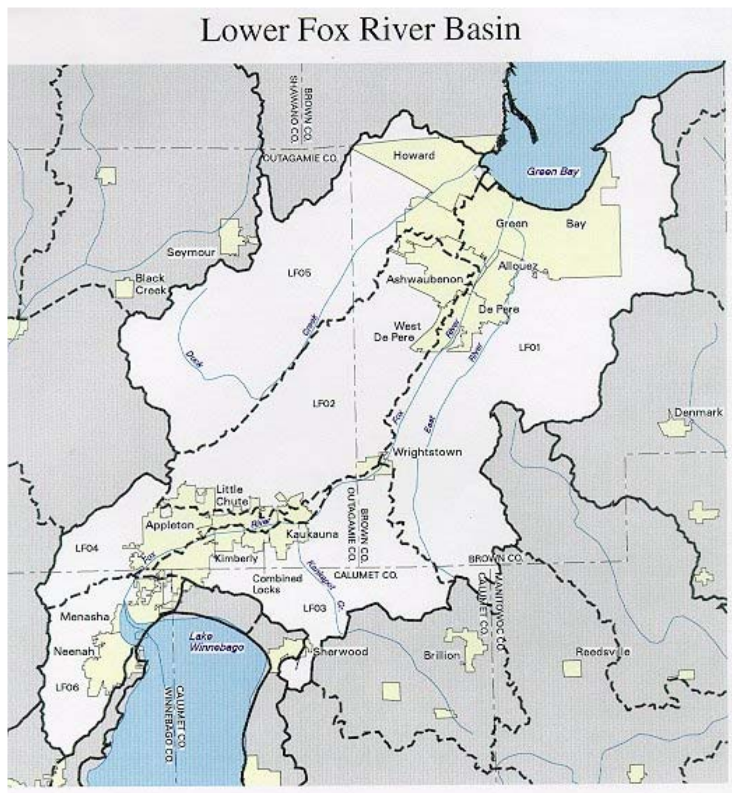
In this study, the behavior of river sediment was observed in the following major components of a sediment processing facility:

1. **Belt Filter Press:** to determine how wet the incoming influent must be for polymer conditioning, and to find out how much water can be pressed from the silty sediment.
2. **Mixer:** to determine whether previously dried sediment and non-dried belt press filter cake can be efficiently mixed to achieve a solids content high enough that the end product will not stick to the heated surfaces of subsequent drying units. Information collected during pilot testing would also be used for sizing full scale units.
3. **Dryer:** to determine how dry the incoming feed must be to prevent plugging the dryer units, and to find out the heat transfer factor to allow sizing of full scale units.
4. **Compactor:** to determine if compacting the material prior to feeding the material to the melter will provide any process benefits.
5. **Conveying and Storing Equipment:** to determine the behavior of sediment in belt conveyors, bucket elevators, sediment storage silos, wet sediment storage areas, screw conveyors, sediment feed system, and rotary air lock usage and limitations.

2.0 RECONNAISSANCE AND SAMPLING PHASE

The lower Fox River between Lake Winnebago and Green Bay is the final stretch of the Fox – Wolf River Basin. The basin contains soils which consist mainly of silts, clays, and organic materials. The sediment in the Fox River comes primarily from overland runoff during rainfall events, which carries the finer material from the soils into drainageways and ultimately into the Fox River and the Great Lakes system.

In order to obtain sediment material similar to the sediment expected to be dredged from the Fox River during the remediation, six river locations were sampled. Since the intent of this study is to characterize sediment handling characteristics that are not impacted by the level of contamination in the Fox River, it was neither necessary nor desirable to use contaminated sediment. Sample locations were selected based upon previously collected information of physical and chemical properties of the sediment. The locations that were chosen had contamination levels that were below the level of concern, but contained sediment with physical properties similar to those found in large areas of the river, where dredging is expected to take place.



2.1 Sample Locations

Testing of the six samples revealed consistency in physical makeup. Grain-size analyses identified all six samples as silts:

- Sample from Deposit CC, from the area just upstream from the Rapide Croche Dam, between Kaukauna and Wrightstown – clayey silt with a little sand and a trace of organics,
- Sample from Deposit X, from the west side of the river downstream of the Heart of the Valley Wastewater Treatment Plant – clayey silt with a little sand and a trace of organics,
- Sample from Deposit W1, from the east side of the river immediately downstream from the Thousand Islands Nature Center, and across the river from Deposit X – clayey silt with a trace of sand and organics,
- Sample from Deposit W2, from the same area as sample from Deposit W1 – clayey silt with a little sand and a trace of organics,
- Sample from Deposit V, from the west side of the river adjacent to the Heart of the Valley Wastewater Treatment Plant – clayey silt with a little sand and a trace of organics, and
- Sample from Deposit M, from the south side of the river upgradient from the Stora Enso paper mill in Kimberly – clayey silt with a little sand and a trace of organics.

2.2 Sample Data

The six samples were also similar in chemical makeup. (See Table 1 – Summary of Laboratory Analysis on Fox River Sediment Samples, below. Items CC – M are the six samples.) Organic content of the samples ranged from 360 – 1109 Btu/lb. The ash content of the samples ranged from 79.9 – 86.6 % on a dry weight basis. The analyses of the samples for various elements and compounds showed consistent results among sample locations. Samples were also analyzed for their relative makeup of fine particles (less than 0.0625 mm) and coarse particles. Material with high degrees of fine particles can compact easily and lead to material handling issues.

The results from sample locations CC – M were compared with testing performed during earlier phases of the Fox River investigation. The results were similar. Based on all the data, a single sample location at W1 was selected to obtain material for this phase of the study. Twelve 55-gallon drums of material were obtained from representative river sediment at that location.

TABLE 1
Summary of Laboratory Analysis
on Fox River Sediment Samples

PARAMETER	CC	X	W1	W2	V	M	Sediment - Complete Sample	Sediment - Coarse Fraction	Sediment - Fine Fraction
COMPOUNDS (% by weight)									
Na_2O	0.68	0.7	0.89	0.85	0.93	0.72	0.82	0.75	0.84
MgO	6.17	7.82	7	7.24	8.34	5.6	6.77	7.06	6.86
Al_2O_3	13.2	13	13.7	13.7	10.9	13	13.9	11.1	13.5
SiO_2	60.9	61.7	63.3	63	64.7	66.3	63.1	61.9	63
P_2O_5	0.36	0.43	0.29	0.34	0.27	0.38	0.39	0.75	0.52
K_2O	3.27	3.3	3.66	3.52	3.28	3.41	3.46	2.68	3.36
CaO	9.96	7.6	5.97	5.99	7.56	5.18	6.14	9.83	6.56
TiO_2	0.67	0.65	0.76	0.73	0.6	0.7	0.74	0.53	0.72
Fe_2O_3	5.35	5.48	5.24	5.27	4.06	5.18	5.36	6	5.39
T250	2480	2497	2566	2561	2518	2663	2572	2455	2557
ELEMENTS (parts per million)									
Vanadium	99	91	110	98	78	89	97	88	92
Chromium	160	135	91	104	90	128	120	172	124
Cobalt	12	12	14	15	<10	11	15	26	15
Nickel	33	29	30	30	20	31	38	47	38
Tungsten	21	19	19	19	17	19	< 10	< 10	< 10
Copper	153	174	88	109	41	159	131	212	197
Zinc	263	351	137	171	73	302	208	203	223
Arsenic	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20
Tin	106	136	97	94	76	109	112	111	114
Lead	210	279	73	109	62	216	113	83	116
Molybdenum	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Strontium	154	138	141	148	143	142	153	220	161
Uranium	< 10	13	< 10	12	< 10	15	21	26	25
Thorium	17	20	17	11	< 10	< 10	24	23	20
Niobium	16	11	16	16	14	14	16	19	18
Zirconium	204	211	238	235	260	219	246	463	485
Rubidium	95	94	100	102	79	95	101	77	98
Yttrium	58	55	60	58	48	54	58	53	59
ASH (% on a dry weight basis)	79.9	80.6	86.6	85	85.6	82.7			
BTU (per lb on a dry weight basis)	1109	1030	360	802	552	942			
MOISTURE (%)	65.5	67.1	50.9	57.7	49.2	65.7			

A composite sample of the 12 barrels was analyzed for the same suite of elements and compounds as the six reconnaissance samples. The results were consistent with those in the reconnaissance samples. When broken down into coarse and fine fractions, the results continued to be similar to those found in the reconnaissance samples.

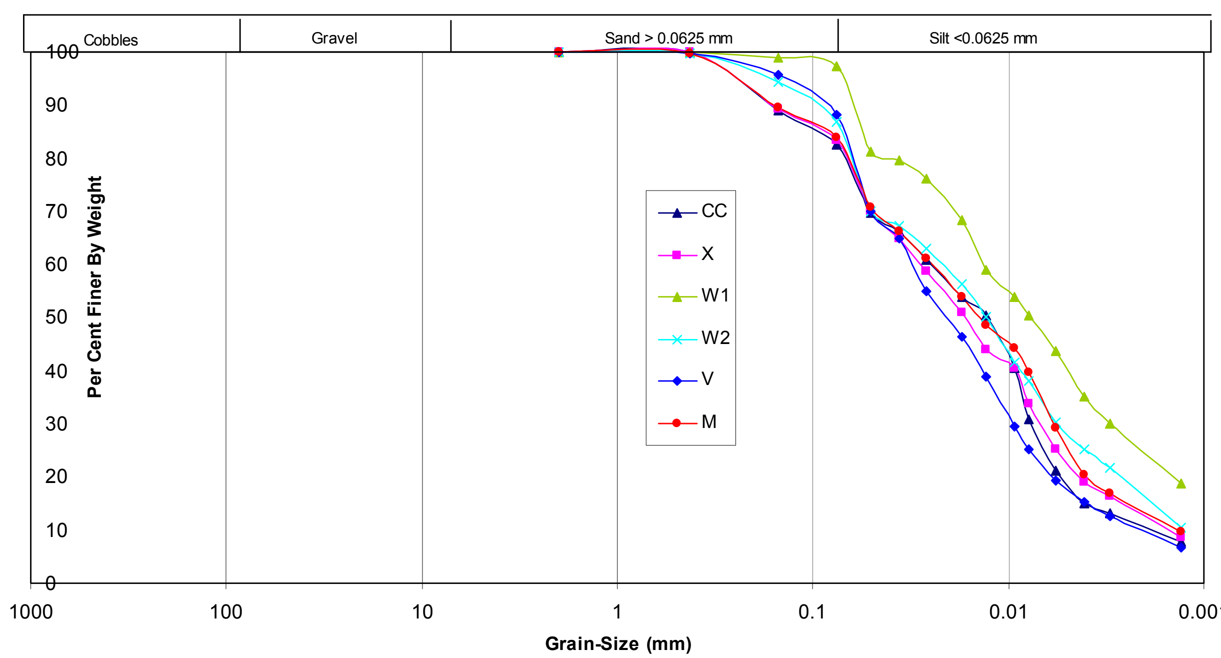
Because of the silty nature of the sediment and high moisture content, it was anticipated that stickiness will be a major issue in processing river sediment. A study of this sediment will yield valuable information regarding sediment handling characteristics.

The following table and graph indicate the particle size distribution of each sample. "Percent finer" means the percent of the sample that was smaller than the indicated grain size.

Particle Size Distribution

	Percent finer, by weight					
Grain-Size (mm)	**CC**	**X**	**W1**	**W2**	**V**	**M**
2	100.0	100.0	100.0	100.0	100.0	100.0
0.425	99.9	100.0	99.9	99.8	99.8	99.8
0.15	88.9	89.3	99.0	94.3	95.7	89.6
0.075	82.5	83.5	97.2	86.9	88.3	84.0
0.0507	69.7	70.0	81.2	70.0	70.1	70.8
0.0362	66.2	64.8	79.5	67.4	65.0	66.3
0.0262	60.9	58.8	76.1	63.1	54.9	61.0
0.0173	53.8	51.0	68.4	56.2	46.4	53.9
0.0129	50.3	44.1	59.0	50.1	38.8	48.6
0.0093	40.6	40.6	53.9	41.5	29.6	44.2
0.0078	30.9	33.7	50.4	38.0	25.3	39.8
0.0057	21.2	25.1	43.6	30.2	19.4	29.2
0.0041	15.0	19.0	35.1	25.1	15.2	20.3
0.003	13.2	16.4	29.9	21.6	12.7	16.8
0.0013	7.9	8.6	18.8	10.4	6.8	9.7

Grain-Size Distribution
Fox River Sediment Samples



3.0 SEDIMENT BEHAVIOR IN THE BELT FILTER PRESS

3.1 Role of Dewatering in Sediment Processing

The dewatering phase of the remediation process of dredged river sediment is an important phase. Reducing water content reduces weight and volume of the sediment. If the sediment is to be transported and disposed, reduced weight and volume decreases hauling and tipping costs. If the sediment is to be treated, removing moisture is necessary for subsequent unit processes.

3.2 Sediment Screening and Thickening

A typical dewatering operation of river sediment starts with the separation of the coarse fraction, including foreign objects, from the fine fraction, usually by a series of screens. The fine-grained silt suspension with its low solids content is fed into a dewatering tank, and thickened by adding polymer. The thickened material is then typically dewatered by belt filter press.

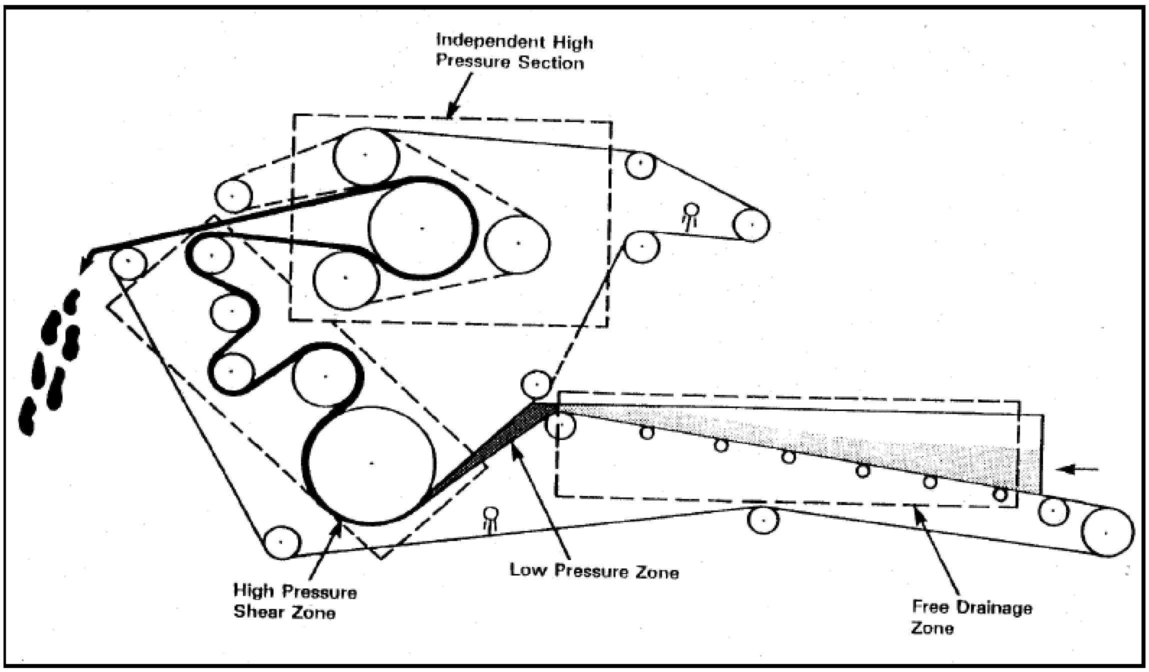
3.3 The Belt Filter Press Process

Belt presses remove water by applying mechanical pressure to a slurry (a dilute mixture of sediment and water) to squeeze out the water. The slurry is sandwiched between two tensioned belts, which weave back and forth through a series of rolls with decreasing diameters. As the diameter of the rolls decrease, the pressure on the slurry sandwiched between them increases.

Belt presses have the following zones:

- polymer conditioning zone, where flocculant is added to facilitate dewatering (flocculants serve as catalysts to cause solids that are suspended in liquids to collect into loosely aggregated masses, which are more easily removed from the liquid) ;
- gravity drainage zone, where the slurry is passed along a flat or slightly inclined porous belt. Freely draining water is drained by gravity through the belt;

- wedge, or low-pressure zone, where the solids are first introduced to both a lower and upper belt. A filter cake is formed here, capable of withstanding the forces of the following high pressure zone.
- pressure zone, where successively higher pressure is applied to the conditioned solids.



Source: U.S. EPA, 1987.

Schematic of a Belt Filter Press

Belt filter presses vary in design. Generally, the longer the detention time of the material in either of the gravity or pressure phases, the better the capability to dewater. Manufacturers alter the length of their units, as well as drum diameters and overall configurations to maximize detention time and dewatering capability.

3.4 Sediment Behavior in a Belt Filter Press

Minergy sent twenty gallons of Fox River sediment to the Andritz AG laboratory, to characterize the behavior of the sediment in various belt filter press configurations. Two studies took place at the laboratory. One involved testing the sediment with various polymers to characterize settling behavior. The other study used various filter press arrangements to determine the sediment's dewatering behavior.

3.4.1 Sediment settling behavior

The sediment sample received by Andritz was first screened to remove rocks, sticks, and other solids larger than 3/8 inch. The sample was stirred, and the solids content was measured to be 38.55%. Water was then added to the sample to reduce the solids content to 19%, which is expected to be the solids content of incoming river sediment during the commercial remediation project.

Several anionic, non-ionic, and cationic polymers were used in various combinations to evaluate sediment flocculating characteristics. Because of the fine-grained nature of the sediment and its biological and minerals content, a two-stage polymer conditioning system was determined to be the most appropriate. The best settling characteristics were found by first adding a low charge density, high molecular weight anionic polymer, followed by a high charge density, high molecular weight cationic polymer. This combination picked up the majority of the fines, and strengthened the flocculent adequately for filter press processing.

The study also determined that, in order to properly mix polymer flocculants with the river sediment, the solids content of the sediment should be 19% or lower. The viscous nature of the clayey sediment at higher solids contents interferes with the mixing process.

3.4.2 Sediment dewatering behavior

Four filter press arrangements were used. All were operated at the same throughput rate of 8 – 10 dry tons per hour. The first belt press unit was capable of achieving a 51 – 54% solids content. The second unit drove out more moisture, achieving a solids content of 55 – 56%. Two additional configurations involved secondary after presses. One of the after presses was able to dewater the filter cake from the first unit to a 58 – 59% solids content, while the other after press, using the same filter cake material, achieved an even better 64 – 66% solids content.

Sediment Characterization
in Various Belt Filter Press Configurations

Unit	Feed Solids Content	Cake Solids Content
SMX-S8	19%	51-54%
S8P	19%	55-56%
HIP	51-54%	58-59%
S4P3	51-54%	64-66%

As will be discussed in the Dryer section of this report, the sediment tends to be sticky and to plug paddle and disc dryers, unless the solids content of the sediment is above 75%. It is generally more cost-effective to achieve this solids content by back-mixing already dried material with wet incoming filter cake, rather than by additional dewatering efforts to achieve a dryer filter cake. Adding capacity in dryer units is generally more cost-effective than adding filter press capacity.

The study concluded that dewatering dredged sediment to solids contents greater than 50% is feasible. Using secondary presses can increase solids content to as high as 64-66% solids;

however, the cost-benefit of such an installation needs to be studied. The study also concluded that none of the belt presses was capable of dewatering the river sediment to 75% or more solids content.

4.0 SEDIMENT BEHAVIOR IN A MIXER

4.1 Role of Back-Mixing in Sediment Processing

River sediment consists primarily of silt. In the process of dewatering and drying, the sediment goes through a range of solids content where it is sticky and difficult to process.

The dryer studies performed in this analysis found that solids contents below approximately 75% will cause plugging issues in commercial industrial dryers. Cake solids produced by belt filter press will have a solids content less than that, in the material's sticky range. Back-mixing of already dried material with the belt press filter cake is the most cost-effective way of increasing solids content, so that the river sediment can be processed in the dryer units. Any potential dusting of dry sediment will be address by using enclosed conveyors and transfers in the back-mixing system.

Mixing is typically performed in paddle mixers, or pug mills. A typical design involves a horizontal trough with dual shafts extending the length of the trough. The shafts contain a series of paddles, which can be pitched in various directions, depending on the feedstock. The feed enters one end of the unit, and leaves the other. As the material moves down the length of the trough, the rotating paddles move the material from the bottom of the trough up each side and then back down again, mixing the contents.

4.2 Testing a Paddle Mixer to Determine Sediment Behavior

Minergy sent samples of Fox River sediment to the Feeco International laboratory, Green Bay, WI, to characterize the behavior of the sediment in a paddle mixer. Wet samples with 39% solids content and dried samples with 99% solids content were blended in a mixer, in an attempt to create small granules with a solids content above 65%. (At the time of the back-mixer testing, the dryer tests were not yet concluded, so it was not known at the time that Fox River sediment would need to be back-mixed to around a 75% solids content.)

Three tests were performed. All involved mixing a wet sample at a rate of 1267 pounds/hour with a dried sample at a rate of 1067 pounds/hour. The paddle mixer was operated at a speed of 56 rpm. The following observations were made during the tests:

1. In the first test, all of the paddles on the shafts were left facing forward. The final mix had a solids content of 66%. However, some larger (> one-inch) wet sediment lumps remained in the final mix.

2. The second test was run similar to the first test, except that the last three sets of paddles on the shaft were reversed, to force a portion of the sediment back against the flow prior to final discharge from the mixer. The wet lumps broke up and blended better with the dried material. There were fewer large (> one-inch) wet sediment lumps in the discharge. The final mix had a solids content of 69%.

3. In the third test, more paddles were reversed. The last two sets were reversed, the next set was left in the forward position, and the next two sets were reversed. In addition, the dry material portion of the feed was pre-ground through a blade/hammer mill without a screen, reducing the material to mostly powder. This produced increased mixing, with the mixed material having a particle size of less than ¼-inch. The final mix had a solids content of 69%.

4.3 Discussion of Test Results

The mixer tests confirmed that the paddle mixer is an appropriate high volume device to back-mix dried river sediment with sediment filter cake, increasing the solids content of the product. The paddle mixer is designed to handle feedstocks of various moisture contents. There were no processing complications arising from the silty nature of the sediment in the solids content range of 39 – 69% observed during the study.

A blade mill may be an appropriate device to reduce the size of the dried sediment feed. Reducing the size of the dried feed enhances the mixing, and produces a finished product of smaller size.

The mixing tests were conducted to produce an end product of 65% solids content. Subsequent studies of industrial dryer units have determined that back-mixing must achieve a solids content above around 75% to avoid the river sediment's sticky phase. There is no reason to believe that the paddle mixer will have any difficulty in achieving that higher level of solids content.

5.0 SEDIMENT BEHAVIOR IN A DRYER

5.1 Role of Drying in Sediment Processing

Several sediment management options can achieve process improvements by pre-drying the feedstock beforehand. Drying is one of the most important industrial processes. It is estimated that 10 – 15 % of all energy usage in the United States is consumed in industrial drying operations. Drying is often needed to improve the quality of a product, reduce weight for transportation purposes, preserve a substance, or to prepare a material for further processing.

The consideration of potentially processing the sediment in a vitrification system like the GFT necessitates the analysis of pre-drying. Minergy's research and experience in its melting facilities has indicated significant process benefits and energy efficiency improvements by removing as much moisture as possible before feeding into the melter. Sediment needs to be dry enough to flow through the feeder into the melter. The charging unit is very hot at the end entering the melter. As river sediment approaches the melter in the charger, any moisture in the sediment is vaporized and driven back toward the front of the charger. As moisture moves through the feeder, it tends to impair movement of the silty river sediment, making it sticky and immobile.

Moisture also impedes the melting process, since the volume of water entering the melter must be managed. Energy is consumed in vaporizing and driving off the water through the system's exhaust system. The design size of the melter itself and exhaust treatment system must be adequate to take into account the management of water.

Earlier work by Minergy associated with this Study determined that the melter feedstock should have a solids content above 90% for efficient operation. Dewatering processes alone are not capable of achieving high enough solids contents for sediment feedstocks of melting operations. Drying is a necessary additional phase of the treatment train.

5.2 The Drying Process

Drying is accomplished by raising the temperature of water in a material above its boiling point so that it vaporizes. The water must then be driven out of the system before it cools and condenses back to a liquid form.

There are three common ways to bring heat from a heat source to water: conduction, convection, and radiation. Conduction moves heat from particle to particle, primarily in solids, with heat moving from warmer to cooler particles. Convection moves heat through air or with flowing fluids, moving toward cooler places. Radiation beams heat through space from one object to a cooler object. Industrial dryers rely on one or more of these methods to dry materials.

Dewatered river sediment is a combination of silt, clay, and sand particles, water, and air. Drying is the process of transferring heat to the sediment in a way that it reaches, vaporizes, and drives off the water in the sediment. As the drying process takes place, the sediment's structure changes, which alters the heat transfer and material handling properties of the system.

Because of the complex nature of the sediment drying process, forecasting the performance of any particular drying method, or the behavior of sediment in any particular dryer unit, is difficult.

Theoretical models based on thermodynamic principles are generally inadequate to explain the complex interactions taking place when sediments undergo drying. Actual testing of materials within large drying units is the standard method of observing material behavior and dryer performance.

Typically, such characterizations are performed by the dryer manufacturer, on large pilot-scale dryers. Most dryer manufacturers have significant experience in running dryer tests, and have significant data from past installations of their dryers. As a result, manufacturers are generally able to size units appropriately, and provide performance guarantees.

Optimizing the drying process involves getting high heat transfer at a low energy cost, over a high throughput. Heat transfer is typically reported in the units of Btu/hr/sq ft/deg F, which is the thermal input necessary on an hourly basis to heat a square foot of the material one degree Fahrenheit.

5.3 Types of Industrial Dryers

There are two basic types of industrial dryers: indirect and direct dryers.

5.3.1 Indirect dryers

Indirect dryers use a hot surface to heat the material, primarily by conduction. Heat is conducted into particles by the hot metal walls of the containing vessel. The particles that are heated pass on the heat to particles further along. The process is slow, because heat conduction is low in most solids, and is retarded in pore areas within the solid due to the presence of air.

The goal is to heat the metal surface high enough, so that the temperature of the solid particles in contact with the metal is above the water's boiling point. Then evaporation can take place. Drying in indirect dryers is speeded up by agitating the material, which brings cooler, wet particles continuously into contact with the heating surface.

Thermal oil is often used as the heat transfer medium in indirect dryers.

Types of indirect dryers include disc, paddle, drum, rotary, and screw conveyor dryers. The first two have been used commercially for years to dry sludges and sediments. Of the various dryer technologies, indirect disc and paddle dryers have been found to be the most cost-effective methods of applying heat to many sludges and sediments.

5.3.2 Direct dryers

Direct dryers heat the solids by contacting them directly with hot air through the convection process. Unlike in indirect drying, where pores inhibit heating, in direct drying, pores enhance heating, since the heat is transferred by hot air. Air brings in the heat and carries out the evaporated moisture.

The main design considerations are to achieve the targeted dryness with the least amount of airflow in the least amount of time. The airflow and heating time is dependent on the required evaporation rate, as well as the influent and effluent temperatures of the system air, which dictate how much water can be removed by the air. The best dryer efficiency occurs in a system with the highest air temperature at the inlet and the lowest air temperature at the discharge.

Direct dryers differ greatly in how the materials move through the various systems. In some methods the materials are static, while in others they move along belts. Some types of dryers tumble the solids, while others atomize them. The duration of heating also varies considerably among the various methods of direct drying.

Types of direct dryers include conveyor, flash, fluid bed, rotary, spray, and tray dryers.

5.3.3 Disc Dryer

Disc dryers have hollow, full-circle discs, which are closely spaced on one or more shafts situated in a box-like trough. The discs, shafts, and housing are heated. The feed may flow parallel to a single shaft or multiple shafts, or perpendicular to multiple shafts. The closely spaced arrangement of the heated discs provides both agitation and a high heat transfer surface area per unit of material to be heated.

A weir at the end of the box controls the elevation of the material. The box can be inclined to assist in moving the material.

5.3.4 Paddle Dryer

In a typical paddle dryer arrangement, dual parallel intermeshing paddles slowly revolve in opposite directions in an enclosed trough, agitating and heating the material. The box, paddles, and shaft are all heated with thermal oil, providing a large surface for heat transfer into the material. In a continuous process, the feed is metered into the inlet end of the trough and displaces product toward the discharge end. Product is discharged over a weir that is used to maintain trough level.

5.3.5 Drum Dryer

Drum dryers consist of one or more heated, rotating drums. Liquid feeds are rolled or splashed onto the outside of the drums, forming dried flakes, which are then scraped off by a blade.

5.3.6 Rotary Dryer

The most common indirect rotary dryer is the steam tube rotary dryer. The dryer is cylindrical in shape, is sloped to promote movement of the feed, and contains rows of steam tubes, which heat the material. The dryer unit rotates, which encourages the material inside the dryer to fall and break up.

5.3.7 Screw Conveyor Dryer

The screw conveyor dryer has a hollow screw in a jacketed trough. Material is pushed through the dryer with little intermixing, and heat transfer is generally low due to the lack of agitation.

5.3.8 Conveyor Dryer

In the conveyor dryer, material rides a continuous metal screen or belt within a rectangular enclosure. In many designs, at various stages along the enclosure, air is either blown over the top of the material, or alternatively up through the material from below, to achieve uniform drying. There is very little agitation of material.

5.3.9 Flash Dryer

Flash dryers consist of vertical ducts, in which high velocity air is introduced into the bottom of a duct, together with the material to be dried. The high velocity of the air carries the material from the bottom of the duct out of the top of the duct, drying the material in the process. Because of the high velocity of the air, the residence time of the material is typically less than three seconds, which only allows unbound water to be driven off.

5.3.10 Fluid Bed Dryer

In a fluid bed dryer, the material to be dried is placed in a shallow layer onto a bed with a perforated plate as a floor. Hot air is blown up through the plate from below, lifting and drying the particles. The fluid bed of material behaves like a liquid. As more wet material enters the chamber, dried material flows over a weir into a cooling chamber.

5.3.11 Direct Rotary Dryer

Direct rotary dryers are similar to indirect rotary dryers, and consist of an inclined, rotating cylinder. Hot air is supplied either at the top end of the unit, moving parallel to material flow, or at the bottom end of the unit, moving countercurrent to material flow. Material moves through the dryer from the top end, cascading down the cylinder as the cylinder rotates, assisted by the head of the incoming material. Drying takes place primarily as the solids fall over the lifting flights.

5.3.12 Spray Dryer

Spray dryer systems atomize liquid feeds, spraying them into a drying chamber, where evaporation takes place. A typical system has an upright conical tank, with the feed and hot air introduced together at the top. Moist air is blown out of the system near the bottom, and dried solids leave the unit at the bottom.

5.3.13 Tray Dryer

Tray dryers are loaded with material to be dried, and hot air is blown over the top, heating the material and trays. These types of dryers are typically loaded manually and operated in batch mode.

5.4 Bench-Scale Results from Hazen Research Laboratories

During the dryer demonstration portion of the Phase 3 EPA SITE testing program, Fox River sediment was dried at the Hazen Research Laboratory in Golden, CO, in a small Holo-Flite indirect disc dryer. The purpose of the testing was to determine the fate of various contaminants during the drying process. The study was set up to monitor all discharges from the system, as Fox River sediment was dried from an average solids content of 62.9% to an average content of 93.4%.

The primary purpose of the testing was to monitor PCB fate during the drying process. However, secondary observations were also made during the tests, which provided preliminary information on how sediment can be expected to behave in a full-scale drying operation.

The sticky nature of the sediment was an early observation. Pre-mixing sediment with dried sediment was necessary to run the tests.

Information regarding the dryer's heat transfer and energy consumption was also gathered. The heat transfer coefficient of the dryer was found to be 9 Btu/hr/sq ft/deg F. However, this information is of limited usefulness, since the flights of the dryer were not kept full, and the unit was a small research unit. The tests were not performed to optimize heat transfer.

5.5 Pilot-Scale Results from Dryer Manufacturers

As part of the present study, Minergy contacted industrial dryer manufacturers to evaluate sediment behavior in various large drying units, which have had commercial applications with the same or similar feedstocks.

Minergy utilized three indirect dryer models. The dryer types used were an indirect paddle dryer by Komline-Sanderson, and indirect disc dryers by Metso Minerals and Hosokawa Bepex. All have had significant application histories in the sludge-drying area. All three manufacturers have in-house testing facilities, to estimate operating characteristics of the customer's feedstock. The manufacturers have significant marketplace data on their dryers' performances, and are able to propose full-scale applications with performance guarantees.

Minergy sent two drums of Fox River sediment to each of the three manufacturers. The sediment was not dewatered prior to shipment. Each manufacturer reported different as-received solids content, based upon the degree of decanting they performed prior to drying. The manufacturers dried the river sediment under controlled conditions, observing the sediment's behavior in dryers of adequate size to estimate scaled-up heat transfer and energy consumption factors.

5.5.1 Komline-Sanderson

The Komline-Sanderson dryer used was their Nara paddle dryer model 1.6W-30. The dryer is an indirect type dryer with paddle discs. Dual counter-rotating shafts with hollow, wedge-shaped paddles mechanically agitate, mix, and heat the feedstock. The heat transfer medium is thermal oil. The dryer model used in the study is presently being used in numerous commercial applications, primarily to dry sludges at industrial and municipal wastewater treatment plants.

Testing took place at Komline-Sanderson's laboratory facility in High Bridge, NJ. The data objectives of the tests were three-fold:

1. To determine the physical handling characteristics of the river sediment during the drying process.
2. To observe the river sediment's sensitivity to heat and possible fouling.
3. To calculate the heat transfer rate obtained during the drying process.

Komline-Sanderson decanted approximately 20 pounds of water off of each of the two barrels of river sediment prior to testing. Two runs were conducted.

Test 1

The feedstock had an average solids content of 41.2%, and a bulk density of 83 pounds per cubic foot. (See Table 2 – Sediment Behavior in Various Dryer Units) The feed rate was 240 lbs/hr of wet feed, with a hot oil supply temperature of 350^{o} F.

The material began to immediately stick to the surfaces of the dryer. After about 45 minutes, most of the dryer surfaces in contact with feed were fouled. A hard layer of solidified material about 1/8 inch thick was observed on the paddles. The drying operation was stopped, allowing the material in the dryer to quickly dry. Material caked to the surfaces of the dryer generally broke free, leaving behind clean paddles.

The moisture content of the feed in Test 1 was in a range causing a sticky material, which did not move well through the paddle dryer. Rather, the material quickly hardened into a cake, covering the heat transfer surfaces, reducing heat transfer, and reducing material movement through the dryer.

Test 2

To prevent the fouling which prematurely ended the initial test, dried river sediment was mixed with the wet raw feed during the second test, to provide a drier, non-sticky feedstock. The mixing took place in the dryer. Komline-Sanderson alternated adding 20 pounds of wet feed with 20 pounds of dried feed every five minutes.

A total of 240 lbs/hr of wet feed averaging 41.2% solids content and 240 lbs/hr of dried feed averaging 98.3% solids content were run through the dryer, resulting in a feedstock with a 71.5% solids content. The hot oil supply temperature was 394 ^{o}F, with the hot oil return temperature averaging 360 ^{o}F. The dryer was sloped at 2.5^{o}, and the material moved well through the dryer.

Discussion of Komline-Sanderson Dryer Tests

The Komline-Sanderson Nara paddle dryer is capable of achieving very high solids contents in river sediments, around the 98% range, as long as the incoming feedstock is dryer than around 71.5% solids content. Feedstocks with lower solids contents are sticky, binding to heat transfer surfaces, severely hampering heat transfer and eventually halting movement of the material through the dryer.

An overall heat transfer coefficient of 30.6 Btu/hr/ft^2/^{o} F was calculated.

5.5.2 Metso Minerals

The Metso dryer used was a multiple screw Holo-Flite dryer. The dryer is an indirect disc dryer. Rotating shafts with discs mechanically agitate, mix, and heat the feedstock. The heat transfer medium is thermal oil. The Holo-Flite dryer is presently operated in over 3000 installations worldwide.

The objectives of the tests were to dry the test material from 70% solids content to an end product of 90 – 95% solids content, to observe the behavior of the river sediment during the drying process, and to calculate the overall heat transfer coefficient during the process.

Two runs were reported.

Test 1

The feedstock had an average solids content of 71.1%, and a bulk density of 53.1 pounds per cubic foot. (See Table 2 – Sediment Behavior in Various Dryer Units, above.)

The river sediment was hand fed into the dryer. At first the material lightly coated the screws, but after a period of time, the material built up on the surfaces to the point that the material would no longer convey. The drying operation was stopped.

Test 2

In order to increase the solids content to avoid fouling within the dryer, the original feed material was mixed with material that had been dried. A batch of 193.5 lbs of original material at 71.1% solids content was mixed with 36 lbs of dried material at 98.9% solids content, to produce a sample containing 75.5% solids content, and having a bulk density of 60.4 pounds per cubic foot. The mix was then rolled on a drum roller for approximately 40 minutes.

The sediment was fed into the dryer at a rate of 327 lbs/hr. The hot oil supply temperature was 603 ^{o}F, with the hot oil return temperature averaging 575 ^{o}F. The material moved well through the dryer. The end product had an average solids content of 93.3%.

Discussion of Metso Dryer Tests

The Metso Minerals disc dryer is capable of achieving very high solids contents in river sediments, around the 93 – 94% range, as long as the incoming feedstock is dryer than around 75.5% solids content. Feedstocks with lower solids contents are sticky, binding to heat transfer surfaces, severely hampering heat transfer and eventually halting movement of the material through the dryer.

An overall heat transfer coefficient of 17 Btu/hr/ft^2/^{o} F was calculated.

5.5.3 Hosokawa Bepex

The Bepex dryer used was their single screw TorusDisc dryer. The dryer is an indirect disc dryer, with four paddles mounted on each disc to enhance agitation, mixing, and heat transfer.

The heat transfer medium is thermal oil. The oil enters the center shaft at the discharge end, exits the shaft at the feed end, then enters the jacket surrounding the shaft and discs. Prior to injecting thermal oil, the rotor shaft is purged with hot air.

The objectives of the tests were to dry the test material from 68% solids content to an end product of 95% solids content, to observe the behavior of the river sediment during the drying process, and to calculate the overall heat transfer coefficient during the process.

Three runs were conducted.

Test 1

The feedstock had an average solids content of 70.4%. The volumetric feeder hopper bridged over when filled, so the river sediment was hand fed into the dryer at a rate of 720 lbs/hr. The material built up between the first disc and the end plate on the feed side to the point that the material would no longer convey. The drying operation was stopped. The hot oil supply temperature was 551 ^{o}F, with the hot oil return temperature averaging 530 ^{o}F. The end product had an average solids content of 99.7%.

Test 2

The second test was similar to the first. The material was manually fed at the lower rate of 420 lbs/hr, and had an average solids content of 67.7%. The drying operation was again stopped due to fouling issues. The hot oil supply temperature was 459 ^{o}F, with the hot oil return temperature averaging 438 ^{o}F. The end product had an average solids content of 99.7%.

Test 3

In order to move the feedstock outside of its sticky range, the original feed material was mixed with material that had been dried. A batch of 400 lbs of original material at 68.0% solids content was mixed with 200 lbs of dried material at 99.7% solids content, to produce a sample batch containing 78.3% solids content. The sediment was fed into the dryer at a rate of 480 lbs/hr. The hot oil supply temperature was 424 ^{o}F, with the hot oil return temperature averaging 403 ^{o}F. The material moved well through the dryer, producing a product with a solids content averaging 98.7%.

Discussion of Bepex Dryer Tests

The Bepex single rotor disc dryer is capable of achieving very high solids contents in river sediments, around the 99% range, as long as the incoming feedstock is dryer than around 78%

solids content. Feedstocks with lower solids contents are sticky, binding to heat transfer surfaces, severely hampering heat transfer and eventually halting movement of the material through the dryer.

An overall heat transfer coefficient of 22.7 $Btu/hr/ft^2/^o$ F was calculated.

5.6 Overall Discussion of Behavior of Sediment During Drying

The appropriate types of industrial dryers to cost-effectively dry large volumes of sediment to this level of solids content are the indirect paddle and disc dryers. Both perform well with a bulk feed having the characteristics of dewatered river sediment, and both are capable of producing a dry enough end product.

The Komline-Sanderson dryer is a multiple-shaft paddle dryer, with paddles rotating counter to each other. The Metso dryer is a multiple-shaft disc dryer, and the Bepex dryer is a single-shaft disc dryer, with paddles on the discs.

During testing, all three dryers achieved solids contents of greater than 90%.

All three dryer manufacturers concluded that the minimum solids content allowable in the incoming feed to avoid plugging problems is around 75%. This is significantly higher than the 60 – 65% range estimated in the earlier dryer tests conducted at the Hazen Research Laboratory. It is suspected that the high lime content in the river sediment tested at Hazen may be the primary reason for the determination of the lower sticky point. In comparison, the sediment used in the current study had not been limed, yielding study results that are more indicative of the sediment behavior in large scale processing. In this present study, all three dryers required mixing of the incoming feed with previously dried material, to increase the sediment's solids content to around 75%, to prevent plugging within the dryer.

In comparing the performances of the various dryers, all dryers achieved the targeted solids content of 90%. The Komline-Sanderson model had the highest heat transfer coefficient of the three units. However, none of the units were operated with their flights fully covered, so the heat transfer coefficients of the dryers were not optimized.

Table 2 – Sediment Behavior in Various Dryer Units

	Komline-Sanderson Nara (Test 2)	Metso Holo-Flite (Test 2)	Bepex TorusDisc (Test 3)
Feed			
Feed solids (%) prior to backmixing	41.2	71.1	68
Feed solids (%) after backmixing	71.5	75.5	78.3
Feed bulk density (lb/ft^3)	83	60.4	
Operating Parameters			
Oil temperature in	394	603	422
Oil temperature out	360	575	402
Feed rate (lb/hr), back-mixed	480	327	480
Product			
Product solids content (%)	98.3	93.3	98.4
Product temperature (^oF)	240	205	
Heat Transfer Coefficient			
U-Value (Btu/hr-ft^2 ^oF)	30.6	17	22.7

6.0 SEDIMENT BEHAVIOR IN THE COMPACTOR OR AGGLOMERATOR

6.1 Role of Dust Reduction in Sediment Processing

River sediment is composed primarily of silt. As it dries, it becomes a powder. It was observed during the melter demonstration portion of the project that a fraction of the dried feed to the melter was remaining in a fine particle state in the melter. There is sufficient gaseous turbulence to capture and melt much of the fine particles of sediment entering the melter. However, some of these fine particles were found to be passing into the melter's stack, where they were being captured in the heat recovery equipment. Fouling of the heat recovery system required significant maintenance.

The sediment feeder used during the melter demonstration was a standard screw feeder that has been used world-wide for charging batch in glass furnaces. The screw feeder was chosen due to its ability to tightly seal the charging hopper to the feeder and the feeder to the furnace. This design was intended to minimize dusting of the sediment feedstock. The unit performed adequately for the melter demonstration. It was identified at that time, however, that melter performance could potentially be improved, and dusting further reduced, by increasing the average size of the feedstock particle, through the use of pelletizing prior to the feeder.

There are two common methods for pelletizing powder:

1. <u>Compaction</u> involves mechanical pressure, often without any binder. Compactors typically produce compacted sheets of material, which are later crushed and screened to produce a flaked or granular form of the desired sized product.

2. <u>Wet agglomeration</u> is a process involving a shaft covered with pins spinning inside a covered box. The feedstock is introduced into the unit along with a binder spray, typically water, and the spinning nature of the pins causes solid particles to form and grow.

6.2 Testing a Compactor to Determine Sediment Behavior

Minergy sent samples of dried Fox River sediment to the Feeco International laboratory in Green Bay, WI, to characterize the behavior of the sediment on a roll compactor. The samples were sieved, and powdered material passing the #10 sieve (2 mm) was used for the study. The beginning moisture content of the samples was 2%.

Four tests were conducted to determine the behavior of the powdered sediment on a roll compactor. Each test was set up to compact the test batch into granules, with as little non-granulated powder remaining as possible. During each successive test, the moisture content of the dried powder was increased, to determine the effect of moisture on compaction.

Each test was run at roll pressures of 1000, 2000, and 3000 psi. Under each test, the highest pressure, 3000 psi, produced the highest degree of granulation and the least amount of fines.

The results of the study showed that sediment moisture content impacted the compactor's ability to granulate the powder. As moisture was added to the sediment powder, more was granulated and less remained as fine powder:

1. In the first test, sediment powder with 2% moisture was compacted. At 3000 psi, 40.5% of the material was retained on the #10 sieve as granules, while 18.1% passed the #50 sieve as dust.

2. In the second test, sediment powder with 4% moisture was compacted. At 3000 psi, 47.4% of the material was retained on the #10 sieve as granules, while 12.5% passed the #50 sieve as dust.

3. In the third test, sediment powder with 6% moisture was compacted. At 3000 psi, 48.3% of the material was retained on the #10 sieve as granules, while 10.6% passed the #50 sieve as dust.

4. In the fourth test, sediment powder with 10% moisture was compacted. Very little dust passed the #50 sieve. However, the granulated material had very little crush strength because of the moisture content of the material.

6.3 Discussion of Compactor Test Results

The compactor study determined that the moisture content of powdered river sediment affects the ability of a roll compactor to granulate the material. As the moisture content of the sediment increased from 2% to 10%, the percentage of the material which successfully granulated increased, and the percentage of the material remaining dust-sized decreased. However, at around 10% moisture, the material coming off the roll compactor did not have the crush strength to allow the formation of granules. There appears to be an upper limit of moisture content with the sediment, above which the roll compactor cannot work.

Below this limit, the addition of moisture reduces the dust levels in the material. However, the addition of water into the melter also has some negative effects. Energy is required to drive off this water in the melter, which increases the operating costs of the process.

An operating cost analysis was performed for two options. The first option would be to increase the operating duty of the heat recovery equipment cleaning system. Cleaning is normally accomplished by blowing high pressure air at the heat transfer surfaces to dislodge build-ups of material. A cleaning system would be furnished regardless of the condition of the feed as some build up would be expected even with a high quality feed material. As feed quality decreases the frequency and duration of the cleaning process will increase. This will increase operating costs by means of higher air compressor operating duty, which increases electric power consumption. The higher air compressor duty is estimated at $ 0.06 per wet ton of feed material.

The second option is to use a roll compactor to condition the material. The cost to operate the roll compactor can be broken into 4 groups. The groups are (1) Furnace efficiency penalty due to water addition, (2) Capital recovery for compactor, (3) Compactor maintenance, (4) Compactor drive motor electrical operating costs. The costs associated with the water additional penalty are estimated at $1.51 / ton. The costs for both additional natural gas and oxygen have been included in this factor. The capital recovery cost factor has been estimated at $0.40 per wet ton assuming a $795,000 compactor purchase price and 10 year project life. The electrical operating costs was estimated at $0.67 per wet ton assuming a 450 HP drive power requirement. Compactor roll maintenance was estimated at $0.25 per wet ton. The total cost of compacting is about $2.83 per wet ton.

The lowest cost option is clearly aggressive air cleaning of the heat transfer surfaces. The combination of the low strength of the compacted material and higher operating costs associated with the roll compactor suggest that pelletizing through compaction does appear to be a desirable option.

6.4 Testing an Agglomerator to Determine Sediment Behavior

Minergy sent samples of dried Fox River sediment to the Feeco International laboratory in Green Bay, WI, to characterize the behavior of the sediment in a pin mixer, which is a type of agglomerator. A fine spray is introduced along with a feed material into the mixer, and the spinning pins create an environment where solid particles form and grow.

Tests were run at various moisture contents, shaft speeds, and dust particle sizes, to determine sediment behavior in the pin mixer. One test was run in batch mode, while eight tests were run in continuous mode:

1. The batch test was run to determine how much moisture would be required to de-dust the dried river sediment, and how much moisture would be too much. A 13% spray did not agglomerate all the fines, while a 17% spray did. The 17% spray, however, resulted in the larger feed pellets breaking.

2. The purpose of the first continuous test (Test #1) was to observe the behavior of the river sediment as it went through the pin mixer. At a 13% spray addition, most of the fines agglomerated. However, some dust was created by the break up of large feed pellets. Laboratory personnel suggested that directing a portion of the spray along the back end of the pin mixer might agglomerate this dust.

3. The purpose of the next three continuous tests (Tests 2 – 4) was to determine how much moisture was required to de-dust just the fine portion (smaller than 18 mesh) of the dried sediment. Under a 9% spray, some dust escaped the system. A 16% spray captured all the dust, but produced over-sized pellets. A 14% spray appeared to provide the best agglomeration of this fine fraction sample, producing appropriately sized pellets.

4. The purpose of the next three continuous tests (Tests 5 – 7) was to observe whether slowing down the pin mixer's shaft speed would cause less breakage of the larger feed material. The tests revealed that breakage occurred at all shaft speeds tested. The slower the shaft speed, the more detention time in the pin mixer, which allowed for a little more exposure to the sprays, creating larger agglomerates and higher discharge moistures.

5. The final test was carried out to determine the lowest required spray moisture level necessary to agglomerate the 4 – 35 mesh portion of the river sediment. A 10% spray moisture level agglomerated a portion of the sediment, but did not entirely de-dust the sample. The pellets produced were small, dry, and not very dense.

6.5 Discussion of Agglomerator Test Results

The tests determined that Fox River sediment can be agglomerated into pellets in a pin mixer under appropriate conditions. Factors influencing the effectiveness of the pin mixer include the amount of moisture sprayed into the unit, the area within the unit that is undergoing spraying, and the pin mixer shaft speed.

All runs carried out with spray moisture additions of less than 14% resulted in fines escaping the process. A 16% spray resulted in overly large pellet sizes in the agglomerated material.

Shaft speed also influenced pellet development. The pin mixer test unit is normally operated at 840 rpm. Slowing down the rotation allowed more detention time within the unit, which exposed the river sediment to more spray, causing the formation of larger pellets. Slowing down the rotation also decreased the amount of breakage of the larger feed pellets, which in turn reduced the amount of dust caused by the breakage.

The spray in the pin mixer used in the study was concentrated near the inlet of the unit. In the runs where breakage of the larger feed pellets was observed, directing a portion of the spray toward the discharge end of the unit would probably agglomerate a portion of the dust resulting from the break up.

However, adding significant quantities of water to the feed is undesirable. The study determined that creating pellets by the agglomeration method with Fox River sediment requires significant water additions to the dried sediment. Pelletizing by agglomeration was therefore determined to not appear to be a feasible option.

7.0 SEDIMENT FLOW CHARACTERIZATION

7.1 Sediment Flow Issues

A river sediment handling operation involves multiple processing steps, to prepare the dredged material for final disposal. The dredging process produces a fluid mixture of sediment with a solids content of around 10%. Water is removed from this mixture during belt filter pressing, resulting in a cake solids material with a solids content between 30-55%. For feeding to a sediment pre-dryer, the solids level is increased to around 75% by mixing dry material with the filter cake prior to entering the dryer. The solids content of the sediment increases to above 90% in the dryer.

The handling characteristics of sediment vary with solids content. At low solids content, the sediment can be pumped. As the material becomes more viscous, other conveying methods become more efficient. The sediment goes through stages where, because of its solids content, the sediment may bridge in hoppers, compact into unmanageable clods, or stick to surfaces in processing units, plugging the units.

7.2 Predicting Flowability of Solids

Samples of river sediment were evaluated at the laboratory of Diamondback Technology, Inc., which specializes in predicting solids flow in bins, hoppers, and feeders. Diamondback has established a number of flow indices for solids, which predict the behavior of solids in these devices. Knowledge of these indices is helpful in designing hopper wall angles and discharge outlet diameters. The indices provide guidance in the selection of materials for the various surfaces coming into contact with the material to be conveyed. The indices can also indicate whether certain conveying devices are inappropriate altogether, or whether additional material processing is necessary prior to conveying by the device.

The laboratory evaluated the following flow indices on actual Fox River sediment samples:

- <u>Flow rate index</u>. This is the maximum solids flow rate expected after deaeration of a powder in a bin.
- <u>Feed density index</u>. This is the density of a material in a feeder.
- <u>Bin density index</u>. This is the density of a material in a bin.
- <u>Springback index</u>. This is the percentage springback after a material is consolidated.
- <u>Hopper index</u>. This is the steepness of a hopper's walls necessary to ensure that material will flow along them.
- <u>Chute index</u>. This is the recommended angle of chutes, feeders, and conveyors necessary to ensure material flow.
- <u>Arching index</u>. This is the recommended outlet diameter in a conical bin to prevent arching of the material at the outlet, causing it to hang up.

- Ratholing index. This is the recommended flow channel diameter in a bin to prevent cavities in the material that cause it to hang up.

Sediment with varying moisture contents was studied.

- Cake Solids. The first area is moving the dewatered sediment, otherwise known as "cake solids" from the belt filter presses. Typical solids content is 30-55%.
- Mixed Solids. Mixing dry sediment with incoming cake solids can improve the overall solids content of the material being handled. Typical solids content after mixing is 70-75%.
- Dry Solids. Pre-drying sediment to a powder material can reduce handling costs and improve the energy efficiency of final treatment process. Typical solids content is 90-100%.

7.3 Handling Cake Solids Sediment

For testing purposes, a sediment sample with a 58.8% solids content was used to obtain the indices.

Sediment from the belt press operations will be stored in piles for varying lengths of time, some potentially longer than others. Depending on final disposal options, the sediment may be moved from these storage piles and placed into a sediment receiving hoppers, which will discharge by live bottom screw feeder to a belt conveyor.

Critical material handling issues include:

- Storage area. The tendency of the sediment to compact, forming large clods.
- Receiving hopper. The ability of the material to flow down the walls of a hopper, and its potential to stick to walls, arch at the live bottom screw feeder, or rathole within the hopper.

- Live bottom screw feeder. The ability of the material to move in a live bottom screw feeder, and its tendency to stick to the flights or trough.
- Belt conveyor. The behavior of the material along a belt conveyor, and its tendency to fall off the sides of the belt or stick to the belt.

The results of indices testing are found in Table of Flow Indices, above. Preliminary conclusions from the testing are as follows:

1. Storage Area -- The material should be reclaimed with a front end loader. An automatic reclaiming system would not be economical in this situation.
2. Receiving hopper – The receiving hopper should be of a straight wall design. This will prevent arching and rat holing within the hopper. To achieve this the live bottom screw feeder will need to have the same inlet dimensions as the receiving hopper. The overall height of the hoppers would need to be kept to a height of 3 feet or less to prevent bridging.
3. Live bottom screw feeder – The feeder screws should not have any internal hanger bearings, and should have no more than two screws driven by a single drive motor. To prevent the sticking from being a serious problem the hopper bottoms could be lined with a UHMW (ultra high molecular weight) plastic.
4. Belt conveyor – The belt conveyor would need to be provided with belt scrapers to prevent build up of sticky material on the belt.

The river sediment is in a highly viscous state at this stage of the process. It should not be allowed to dry out in the receiving hopper, or it will set up and need to be mechanically removed. Furthermore, it will stick to surfaces unless appropriate design features are incorporated. The possibility of pumping, rather than screw feeding or belt conveying, should also be considered.

7.4 Handling Mixed Dry and Wet Sediment

Mixing wet cake solids sediment and pre-dried sediment, in proper proportions, can raise the combination to a level above the point at which the material exhibits significant cohesion. For testing purposes, a sediment sample with a 71.7% solids content was used to obtain the indices.

The results of indices testing are found in Table of Flow Indices, above. Preliminary conclusions from the testing are as follows:

1. Mixer discharge screw conveyor. The feeder screw should not have any internal hanger bearings. The trough of the conveyor should be lined with UHMW plastic to mitigate any potential fouling of the unit.

2. Dryer feed screw conveyor. – The sediment will behave in the dryer feed screw conveyor as it did in the mixer discharge screw conveyor.

The river sediment at this stage of the process is no longer highly viscous, but remains sticky, due to its fine-grained nature. Precautions as indicated above should be observed to prevent arching and ratholing.

7.5 Handling Dry Sediment

Dry sediment is material that is approximately 95% solids. Dust control becomes an issue with fine-grained materials with this low moisture content. For testing purposes, a sediment sample with a 97.9% solids content was used to obtain the indices.

Material handling issues that were studied include:

- Screw conveyor. The ability of the material to move in the conveyor, and the tendency to stick to the flights or trough.

- Bucket elevator. The ability of the material to move behave in the buckets, and the tendency to stick to the bucket walls.
- Dry sediment silo and dry sediment surge bin. The ability of the material to flow down the walls of the hopper, and the tendency to stick to the walls, arch at the discharge, or rathole within the hopper.
- Live bottom screw feeder. The ability of the material to move in the screw feeder, and the tendency to stick to the flights or trough.
- Belt conveyor. The ability of the material to convey along the belt, and the tendency to fall off the sides of the belt or stick to the belt.

The results of indices testing are found in Table of Flow Indices, above. Preliminary conclusions from the testing are as follows:

- Screw conveyor, live bottom screw feeder, and bucket elevator – River sediment with a 97.9% solids content behaves as a slightly compressive powder. No material handling problems are anticipated. However, no internal hanger bearings should be used inside screw conveyors.
- Dry sediment silo and dry sediment surge bin – Arching at the outlet is preventable by making the outlet at least 0.3 feet in diameter. Ratholing should not be a problem for conical hoppers. The necessary hopper design angle is 72^{o}.
- Belt conveyor – There should be negligible hang-up of sediment with a 97.9% solids content on conveying belts. Dust is the primary concern, for which a dust collection system should be provided.

The dried river sediment at this stage of the process is no longer viscous, nor sticky. The material behaves as a slightly compressive powder. It can be stored and fed from silos and surge bins with bottom outlet diameters greater than four inches in diameter.

7.6 Rotary Air Lock Usage

A rotary air lock is a mechanism for providing a tight seal into or out of a material processing system, yet allowing the flow of the feedstock or process output. They are commonly used in industry. They function similar to a revolving door on a building, providing a controlled path for material flow and significantly limited air inleakage.

The use of rotary air locks should be avoided on system handling wet and/or mixed sediment, due to its tendency to be sticky at these moistures. Other tight-seal mechanisms are available, such as the use of tapered screw conveyors. A tapered screw conveyor provides an air seal by operating with its feed screw flights filled to the circumference. The mechanical action of the screw feeder overcomes whatever tendency the material might have to stick, and augers the material forward in the process.

7.7 Sediment Behavior Tables & Graphs

Appendix A contains a series of tables and graphs that the detail analysis of various handling characteristics of sediment at 30% solids (cake solids), 75% solids (mixed solids), and 95% solids (dry solids). Data summarized includes:

- Feed Density Index
- Bin Density Index
- Springback Index
- Arching Index
- Ratholing Index
- Hopper Index
- Chute Index
- Bulk Density vs Consolidation Pressure
- Friction Angle vs Consolidation Pressure
- Strength vs Consolidation Pressure
- Friction Angle vs Wall Pressure for 304 2B Stainless Steel

- Friction Angle vs Wall Pressure for 304-#1 Stainless Steel
- Friction Angle vs Wall Pressure for Carbon Steel

7.8 Summary of Sediment Handling Indices

		Units	Cake Solids	Mixed Solids	Dry Solids
Required Flow Rate		lb/min	283	376	517
Solids Content		%	58.8	71.7	97.9
FLOW RATE INDICES					
	FRI	lb/min	11262	8316.2	1755.4
	FDI	lb/ft³	65.3	50.6	46.5
	BDI	lb/ft³	89.2	66.2	50.4
	SBI	%	0.8	0.8	0.6
HANGUP INDICES					
0 hours					
	AI	ft	8.7	0.4	<0.2
	RI	ft	32.3	23.8	2.1
16 hours					
	AI	ft	14.4	2.5	0.3
	RI	ft	52.6	23.7	7.2
HOPPER INDICES					
304-2B stainless steel					
	HI	degree	5	0	18
	CI	degree	90	90	32
304-#1 stainless steel					
	HI	degree	0	2	14
	CI	degree	90	90	42
New carbon steel					
	HI	degree	7	0	18
	CI	degree	90	90	32

Abbreviation Key

FRI = Flow Rate Index
FDI = Feed Density Index
BDI = Bin Density Index
SBI = Spring Back Index
AI = Arching Index
CI = Chute Index

APPENDIX A

December 11, 2002

JOHANSON INDICIZER™ REPORT

Report For: ***Minergy***
Material: 30% Solids River Sediment
Test Conditions: ***As received at room conditions***
Material Weight: 110.87

<u>FLOW RATE INDICES</u> (Indices Basis: D = 10 feet, d = 12 inches, ϕ = 20)

Flow Rate Index FRI (lb/min)	Feed Density Index FDI (pcf)	Bin Density Index BDI (pcf)	Springback Index SBI (%)
11262	65.3	89.2	0.8

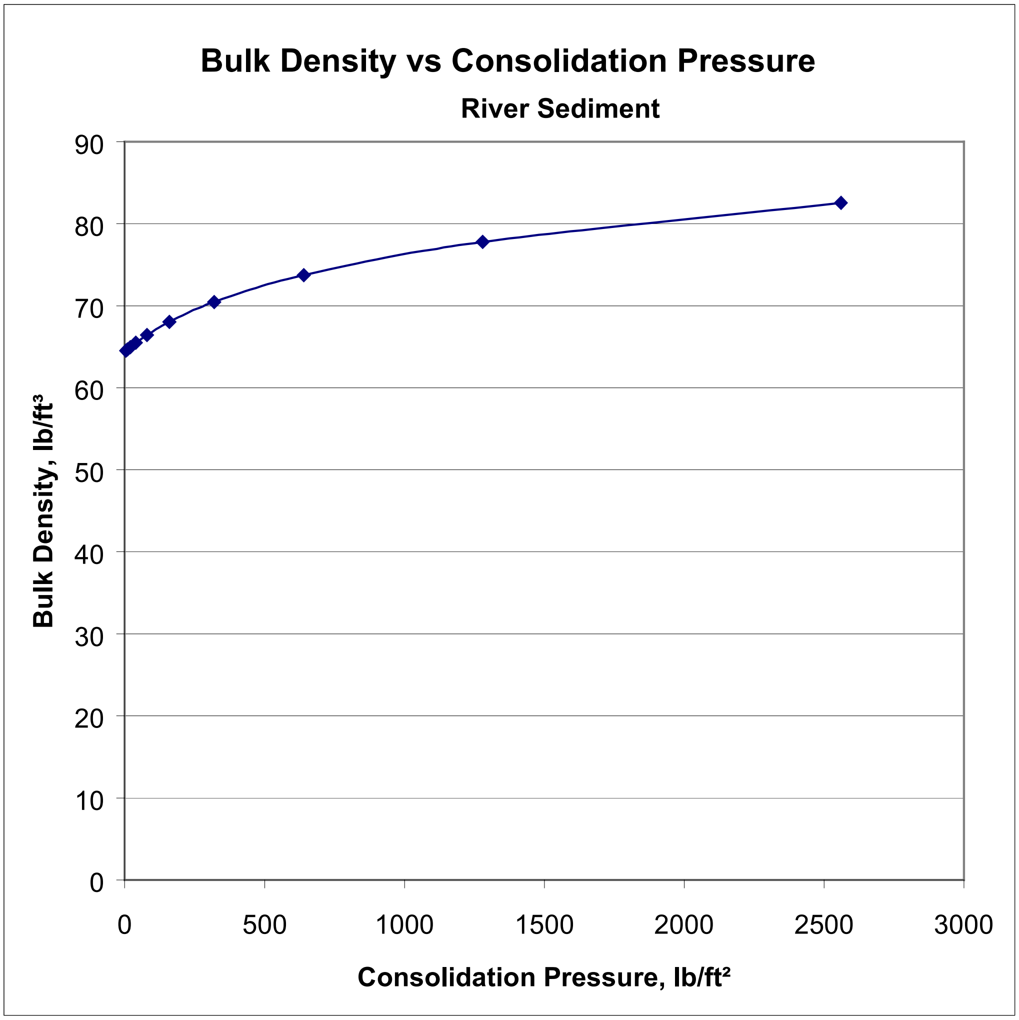
<u>HANG-UP INDICES</u> (Indices Basis: D = 10 feet)

Consolidation Time (hr)	Arching Index AI (ft)	Ratholing Index RI (ft)
0	8.7	32.3
16	14.4	52.6

<u>HOPPER INDICES</u> (Indices Basis: D = 10 feet, d = 12 inches)

Wall Material	Hopper Index HI (degree)	Chute Index CI (degree)
304-2B stainless steel	5	90
304-#1 stainless steel	0	90
Carbon steel	7	90

D = BIN DIAMETER, d = HOPPER OUTLET DIAMETER, ϕ = HOPPER ANGLE

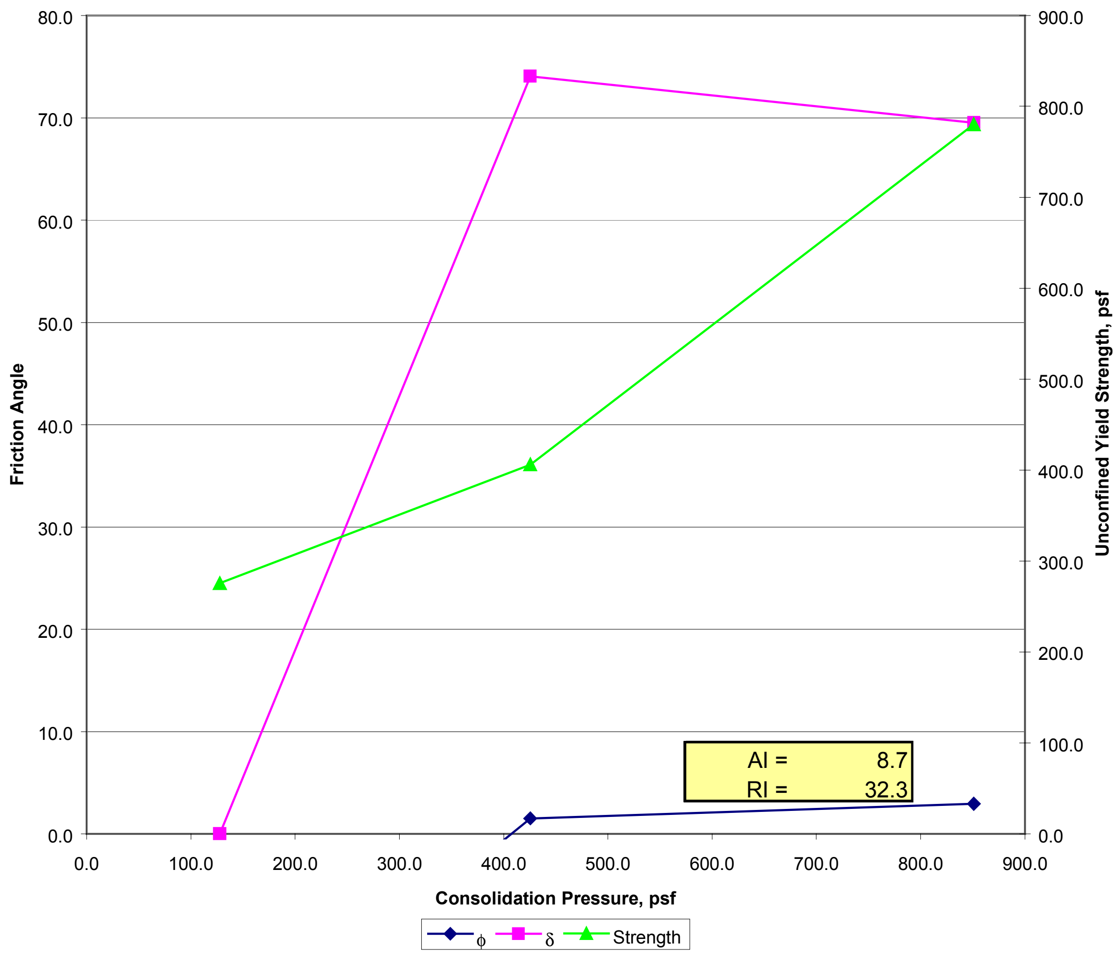


Bulk Density = $\gamma = \gamma o(1+(\sigma/\sigma o))^\wedge \beta$

© Diamondback Technology, Inc. 2001

Job No.: MIN-1
Material: River Sediment
Company: Minergy

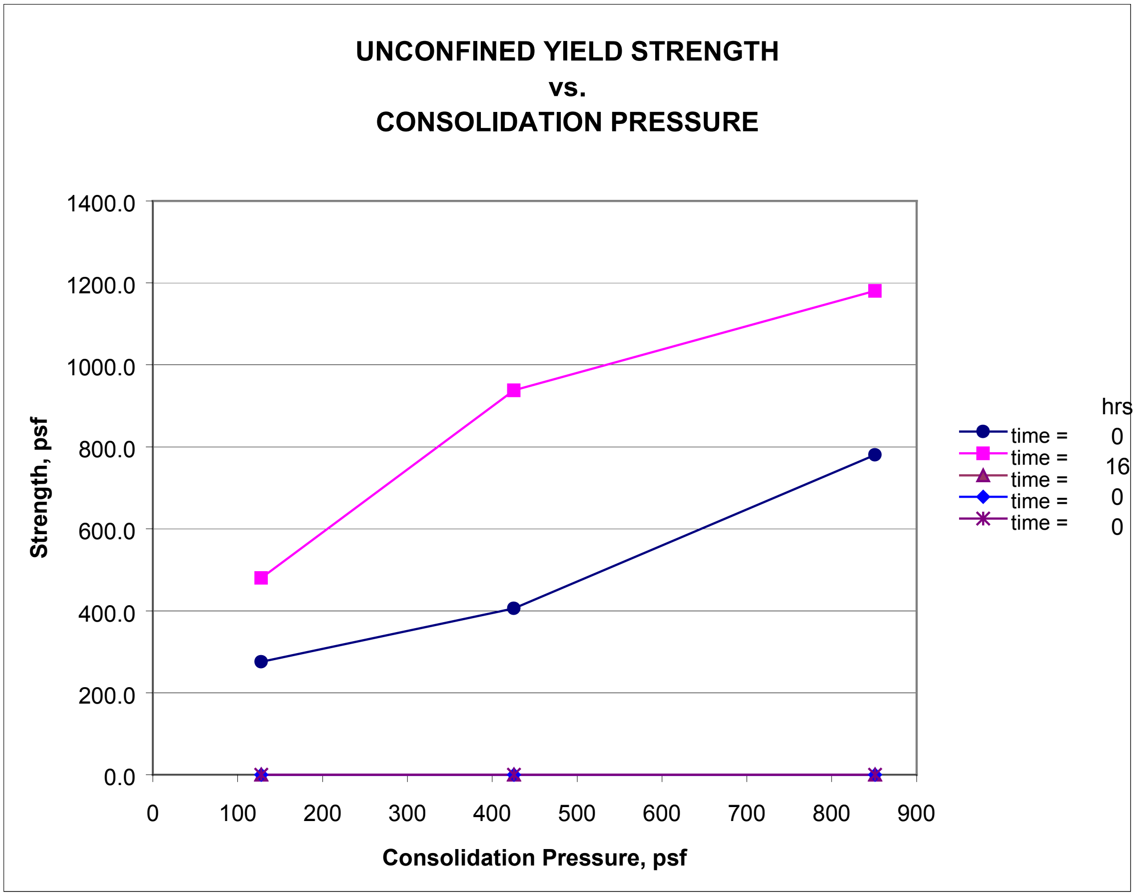
CONSOLIDATION PRESSURE
vs φ, δ and STRENGTH



Temp.	Moisture:	Indicies basis:	
° F	%	D, ft	d, inches
RT	41.2	10	12

© Diamondback Technology, Inc. 2001

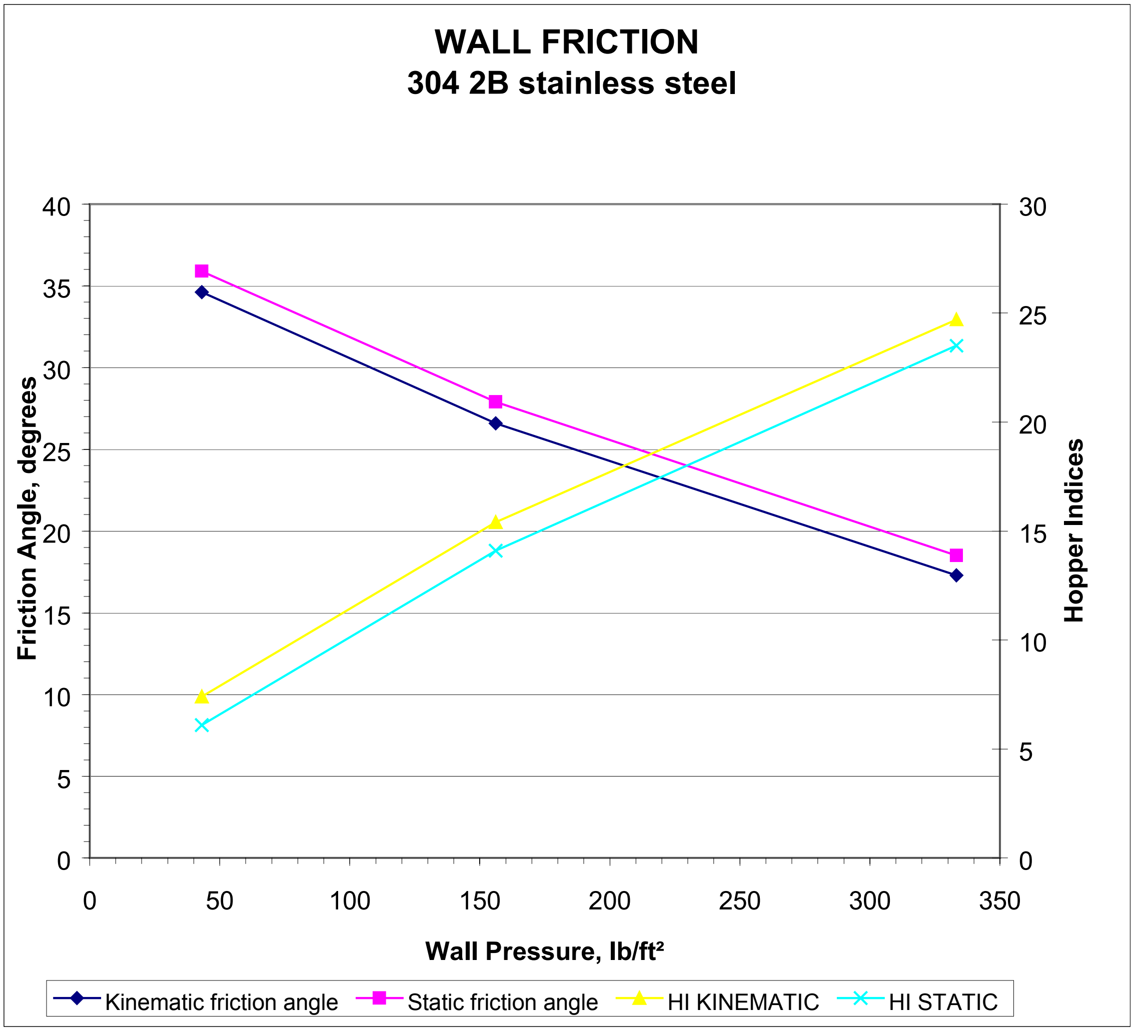
Job No.: MIN-1
Material: River Sediment
Company: Minergy



Density Parameters		
γo	σo	β
64.37924	202.6693	0.095072

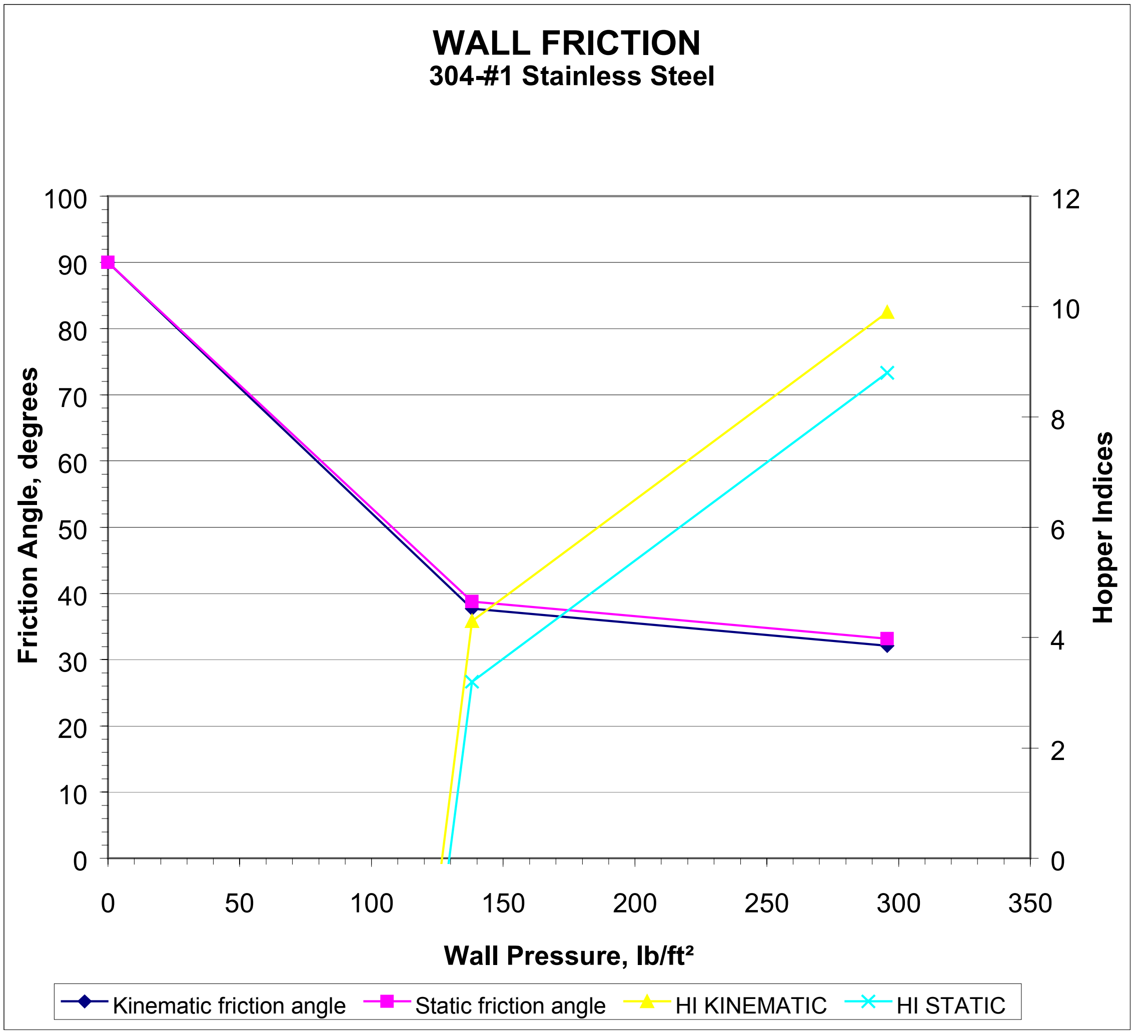
© Diamondback Technology, Inc. 2001

Job No.: MIN-1
Material: River Sediment
Company: Minergy



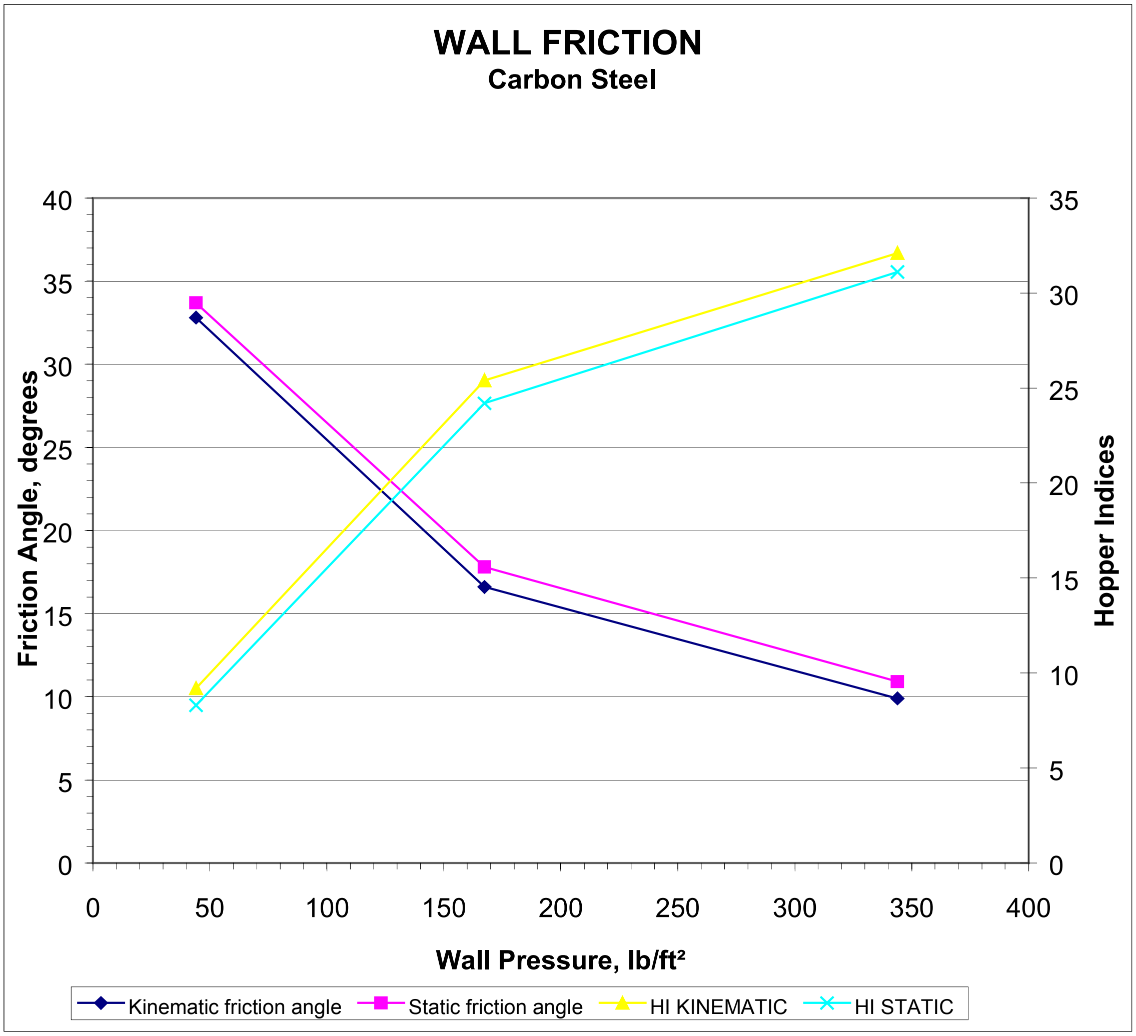
© Diamondback Technology, Inc. 2001

Job No.: MIN-1
Material: River Sediment
Company: Minergy



© Diamondback Technology, Inc. 2001

Job No.: MIN-1
Material: River Sediment
Company: Minergy



© Diamondback Technology, Inc. 2001

Job No.: MIN-1
Material: River Sediment
Company: Minergy

December 11, 2002

JOHANSON INDICIZER™ REPORT

Report For: *Minergy*
Material: Filter cake
Test Conditions: *As received at room conditions*
Material Weight: 82.08

FLOW RATE INDICES (Indices Basis: D = 10 feet, d = 12 inches, ϕ = 20)

Flow Rate Index FRI (lb/min)	Feed Density Index FDI (pcf)	Bin Density Index BDI (pcf)	Springback Index SBI (%)
8316.2	50.6	66.2	0.8

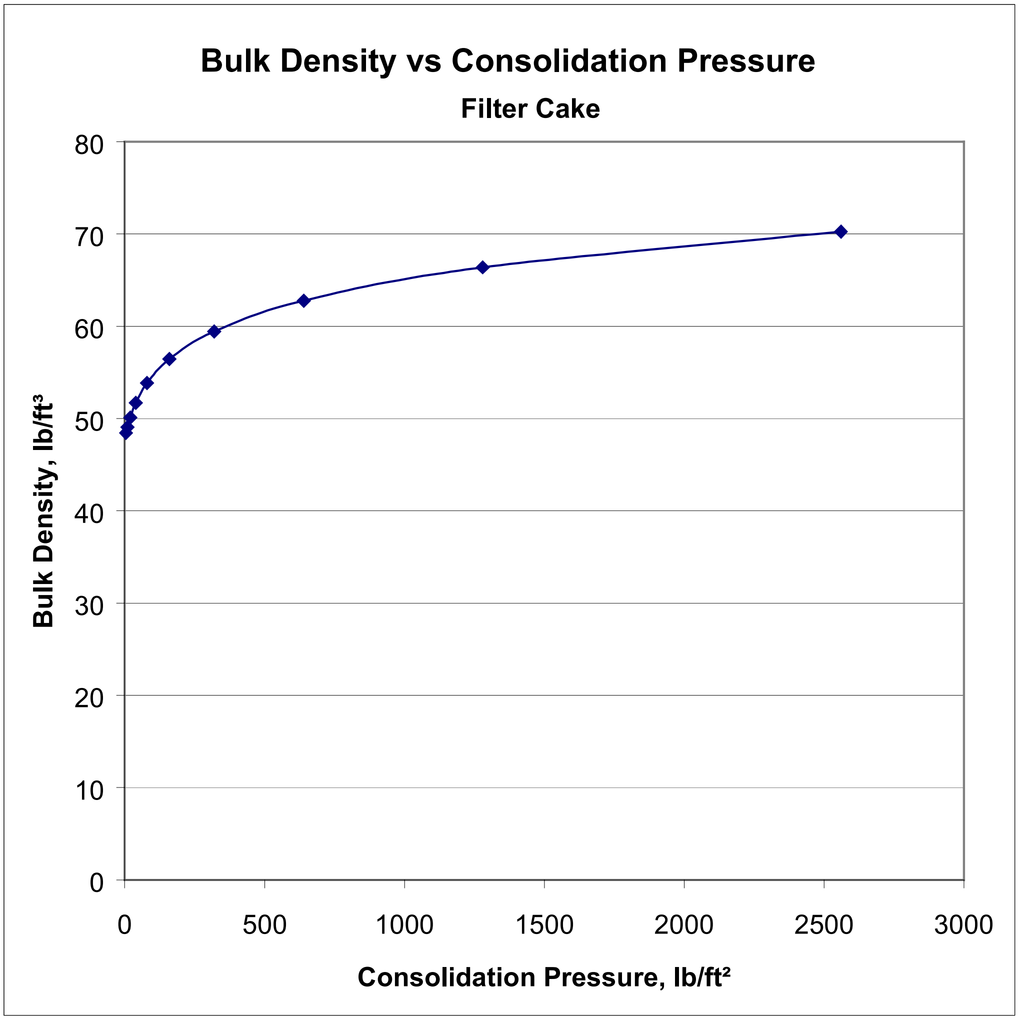
HANG-UP INDICES (Indices Basis: D = 10 feet)

Consolidation Time (hr)	Arching Index AI (ft)	Ratholing Index RI (ft)
0	0.4	23.8
16	2.5	23.7

HOPPER INDICES (Indices Basis: D = 10 feet, d = 12 inches)

Wall Material	Hopper Index HI (degree)	Chute Index CI (degree)
304-2B stainless steel	0	90
304-#1 stainless steel	2	90
Carbon steel	0	90

D = BIN DIAMETER, d = HOPPER OUTLET DIAMETER, ϕ = HOPPER ANGLE

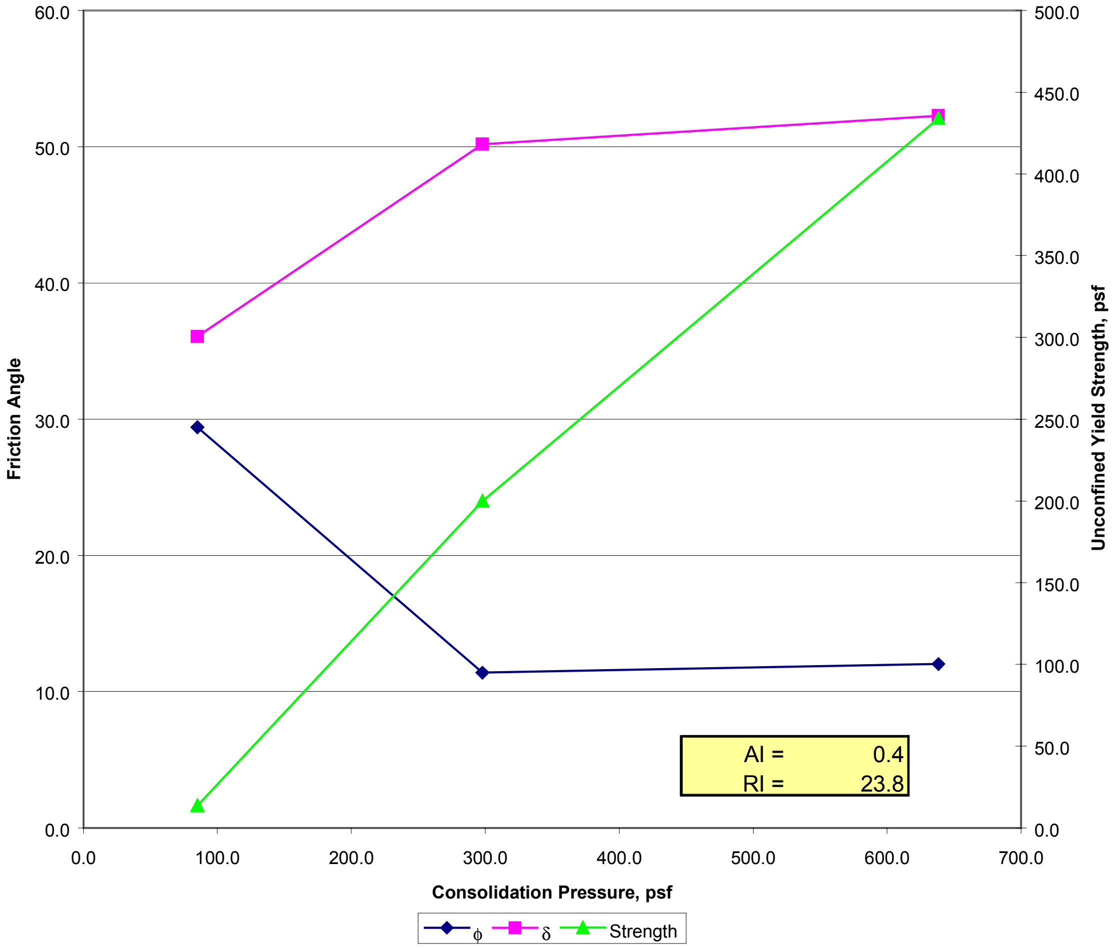


Bulk Density = $\gamma = \gamma o(1+(\sigma/\sigma o))^\wedge \beta$

© Diamondback Technology, Inc. 2001

Job No.: MIN-1
Material: Filter Cake
Company: Minergy

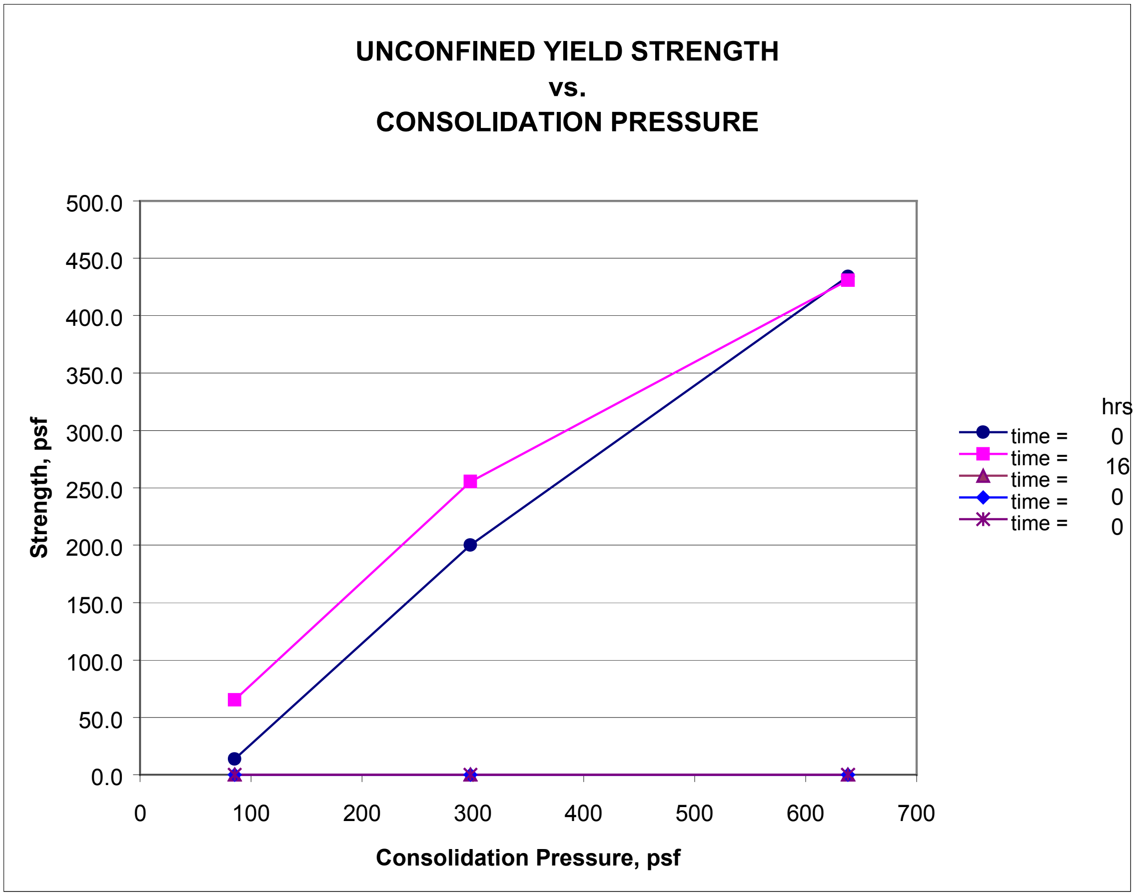
CONSOLIDATION PRESSURE
vs φ, δ and STRENGTH



Temp.	Moisture:	Indicies basis:	
° F	%	D, ft	d, inches
RT	28.3	10	12

© Diamondback Technology, Inc. 2001

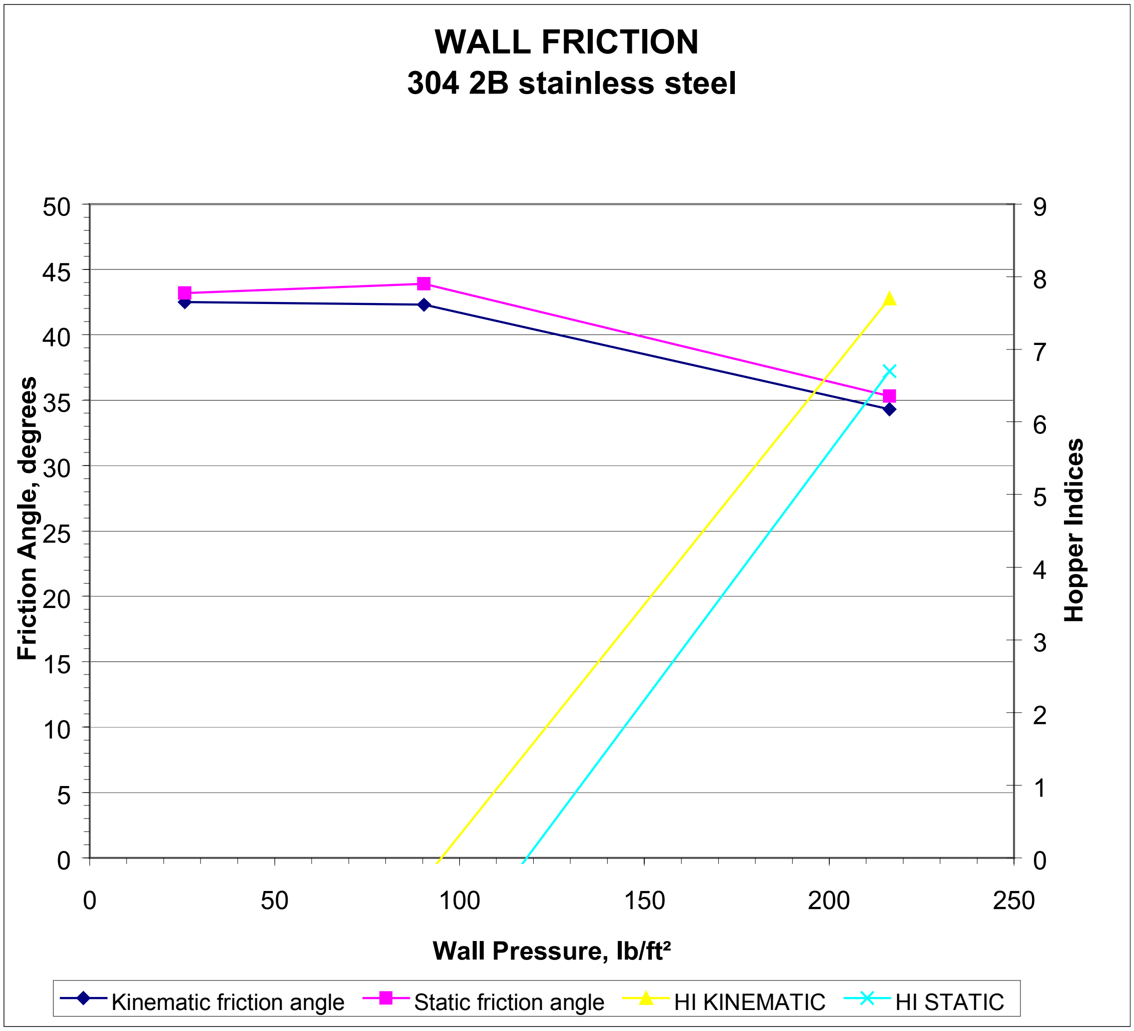
Job No.: MIN-1
Material: Filter Cake
Company: Minergy



Density Parameters		
γo	σo	β
47.66166	23.89349	0.082841

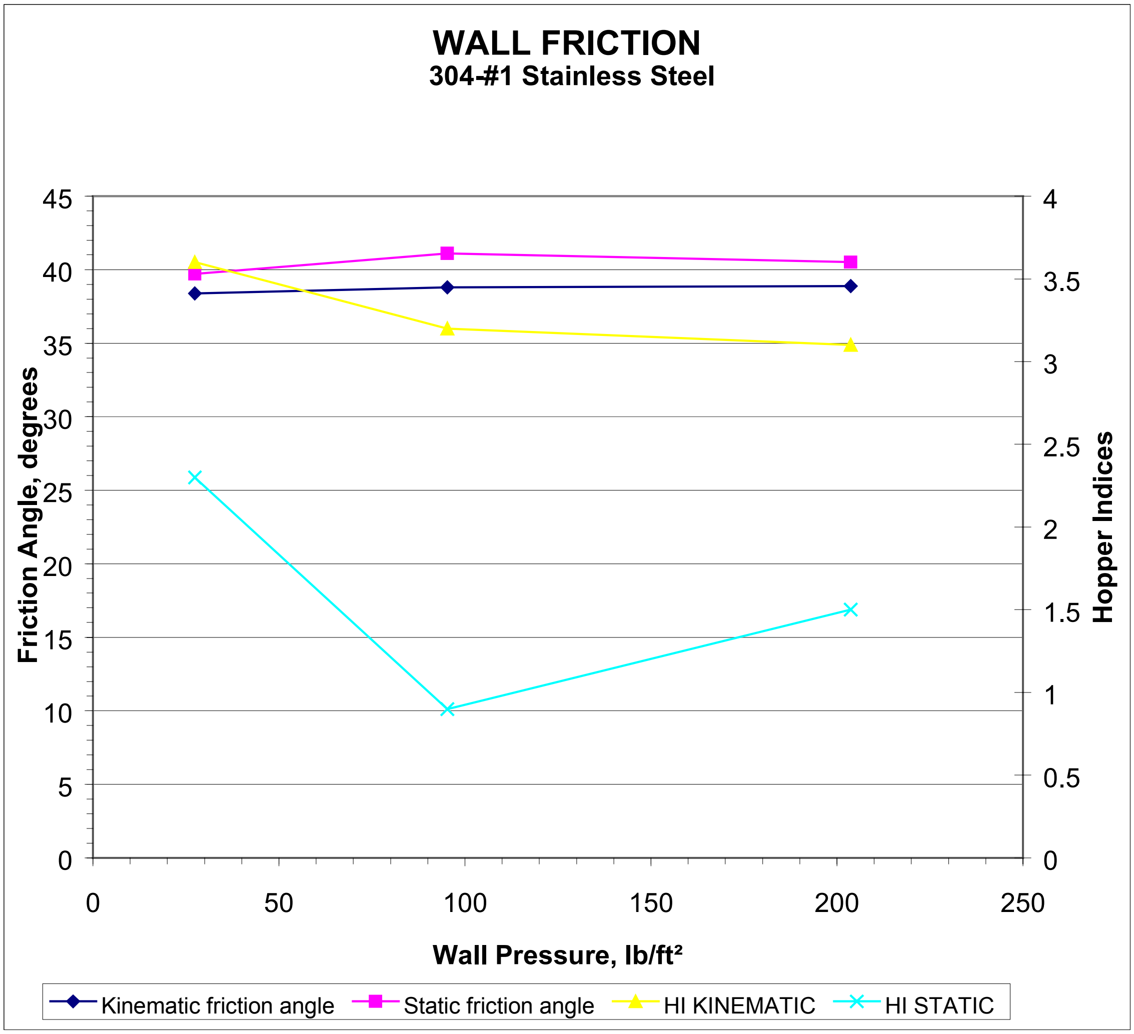
© Diamondback Technology, Inc. 2001

Job No.: MIN-1
Material: Filter Cake
Company: Minergy



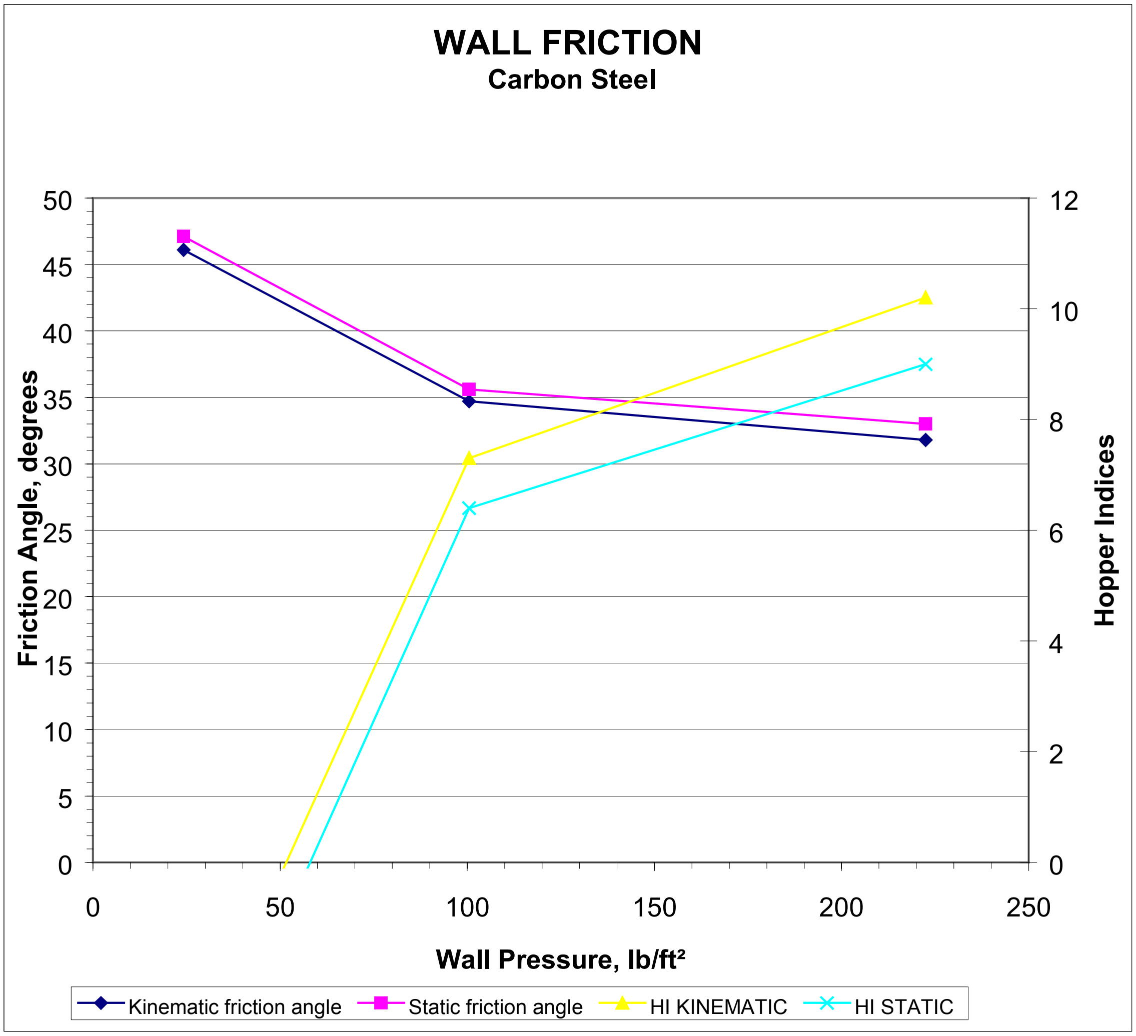
© Diamondback Technology, Inc. 2001

Job No.: MIN-1
Material: Filter Cake
Company: Minergy



© Diamondback Technology, Inc. 2001

Job No.: MIN-1
Material: Filter Cake
Company: Minergy



© Diamondback Technology, Inc. 2001

Job No.: MIN-1
Material: Filter Cake
Company: Minergy

December 11, 2002

JOHANSON INDICIZER™ REPORT

Report For: ***Minergy***
Material: Dry Melter Feed
Test Conditions: ***As received at room conditions***
Material Weight: 75.01

FLOW RATE INDICES **(Indices Basis: D = 10 feet, d = 12 inches, ϕ = 20)**

Flow Rate Index FRI (lb/min)	Feed Density Index FDI (pcf)	Bin Density Index BDI (pcf)	Springback Index SBI (%)
1755.4	46.5	50.4	0.6

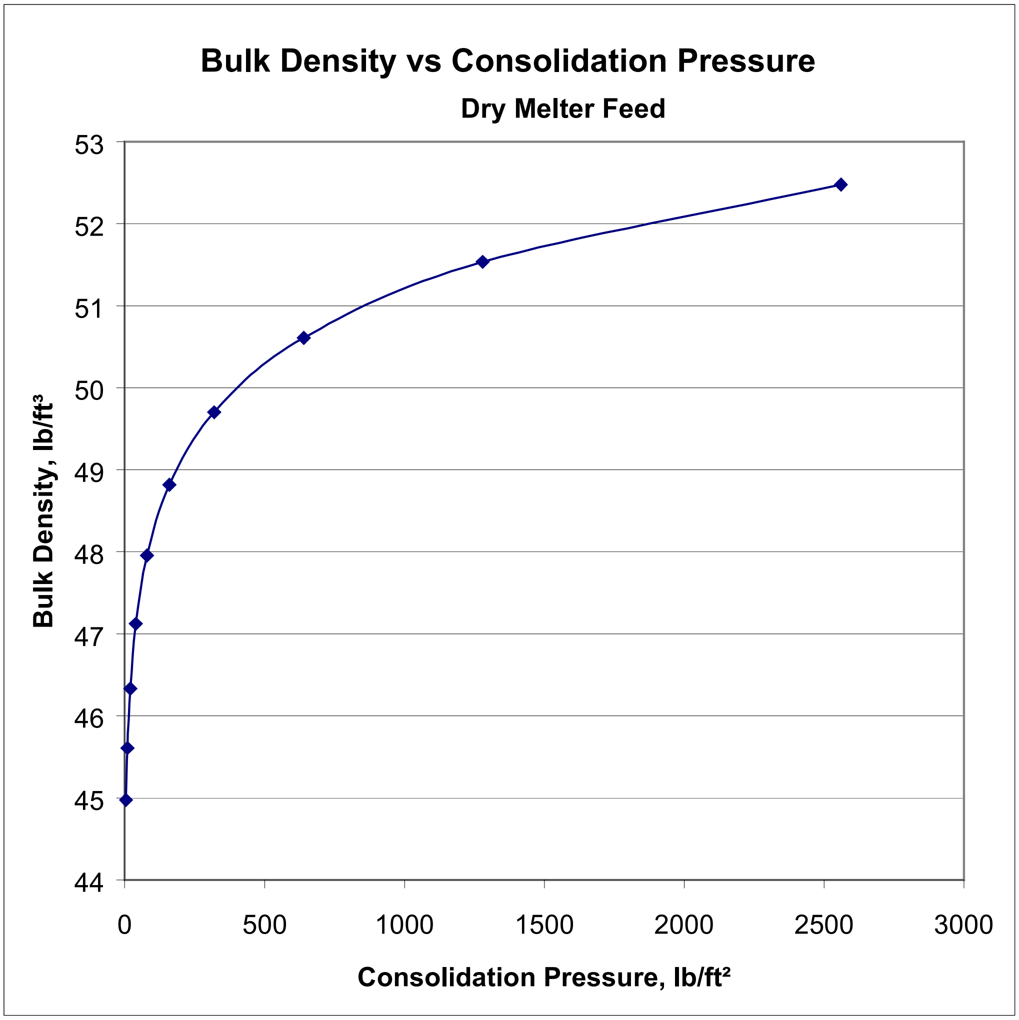
HANG-UP INDICES **(Indices Basis: D = 10 feet)**

Consolidation Time (hr)	Arching Index AI (ft)	Ratholing Index RI (ft)
0	0	2.1
16	0.3	7.2

HOPPER INDICES **(Indices Basis: D = 10 feet, d = 12 inches)**

Wall Material	Hopper Index HI (degree)	Chute Index CI (degree)
304-2B stainless steel	18	31.8
304-#1 stainless steel	14	41.8
Carbon steel	18	32

D = BIN DIAMETER, d = HOPPER OUTLET DIAMETER, ϕ = HOPPER ANGLE

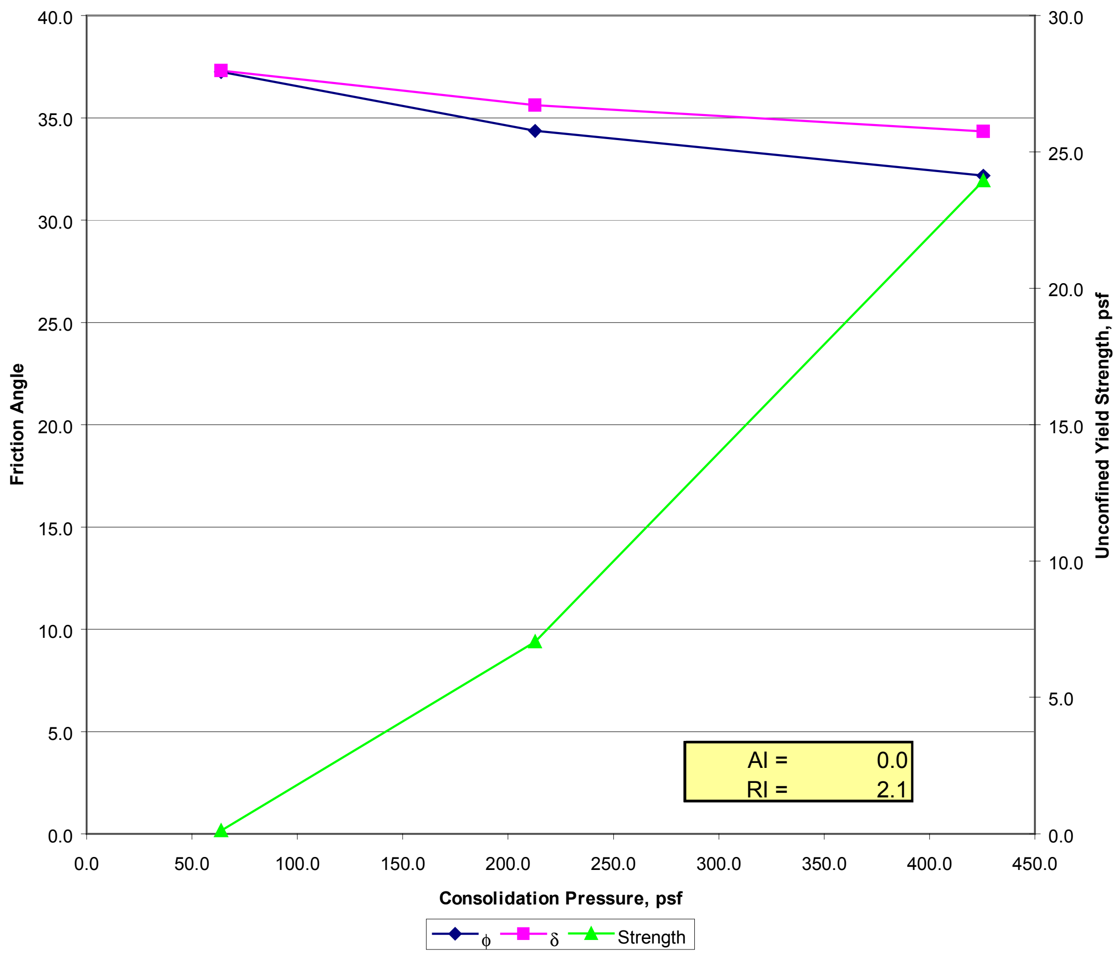


Bulk Density = $\gamma = \gamma o(1+(\sigma/\sigma o))$^β

© Diamondback Technology, Inc. 2001

Job No.: MIN-1
Material: Dry Melter Feed
Company: Minergy

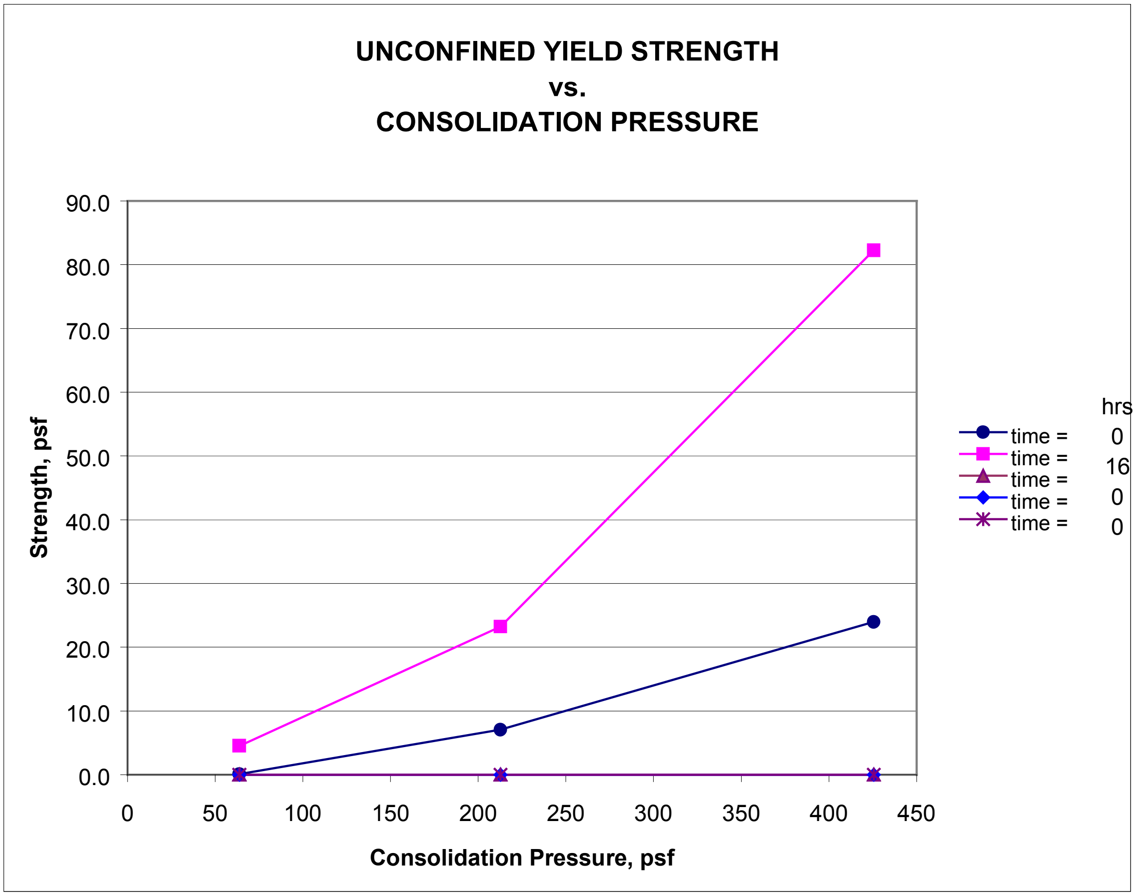
CONSOLIDATION PRESSURE
vs ϕ, δ and STRENGTH



Temp.	Moisture:	Indicies basis:	
° F	%	D, ft	d, inches
RT	2.1	10	12

© Diamondback Technology, Inc. 2001

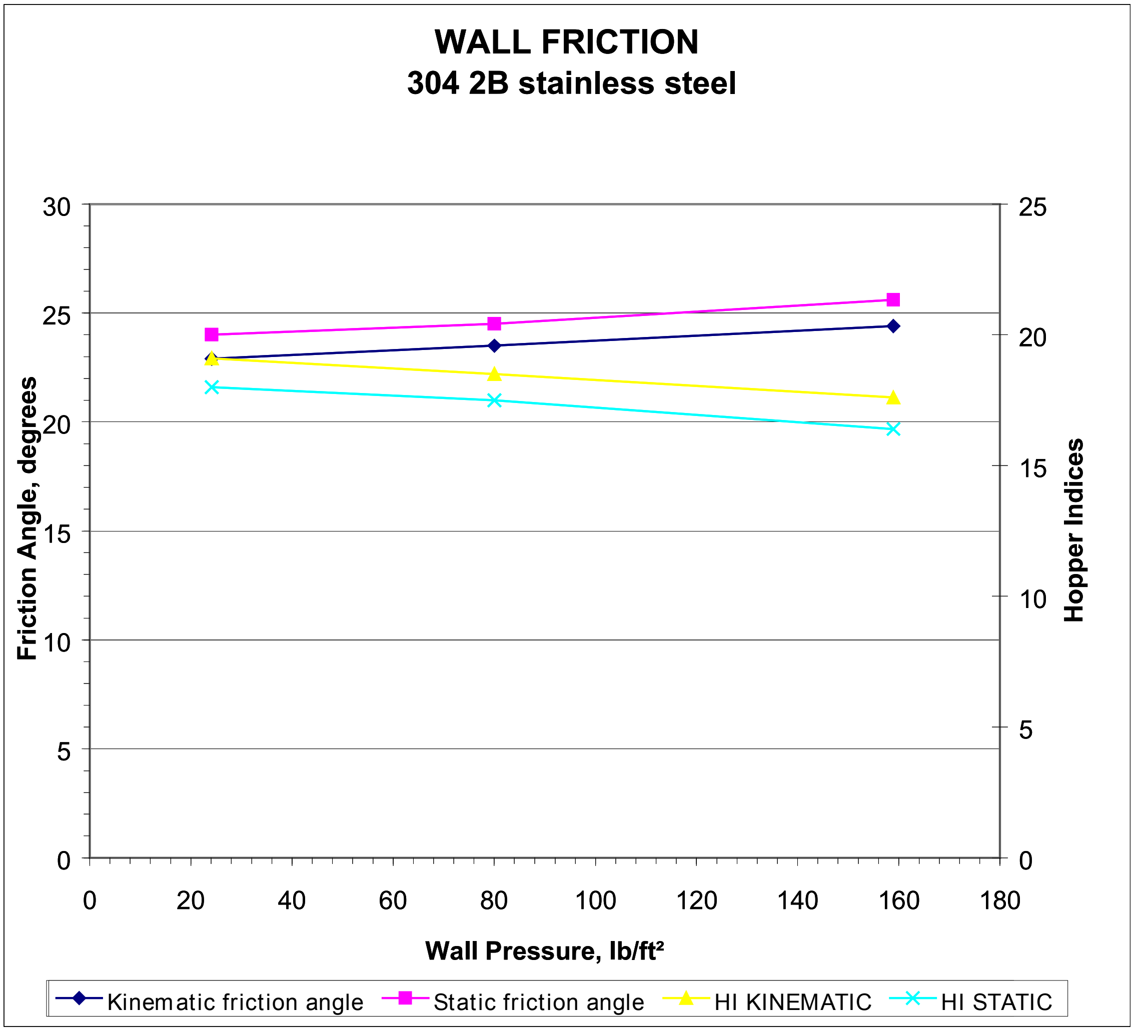
Job No.: MIN-1
Material: Dry Melter Feed
Company: Minergy



Density Parameters		
γo	σo	β
43.5563	2.087595	0.026198

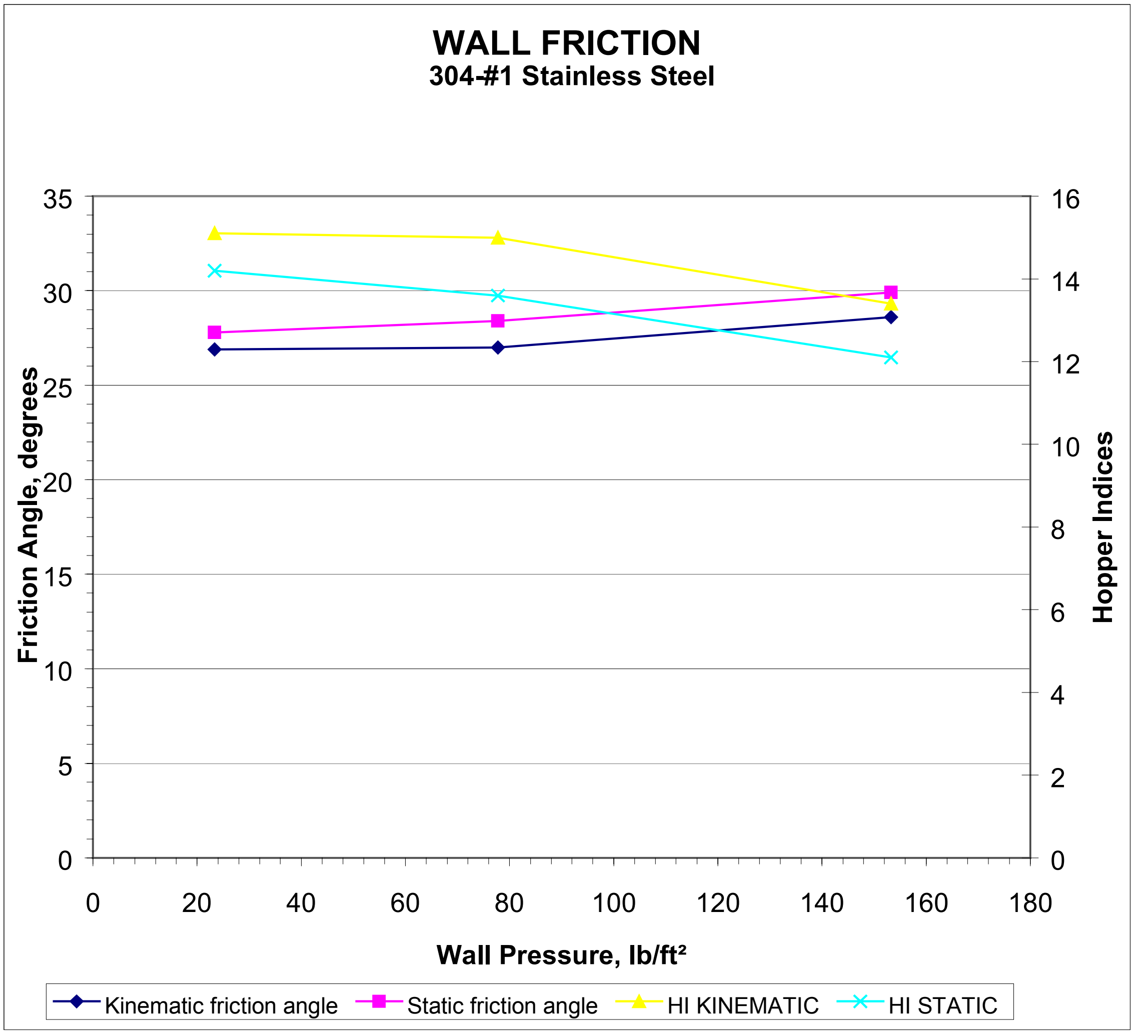
© Diamondback Technology, Inc. 2001

Job No.: MIN-1
Material: Dry Melter Feed
Company: Minergy



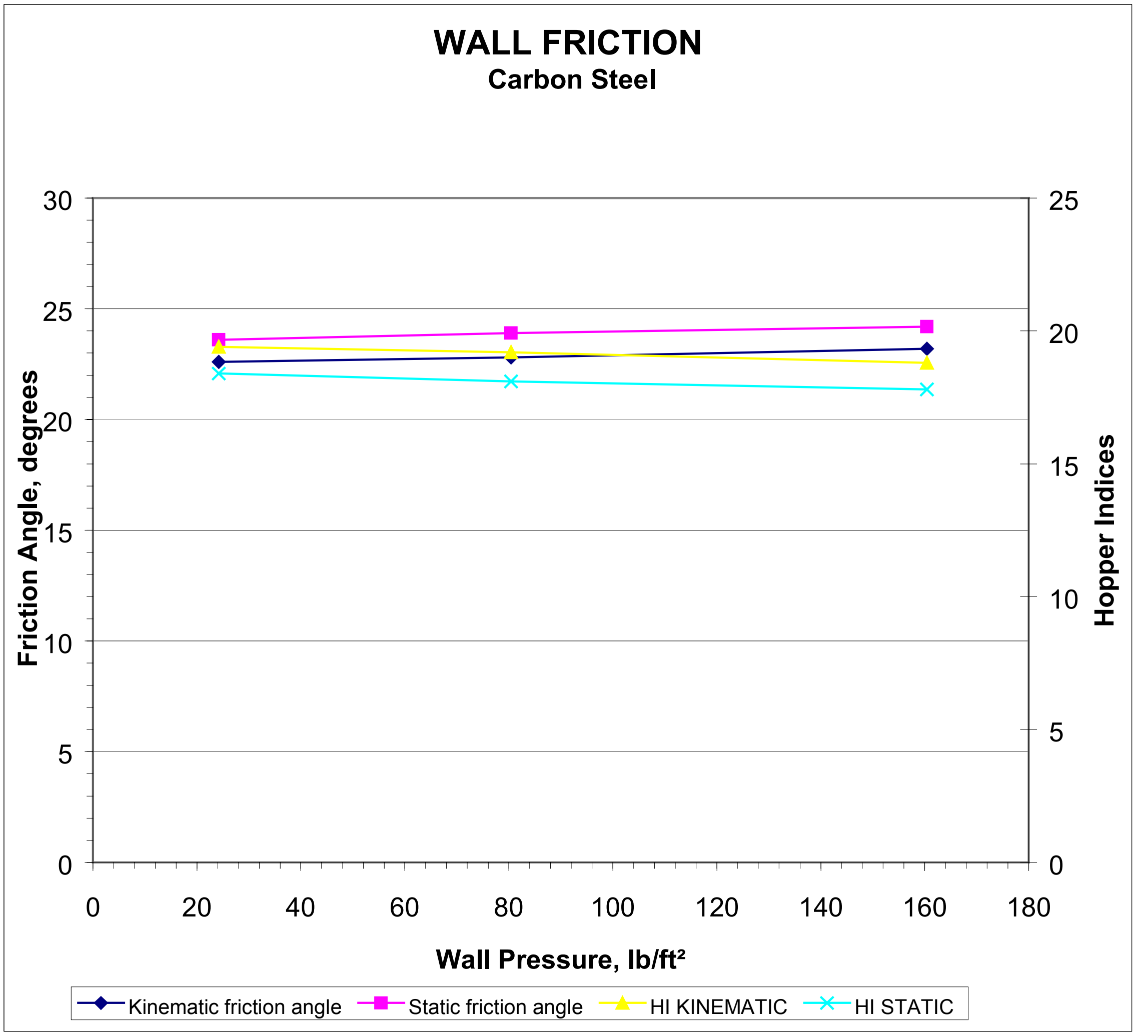
© Diamondback Technology, Inc. 2001

Job No.: MIN-1
Material: Dry Melter Feed
Company: Minergy



© Diamondback Technology, Inc. 2001

Job No.: MIN-1
Material: Dry Melter Feed
Company: Minergy



© Diamondback Technology, Inc. 2001

Job No.: MIN-1
Material: Dry Melter Feed
Company: Minergy

DIAMONDBACK TECHNOLOGY, INC.

MINERGY CORP	
DRY MELTER FEED HOPPER: Overall DWG	
Date: 12- 18-2002	Job #: MIN-1
Drawn By: LVD	Approved By:
Scale: As Shown	Dwg No: MIN-1-P

THIS EQUIPMENT IS COVERED BY ONE OR MORE OF THE FOLLOWING PATENTS:

U.S. PATENTS: 4,286,883; 4,715,212; 4,719,809; 4,757,575; 4,795,266; 4,958,741; 4,986,456; 5,052,874; 5,117,699; 5,289,728; 5,361,945; 5,454,490; 5,622,250; 5,992,689; 6,055,781; 6,086,307; UK PATENT: 2,056,296. CANADIAN PATENTS: 1,145,741; 1,295,492.; 2,040,231; 2,058,942; AUSTRALIAN PATENTS: 588651: 640933. EUROPEAN PATENT: 0252927B1. OTHER U.S. AND FOREIGN PATENTS PENDING.

ALL WELDS BETWEEN HOPPER SECTIONS MUST BE GROUND SMOOTH AND POWER BRUSHED TO BRING SURFACE TO ORIGINAL FINISH.

ALL GASKET MATERIAL MUST BE UNDERSIZED TO PREVENT UPWARD FACING LIPS.

ALL WELDS ON INTERIOR INWARD SLOPING SURFACES MUST BE GROUND FLUSH AND POWER BRUSHED TO BRING SURFACE TO ORIGINAL FINISH (POLISH GRIND MARKS WITH A FINE GRIT FLAPPER WHEEL).

ALL INFORMATION IN THIS DRAWING IS THE EXCLUSIVE PROPERTY OF DIAMONDBACK TECHNOLOGY, INC. AND MAY NOT BE REPRODUCED IN ANY MANNER, DISCLOSED TO THIRD PARTIES OR USED FOR MANUFACTURING OR SELLING THE EQUIPMENT SHOWN WITHOUT PRIOR WRITTEN AUTHORIZATION FROM DIAMONDBACK TECHNOLOGY, INC. 712 FIERO LANE #37, SAN LUIS OBISPO, CA 93401 USA.

THIS IS A PROPRIETARY DESIGN THAT CAN ONLY BE MANUFACTURED BY A LICENSED FABRICATOR. SEE DIAMONDBACK TECHNOLOGY INC. FOR A LIST OF LICENSED FABRICATORS.

VOLUME: 164 CU FT (ABD'S ONLY)

BIN SECTION	HOPPER WALL MATERIAL
A	304-2B SS
B	304-2B SS
C	304-2B SS
D	304-2B SS
E	304-2B SS
F	304-2B SS
G	304-2B SS