

THE HEVI-SAND PROCESS

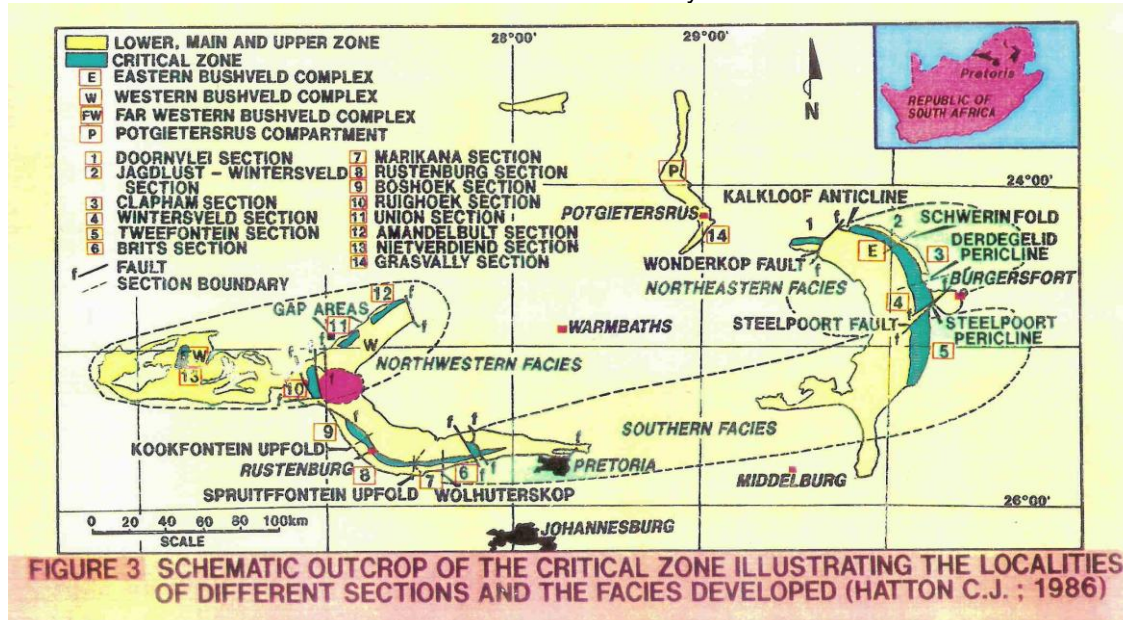
Is this new technology a good reason to consider changing foundry chromite sand quality assurance parameters?

Synopsis

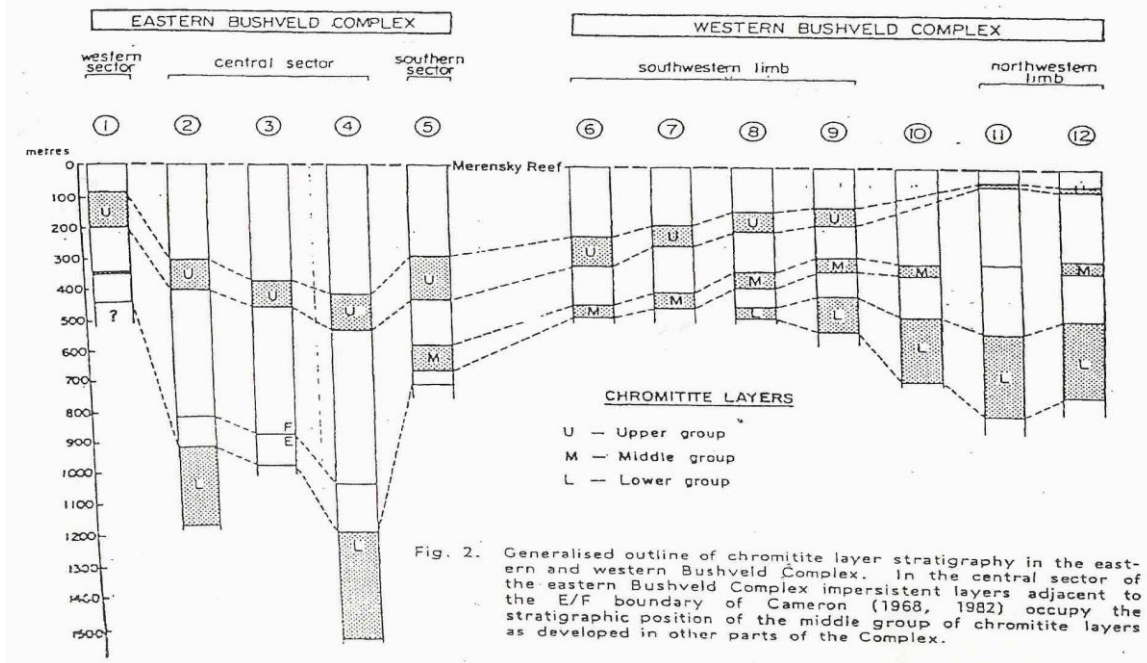
Foundry grade chromite sand production methods and acceptance specifications have changed little in the last 50 years. This paper reviews the old, the existing, and the new "Hevi-Sand Process" used to produce foundry chromite sand. The advent of new mining and processing technology, coupled with changes over the years in foundry practices and procedures, suggests that new and standardized criteria for specifying and testing of Hevi-sand processes products, (foundry chromite sands), is long over due. This paper is therefore presented as a discussion document for change.

The vast majority of chromite sand used in foundries comes from South Africa. While there are large chrome ore deposits in other regions, the type of formation, crystal size and impurities result, in most instances, in undesirable foundry properties. The rest of this paper therefore only considers foundry chromite sands from South Africa.

The area shown in fig1 is the Bushveld complex which contains among other things the worlds largest chrome ore deposits. These deposits were formed through precipitation as an underground magma lake cooled, and have been laid down as seams of variable quality and thickness, caused by each change in the conditions within the magma lake. Subsequent earth movements have twisted the seams so that in some places they are visible on the surface and in others are inaccessible at any reasonable cost.



The seams have been classified into three main groups the upper groups, UG's, the middle groups, MG's and the lower groups LG's. Through reasons of mine-ability and analysis, the UG's are primarily mined for platinum group minerals, the MG's for low grade met grades, ferro- chrome, and the LG's for high grade ferro-chrome, chemical and foundry sands. (see fig 2)



South African Chrome Mining and Processing

Historically and up until 2008, most of the mining has been carried out by large mining houses that are either producing ferro-chrome or servicing ferro-chrome producers. Foundry Sand has always been very much a by-product business ie less than 3% of the mined production ends up as foundry sand.

Typically from 100 tons of mined ore, 33 tons would be Lumpy 44%Cr₂O₃(see fig3), 33 tons small lumpy 42%Cr₂O₃, and 33 tons fines 35%Cr₂O₃. The lumps are fed straight to the smelter for conversion into ferro-chrome, leaving the fines as a problem product due to its low chrome content and high silicates contents. This material is processed via “Humphrey spirals” (see fig3) to wash and concentrate it into a useable product. (Humphrey spirals were developed in the USA during the Second World War).



This concentration usually results in three or four streams of product dependent on the configuration of the plant. For the 33 tons going into the plant, typically you would get 18tons of Met-grade 42% chrome, 9tons Chem.-grade, 3tons foundry grade and 6tons of waste. See fig4 typical Chrome ROM and spiral processing plant layout

A new technology a new idea

In the summer of 2004, price and availability of foundry chromite was becoming an issue. The commodity boom started to create a ferro-chrome shortage and therefore most of the large mining houses concentrated on converting as much chrome ore to ferro chrome as possible, to avoid letting down their core business, ie steel making, which in turn reduced availability and often the quality of foundry sand, which in turn pushed prices up.

Amcol as a long term supplier to the foundry industry decided therefore, to investigate how we could solve our supply and raw material quality problems. As we progressed we realized that because of, history, concentration on core market, internal expertise and pressure, that none of the existing suppliers had a mining operation which focussed solely on foundry sand. Indeed the foundry Sand being produced was as a result of a need to add some value to the fines which are produced during mining for their ferro-chrome operations. We decided therefore that we would concentrate only on foundry and at the same time try to develop a technology which maximised foundry yield, reduced waste and reduced the environmental impact of the process, while removing as many variables as possible from the process, resulting in a product which could be tailor made to improved overall foundry Sand and casting quality.

Through a mixture of our own internal laboratory, external laboratory work, and some of the leading processing companies in the world, we came to understand the process requirements and the limitations of the existing spiral techniques. We concluded that with the right ore body, good liberation, and high technology separation, we could convert in excess of 65% of the mined ore body into very consistent high quality foundry sand, while at the same time reducing water consumption by at least 80%.

The information, pictures and figures below show some important aspects involved in processing chrome ore.



Chrome mining operations at Bathlako



Chrome ROM Crushing and Screening

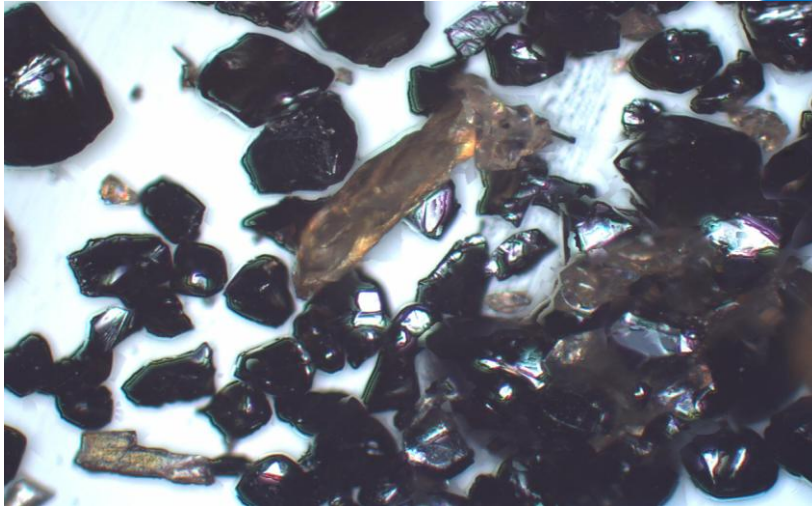


Hard lumpy chrome ore unprocessed

Small Lumpy Chrome ore unprocessed



Washed and crushed chrome ore prior to processing



Crushed and washed chrome ore, note the liberated opaque silicates but also those still attached to the grains.

The chart below shows the assay of crushed unwashed lumpy ore and shows that the majority of the, contaminates (silicates), are held either within agglomerates ie particles above 600micron or as fines.

Product	ative weight fract	SiO ₂		Cr ₂ O ₃		FeO	
		Grade (%)	Recovery (%)	Grade (%)	Recovery (%)	Grade (%)	Recovery (%)
Primary -300 +212 Sinks	10.13	0.51	0.72	46.87	11.54	25.20	11.26
Primary -425 +300 Sinks	20.62	0.59	1.68	46.83	23.48	25.08	22.81
Primary -600 +425 Sinks	28.45	0.63	2.48	46.78	32.37	25.01	31.38
Secondary -600 +425 Sinks	32.76	0.67	3.05	46.78	37.26	24.97	36.08
Secondary -425 +300 Sinks	35.96	0.70	3.51	46.77	40.89	24.94	39.57
Primary -212 + 150 Sinks	44.44	0.79	4.88	46.70	50.47	24.99	48.98
Secondary -300 +212 Sinks	46.94	0.82	5.37	46.67	53.27	24.98	51.71
Primary -150 +106 Sinks	52.66	0.91	6.62	46.60	59.67	24.97	58.00
Secondary -212 + 150 Sinks	55.12	0.97	7.46	46.55	62.39	24.95	60.66
Secondary -150 +106 Sinks	57.32	1.06	8.44	46.47	64.77	24.93	63.02
Primary -300 +212 Floats	59.62	1.26	10.40	46.30	67.12	24.85	65.34
Primary -425 +300 Floats	62.13	1.52	13.11	46.07	69.60	24.74	67.80
Primary -106	71.05	2.44	24.10	45.22	78.11	24.36	76.32
Primary -212 + 150 Floats	73.23	2.67	27.17	45.01	80.14	24.26	78.35
Primary -600 +425 Floats	76.13	2.99	31.63	44.73	82.80	24.14	81.05
Secondary -300 +212 Floats	79.26	3.47	38.24	44.32	85.42	23.97	83.82
Secondary -212 + 150 Floats	81.61	3.84	43.52	44.01	87.34	23.85	85.85
Secondary -106	89.28	4.91	60.87	43.07	93.51	23.46	92.36
Secondary -150 +106 Floats	90.99	5.14	65.02	42.87	94.85	23.37	93.80
Secondary +600 um	92.12	5.30	67.85	42.74	95.73	23.32	94.75
Primary -150 +106 Floats	93.02	5.48	70.83	42.57	96.28	23.24	95.33
Secondary -425 +300 Floats	96.52	6.18	82.85	41.99	98.53	23.01	97.94
Secondary -600 +425 Floats	100.00	7.20	100.00	41.13	100.00	22.67	100.00

	Cr%	Si%	Recovery %	Cr %	Si %	
10.13	474.7931	5.1663	10.13	474.7931	5.1663	
10.49	491.2467	6.1891	10.49	491.2467	6.1891	
7.83	366.2874	4.9329	7.83	366.2874	4.9329	
4.31	201.6218	2.8877	4.31	201.6218	2.8877	
3.2	149.664	2.24	3.2	149.664	2.24	
8.48	396.016	6.6992	8.48	396.016	6.6992	
2.5	116.675	2.05	2.5	116.675	2.05	
5.72	266.552	5.2052	5.72	266.552	5.2052	
2.46	114.513	2.3862	2.46	114.513	2.3862	
2.2	102.234	2.332	2.2	102.234	2.332	
2.3	106.49	2.898	2.3	106.49	2.898	
2.51	115.6357	3.8152	2.51	115.6357	3.8152	
8.92 Throw Awa	403.3624	21.7648				
2.18	98.1218	5.8206	2.18	98.1218	5.8206	
2.9	129.717	8.671	2.9	129.717	8.671	
3.13 2 Throw			3.13	138.7216	10.8611	
2.35 2 Throw			2.35	103.4235	9.024	
7.67 Throw Away						
1.71 2 Throw			1.71	73.3077	8.7894	
1.13 Throw Away			1.13	48.2962	5.989	
0.9	38.313	4.932	0.9	38.313	4.932	
3.5 2 Throw			3.5	146.965	21.63	
3.48 2 Throw			3.48	143.1324	25.056	
	22.97	3571.243	87.9902		3821.727	147.5749
afs54	77.03	46.36171	1.142285	83.41	45.81857	1.769271

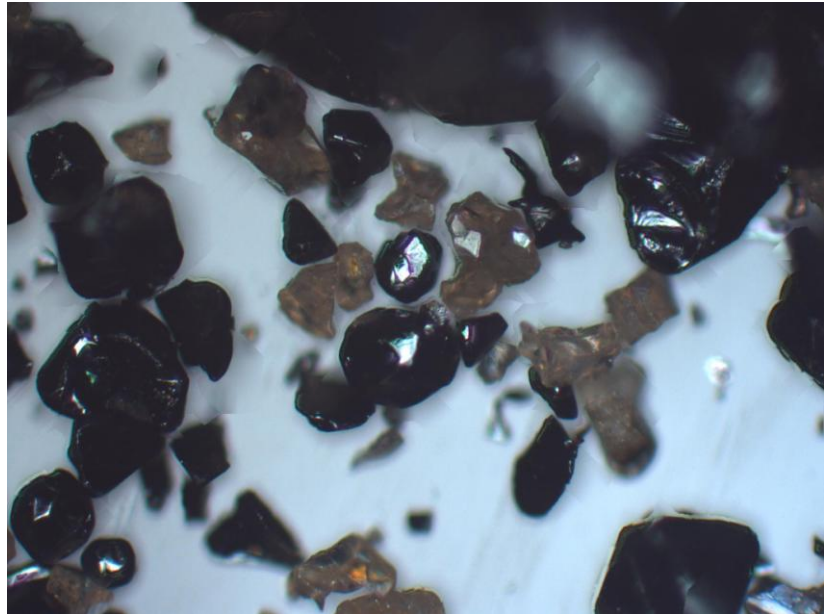
Resulting analysis if throw away all fines and float of secondary material

Resulting analysis if only throw away fines

We therefore concluded that crushing and sizing along with liberation must be controlled to maximise yield. When we looked at existing plants, most producers were using either Ball or rod mills to bring their spirals plant fines feed to grain size. The problem with this approach is that it is akin to taking a sledge hammer to crack a nut and while reasonably effective at getting down to grain size and liberation levels it also damaged a lot of crystals and resulted in a lot of waste fines, in some cases in excess of 35% of the feed, whereas the calculable waste should be less than 10%.

After much discussion and trial work with various mill manufacturers we eventually got equipment from a USA manufacturer which could achieve impact liberation and sizing with little chrome crystal damage.

The image to the right shows: High level of liberation with little Crystal damage utilizing controlled impact.



Having achieved a significant improvement in liberation we then considered how to reduce water consumption and avoid the control difficulties surrounding the operation of conventional spiral plants. After many trials and brain storming sessions we decided to concentrate on wash process followed by dry separation. This resulted in various trials etc with some of the equipment shown in fig9. These are rare earth magnets, electrostatic separators and density separators.



The work resulted in our utilizing a mixture of fluidization, air classification, rare earth magnets and electrostatic separation and grain size classification. By combining these technologies we managed to achieve an 85% yield of saleable product through the process which also allowed us to produce multiple Hevi-Sand sizes without increasing impurities.



Qemscan data showing very low impurity levels.

The Data below shows how the HS Process has resulted in some interesting outcomes regarding chemical analysis, acid demand, size distribution and the resultant performance in this case with Alkyd type resin.

Sieve Tests	ASTM Sieve No												AFS No
	6	12	20	30	40	50	70	100	140	200	270	Pan	
Current Material	0	0	0.187	3.462	21.557	42.062	27.473	5.125	0.118	0.016	0	0	41.5
Hevi-Sand Tested In-house	0	0	0.06	3.049	19.241	30.862	27.019	13.912	4.95	0.871	0.036	0	48.2
Hevi-Sand Tested Externally	0	0	0.11	3.12	20.21	34.02	28.05	12.17	1.93	0.06	0	0	44.9

Acid Demand	PH3	PH4	PH5
Current Material	8.1	5.2	3.8
Hevi-Sand	4	2.2	1.8

Turbidity ppm	
Current Material	320
Hevi-Sand	>200

Chemical Analysis	Cr2O3	SiO2	CaO	FeO	LOI	Moisture
Current Material	45.80 %	1.30%	0.53%	N/A	0.85%	0.04%
Hevi-Sand Tested In-house	47.90 %	0.74%	0.39%	25.9	0.78%	0.05%
Hevi-Sand Tested Externally	48.23 %	0.92%	0.43%	N/A	0.80%	0.06%

Tensile Tests	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Avg.	
Current Material	0.643	0.999	0.854	1.024	1.055	0.665	0.873	(38% Increase in Tensile Strength compared to their existing material)
Volclay Hevi-Sand	1.222	1.352	1.451	1.086	0.922		1.207	

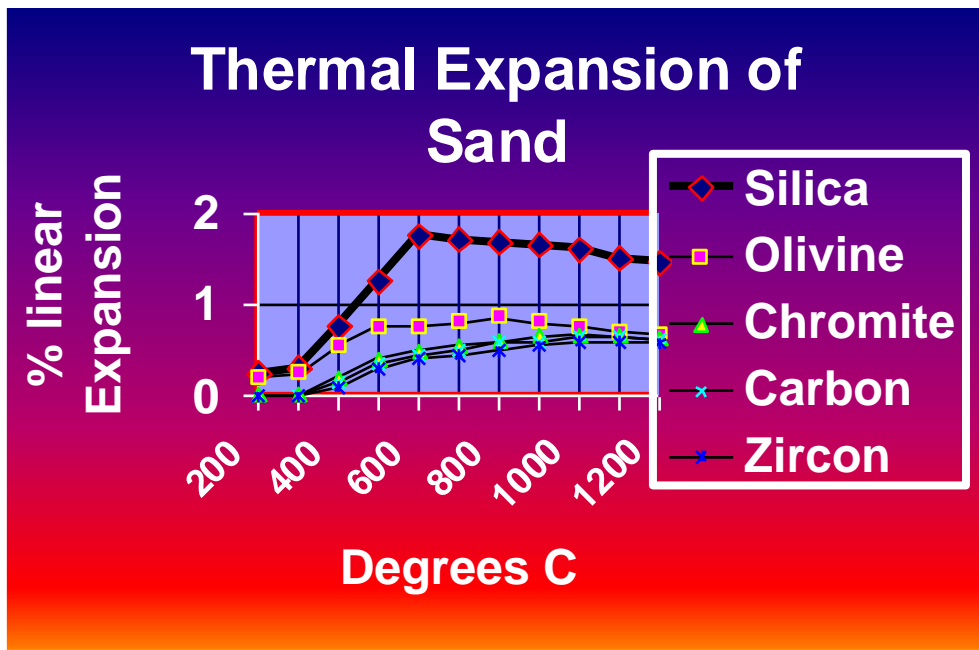
As we have refined the process we are producing product which typically contains fewer impurities ie assaying typically >47.5% Cr and <0.6SiO2. Furthermore, environmentally the process results in 70% reductions in water consumption and waste, along with a 50% reduction in power, when compared to our traditional spiral plant.

Given the above it drove us to try and understand more clearly how supply, time and foundries practical experience had driven there understanding of and coloured how they defined good or bad chromite sand.

Why do foundries use chromite sand?

Chromite has a number of interesting properties useful to foundries:

1. Linear Expansion (see graph) this property helps with internal and external casting dimensions, while minimising the occurrence of veining.



2. Heat abstraction (see graph) on large castings in particular quality can be significantly improved if as the mould is filled a solidifying skin is created as the metal rises up the mould face. The high heat abstraction rate increases the thickness of the solidified skin reducing the risk of it being washed away allowing faster filling times. This high heat abstraction rate also aids in inhibiting penetration and burn on defects.

FREEZING TIME 150mm SPHERE, (MIN)	SOLIDIFICATION TIMES REF. TO SILICA SAND	
COPPER CHILL	4.2	.24
STEEL CHILL	4.3	.25
GRAPHITE MOLD	5.1	.30
CHROMITE BOND	13.4	.79
ZIRCON BONDED	13.8	.82
OLIVINE BONDED	15.8	.93
CHAMOTTE BOND	17.0	1.00

3. High fusion point 1850c, making in particular, core removal easier and improving cleanliness of feeder necks reducing the risk of the cutting flame being deflected into the casting.
4. It is chemically basic PH 6.5-7.5 making it less prone to, being wetted by steel, and slag reactions, when coupled with points 1-2-3 reducing penetration and burn on defects.
5. It does not react with manganese steels as does silica sand.
6. It has high permeability when properly vented reduces core temperatures and gas defects
7. It is reclaimable.

Foundry problems with current supply

Most of the chromite sand used in foundries, is used in conjunction with resin binder systems. Many of these systems rely on high efficiency mixers with low additions levels, typically; resin 0.8% + an acid catalyst 0.125%. Therefore small variations in sand quality can have a significant effect on these small additions and on the resultant moulding sand properties.

1. Changes in acid demand / PH caused by poor water quality during processing or high levels of alkaline impurities (silicates), can cause the resin not to harden properly, or too late, or too soon (if the sand quality improves over the norm).
2. Changes in Turbidity as above, but also increased incidence of double skin defects, (see paper by same author).
3. Dust and segregation, caused by packaging, storage silo design (see picture), incomplete liberation, results in nuisance dust, variable sand curing times, and increased resin requirements.

The problems above can increase resin costs, result in moulds being scrapped, or add four months to the fettling and inspection time of large castings.

It is therefore no surprise, that, foundries take chromite sand quality seriously, and test and specify some or all of the following parameters.

1. Chemical Analysis
2. Acid Demand at PH 5, PH 4, PH 3.
3. PH
4. Turbidity
5. Loss on Ignition
6. Afs. Number
7. Sieve analysis distribution.
8. Fines

We were surprised therefore when we started to collate foundry purchase specifications, while at the same time trying to decide what foundries would consider to be the ultimate specification, to find the wide variations and test methods employed. Fig 5, shows some of these specifications.

Typical foundry chromite order specifications

Cr%	FeO%	SiO2%	CaO%	Turbidity	AFS	fine s	LOI	PH	Acid demand, ph 3, ph4, ph5
>46%	<29%	<1%	<0.5%	<250ppm	NA	<1%	NA	<8.5	10ml, 6ml 4ml
>45%	<29%	<1%	<0.5%	NA	50	<5%	NA	NA	NA
>44%	<25%	<4%	NA	NA	42	NA	NA	NA	NA
>44%	<29%	<4%	<1.0%	<400ppm	50	NA	0.5%	NA	NA
>46%	<25%	<0.6%	<0.4%	<150ppm	48-52	<1%	0.1%	<8.0	8ml 4.5ml 2.5ml
>46%	<26%	<0.6%	<0.4%	<250ppm	60-70	<1%	0.1%	<8.0	8ml 4.5ml 2.5ml

As you can see the range of specifications encompass nearly everything which could be described as chromite. From further investigation it seems these specs have been developed based on, either, out dated information or by what has been available in the local market place, coupled with spec modifications based on historic product quality problems, resolved via adjustments in afs or fines, rather than addressing the fundamental realities of producing the product. It was also clear from our own experience and talking to foundry users that there had been many quality arguments over the years, which had often turned out to be differences in test methods. We therefore decide we should start to compare the various test methods.

Test Methods.

Chemical analysis

Many foundries do not have equipment to test the chemical composition of chromite sand but the majority of those that do use XRF. One might think that this very expensive computer controlled method of analysis would produce very accurate and reproducible results, however the calibration control program being used on the XRF must be tailored to measure the high levels of chrome, iron and magnesium typically seen in chromite sands. The proper chromite standards need to be used for calibration to ensure accuracy in the desired ranges for each element. For example SARM 9 is a certified chromite standard from the critical zone of South Africa's Bushveld complex where much of the world's foundry chromite sand is sourced, it is a low silica chromite and represents a very good standard to form a calibration around, as opposed to a high silica chromite standard from Kazakhstan or the like. The XRF instrument prepares a standard curve for each element based on certified standards; the instrument quantifies the fluorescent counts generated after hitting the sample with x-rays at a given angle, the counts are then tied back to the certified value of the standard (this is a very simplified explanation, more detailed information on XRF theory may be found by contacting Panalytical Instruments). The values or counts are depended on sample preparation and sample matrix (you may get different counts measuring Calcium in bentonite as opposed to Calcium in chrome ore). The values for all the elements analyzed are added up into a sum, in figure 6 below, SARM 9 has a sum of 98.5 meaning if you analyzed the specified elements you should be analyzing 98.2% of that material, the remaining amount is composed of trace elements not measured. Even using the same standards, differences can arise from how the standard curve is set up (which points are included, which are considered outliers etc). Figure 7 shows two chromite calibrations using the same set of chromite standards while chromite calibration 2 gives preference to data points from South African Chromite standards; calibration 1 treats data points from all standards with equal importance.

Most certified samples are ball milled resulting in a very fine particle size which is advantageous for XRF analysis since it helps to ensure homogenous distribution of all the phases in a given sample, some sample preparations even include preparing a fused glass sample to provide an ideal sample matrix for the XRF to read, however this preparation is more expensive than traditional "pressed powder" sample preparations as it requires additional equipment and reagents. Typical chrome sand to be analyzed in a laboratory setting is not ball milled and in most cases, due to the high hardness, grinding of the chromite proves to be difficult unless the right equipment is used. Coarsely ground samples will have low sums on the XRF instrument which can skew results in either direction. (See figure 7). We have found that grinding the samples by hand with a mortar and pestle (of corundum or sintered alumina, not agate) gives us typical sums between 82-88% and that the results can be normalized to 98.5% (to match our target calibration standard SARM 9).

Figure 6: Certified values for Chromite Standard SARM 9

Standard Name	Certified Values- As reported on C of A						SUM
	Cr ₂ O ₃	SiO ₂	FeO	MgO	Al ₂ O ₃	CaO	
SARM 9	46.45	0.61	24.96	10.85	15.17	0.16	98.20

Figure 7: Differences between chromite calibrations

	Chromite Sand	
	Chrome calibration 2	Chrome calibration1
Cr ₂ O ₃	45.308	41.697
SiO ₂	0.526	0.642
FeO	24.634	20.191
MgO	9.874	5.427
Al ₂ O ₃	13.333	12.387
CaO	0.12	0.141
Sum:	93.795	80.485

Figure 8: Particle Size and XRF data on Hevi-Sand ground to varying fineness

Screen Size	Mesh	Amount retained (g)					
		#1	#2	#3	#4	#5	#6
106 µm	No.140	7.32	6.4	4.59	2.69	2.69	1.73
75 µm	No.200	1	1.44	1.33	1.4	2	1.76
53 µm	No. 270	0.52	0.84	0.85	0.99	1.39	1.53
45 µm	No. 325	0.25	0.5	0.52	0.58	0.82	1.05
20 µm	No. 635	0.57	1.04	1.14	1.58	2.52	3.41
Pan	Pan	0.48	1.11	1.01	1.06	1.53	1.06
	total	10.14	11.33	9.44	8.3	10.95	10.54
% passing 200 mesh		17.95	30.80	37.29	50.72	57.17	66.89
XRF Data		%					
	Cr ₂ O ₃	42.988	40.438	41.495	42.663	44.707	45.07
	SiO ₂	0.958	1.913	1.493	1.325	0.572	0.626
	FeO	23.748	22.264	22.778	23.538	24.753	24.964
	MgO	9.618	9.983	9.556	9.718	9.83	9.895
	Al ₂ O ₃	12.841	12.793	13.408	13.313	14.132	14.341
	CaO	0.111	0.111	0.105	0.101	0.092	0.092
	Sum	90.264	87.502	88.835	90.658	94.086	94.988

Inductively coupled Plasma (ICP) instruments are sometimes employed for chemical analysis of chromite as well; however this method requires complete digestion of solids into a liquid matrix for analysis, and this means very strong acid (usually Hydrofluoric acid) heated under pressure to fully digest silica. This method can be more time consuming and requires additional equipment and safety precautions due to the issues handling such strong acid presents.

ACID DEMAND / PH

These tests do seem to be pretty well under control although variations in procedure do produce variations in results the deviation is very small.

LOI

Some foundries specify LOI values in their acceptance specs but have often not checked it or the test method. If an uncontaminated chromite is tested in an oxidizing atmosphere there is a weight gain due to FeO becoming Fe₂O₃ and Fe₃O₄. If the test is carried out in a reducing atmosphere there should be no weight loss.

It is therefore important to specify temperature / time and atmosphere to achieve consistency of result. Figure 8a shows a chromite sand tested in a Nitrogen environment on a TGA instrument (thermal gravimetric analysis), and Figure 8b: shows a chromite sand tested in air, note the oxidizing weight gain observed in air.

Figure 8a: TGA analysis in Nitrogen Environment

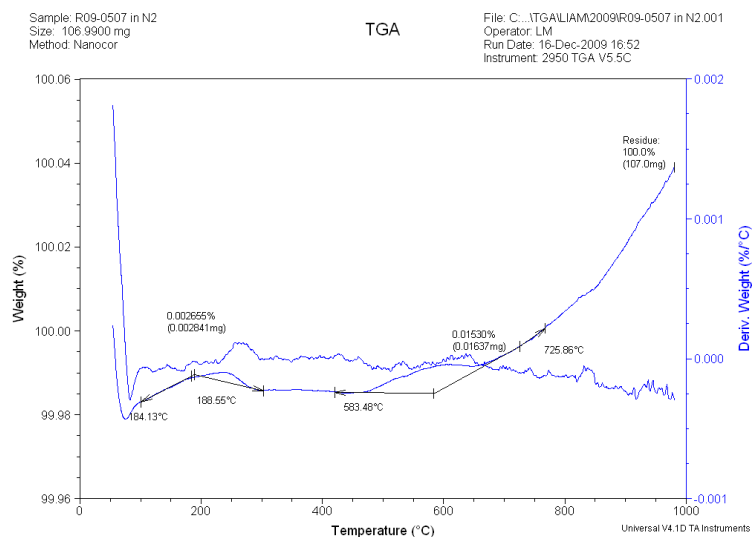
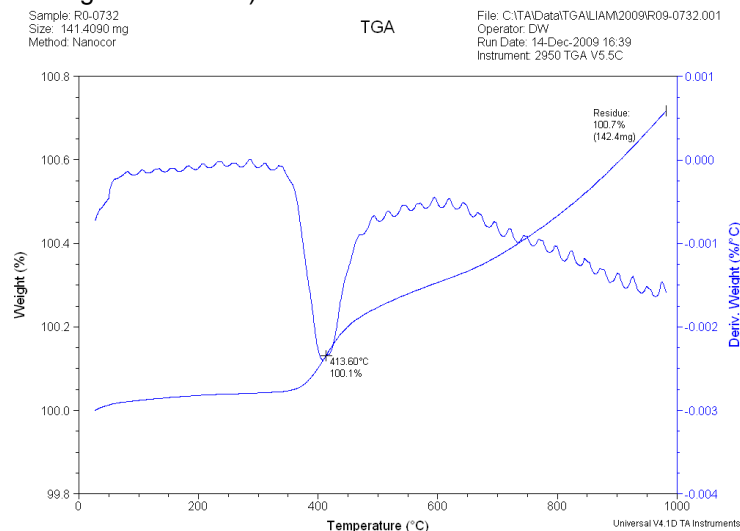


Figure 8b: TGA in air (oxidizing environment)



Turbidity

This is one of the most contentious tests and an area where there is little or no meaningful interpretation of the results. Turbidity as it relates to chromite sand can be thought of as a measure of the light scattering caused by suspended particles in a liquid. The typical test method for most turbidity tests involves agitating chromite sand in water for a fixed amount of time and then allowing the heavy chrome sand to settle for a fixed amount of time and measuring the resulting water for turbidity, the suspended material in the water is generally thought to be low melting point silicate impurities which are thought to contribute to certain types of casting defects (see paper by J.D. Howden *Chromite Double Skin Defect on Heavy-Section Steel Castings*). So lower turbidity values are generally thought to be advantageous.

Most of the historical specifications for chromite sand define Turbidity in Parts per Million (ppm) of silica. This is a reference to the Jackson Turbidity Test, which has been the industry standard for turbidity measurement for many years. This test uses a flat bottomed glass cylinder (known as a Jackson Tube, see fig 9) with a candle flame placed approximately 10 cm (4 inches) from the bottom, liquid is poured slowly into the tube while examining the flame down the cylinder and through the liquid. The tube is calibrated against solutions of diatomaceous earth (with silica present as silicic acid in the shells of the diatoms), a series of dilutions is typically made (1000, 500, 250 ppm) and added to the cylinder slowly. Designations are made on the cylinder for each standard based on the height of the cylinder each solution reached to obscure the candle flame. This method of calibration is subject to the consistency of the diatomaceous earth and of the care taken to calibrate and make the corresponding designations on the cylinder. These measurements are sometimes called Jackson Turbidity Units or JTUs . The use of the candle flame as the light source presented some drawbacks for analyzing samples with very fine suspended particles, color, and low turbidity. Modern instruments for turbidity measurement utilize a fixed light source, typically at a 90° angle from the light source, generally decided to be best for detecting light scattering, and generally referred to as Nephelometers. Also most modern instruments have adopted the Nephelometric Turbidity Unit or NTU as the preferred unit of measurement. The NTU, FTU, FAU are all equivalent as they are all based on the use of primary Formazin suspensions as turbidity standards, but do not correlate well to JTU measurements, some literature cites ratios of 1 JTU= 4 NTU and others that cite 1JTU= 0.053 NTU). Formazin standards are highly reproducible and prepared from traceable consistent materials, and commercial standards are readily available. Depending on the intended application modern electronic turbidity meters may employ additional detectors as well to compensate for color, and particle size effects and to ensure increased accuracy over larger calibration ranges. For low level turbidity measurements of drinking waters a portable turbidity meter with only a 90° detector may be suitable, while higher turbidity samples (<100 NTU) may require dilution to be analyzed on this instrument .Other instruments such as the Hach 2100 N turbidity meter utilize a three detector system (traditional 90° detector as well as a forward-scatter, and transmitted light detector) which helps reduce the effects of color differences in turbidity measurements. This instrument is more suited to chromite turbidity applications, does not require dilution for samples under 4000 NTU, and is easy to standardize with readily available standards. (Figures 10 and 11 show a portable turbidity meter and a larger laboratory bench-top model).

We believe that the industry should standardise on the NTU.

Figure 9: Jackson Turbidity Apparatus



Figure 10: Portable Turbidity Unit



Figure 11: Laboratory Bench top model Turbidity Meter



As was mentioned previously the typical turbidity test for chromite, regardless of the analytical method, involved agitation of dry chrome sand in water for a fixed amount of time in a effort to suspend the small particle sized tramp material associated with the chromite. A short amount of time is allowed to pass after agitation to allow the heavy solids to settle before the water is decanted and measured. The typical form of agitation of the chrome sand has been shaking the chrome and water together for 1 minute in a sealed jar by hand. What quickly becomes apparent with this method is that the harder you shake the jar the higher the turbidity. It was seen that “shake” test was very prone to variation due to differences in shaking velocity between users (see table 1 in appendix), with the same sample showing a range of 378 to 739 NTU depending on the operator. Clearly there is a need to somehow standardize this test to get accurate, reproducible results. Several alternative agitation methods were investigated including magnetic stirring, horizontal shaking table, and rotary devices. Another variable that influences turbidity results is agitation time, it was seen that increased agitation time led to increased turbidity results regardless of agitation method, and at 30 minutes of agitation time turbidity was still increasing. It appears that the chromite is not being degraded and creating fines during the extended agitation so it is assumed that the extended agitation is simply liberating more and more finely sized material into suspension or perhaps breaking up the tramp material increasing the surface area of the suspended material and causing it to scatter more light. The testing indicated that even what is considered good quality , low turbidity chromite sand could yield >1000 NTU

turbidity values with extended mixing time. Since the goal was to create a reliable standardized method for turbidity measurement a familiar practical time of 1 minute agitation and 30 seconds settling time was decided upon. Additionally a wrist-action shaker was utilized to standardize the differences between individual user shaking velocities. The wrist action shaker proved to be the most advantageous method for reducing variability; it is designed to simulate the human wrist movement, fully agitates the sample and provides reproducible results when used with a suitable turbidity meter (see Table 2 in appendix). The same small experiment was performed with individual operators using the wrist action shaker instead of the traditional shake method and the results trend much closer to each other. Our preferred method of analyzing turbidity in chrome sand is presented in Appendix B-Methods and Procedures

Sieve Analysis, Fines, AFS number

These tests which on the face of it seem very simple and reproducible again turn out to be very contentious. This is really because no one really specifies clearly either the sieve type, sizes, or what they define as fines. Foundries often specify an AFS number which is actually meaningless in its self, as many materials can meet this spec but foundries would not necessarily be happy with the material supplied. Below are a series of figures and tables showing the scale of the potential differences in reporting the same sample by different methods and a series of materials which would meet a foundries spec but which they would be unhappy with.

The sieve analysis to the right is the same sample of sand put through British standard sieves and ASTM sieves; these combinations of sizes are typical of the sieves people use in practice. In the right hand column are the micron sizes which match up with some of the sieve numbers and not others. This coupled with the method of AFS calculation, (i.e.

sieve size micron	BS mesh			ASTM US		
	% retained	Sieve No	Calc	%retained	Sieve No	Calc
2mm		8	0		10	0
1.7mm		10	0		12	0
1.4mm		12	0		14	0
1.18mm		14	0		16	0
1mm	0.5	16	6		18	0
850		18	0	0.9	20	14.4
710	1.2	22	19.2		25	0
600		25	0	3.1	30	62
500	2.3	30	50.6		35	0
425		35	0	19.6	40	588
355	33.6	44	1008		45	0
300		52	0	32.5	50	1300
250	27.2	60	1196.8		60	0
212		72	0	27.5	70	1375
180		85	0		80	0
150	31.6	100	2275.2	13	100	910
125		120	0		120	0
106	3.4	150	340	2.9	140	290
90		170	0		170	0
75	0.2	200	30	0.5	200	70
63		240	0		230	0
53		300	0		270	0
pan		pan	0		pan	0
	Total		AFS No	Total		AFS No
	100		49.3	100		46.1

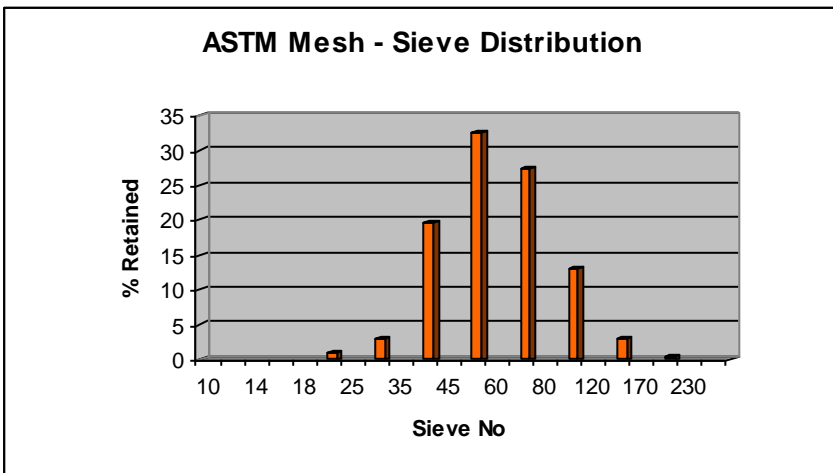
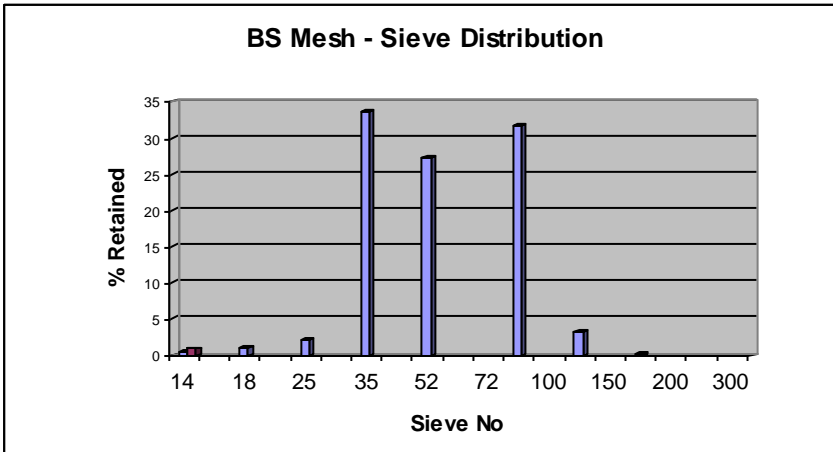
% retained multiplied by the previous sieve number, then the calc column added together and divided by 100), leads to different AFS numbers which could possibly cause the material to be deemed out of spec from a foundries perspective. Even more startling is the appearance of the sieve analysis chart, showing a double peak on the British standard sieves, compared to the more typical ASTM graph, even though it is the same sand.

If one analyses the differences one can see that over 92% of the material is between 425 – 150 micron and that something around 70% is between 425 –and 212 micron. What appears to be a big difference at first glance is in fact irrelevant and is caused by the majority of the crystals being very much the same size as the sieve apertures, therefore a change a small change in aperture size results in a big change in the quantity retained.



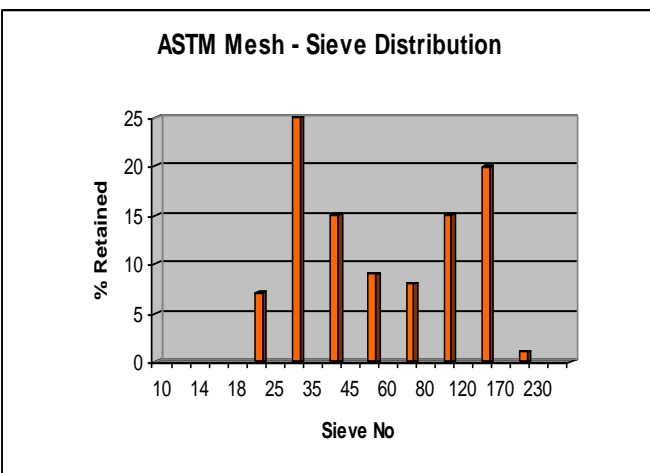
HEVI-SAND[®]
FACE TO FACE

TECHNICAL DATA



ASTM US		
%retained	Sieve No	Calc
	10	0
	12	0
	14	0
	16	0
	18	0
7	20	112
	25	0
25	30	500
	35	0
15	40	450
	45	0
9	50	360
	60	0
8	70	400
	80	0
15	100	1050
	120	0
20	140	2000
	170	0
1	200	140
	230	0
	270	0
	pan	0
Total		AFS No
100		50.1

If we take another example where foundries ask for a nominal 50% afs and less than 1% fines on the pan, then they could be shipped the material below,



The chart demonstrates that by foundries not defining accurately what they want they run the risk of getting something very undesirable that meets their specification.

Discussion of Chromites beneficial properties, in relation to foundries, real requirements.

In order to decide on what properties truly matter to foundries it is important to consider the effects of each of the test parameters and the practical disadvantages of deviation from the results. Therefore in reviewing these effects one must consider what foundries are trying to achieve by using chrome sand.

1. Rapid Heat abstraction rate.
2. Good permeability reducing gas pressures and overheating.
3. Low thermal expansion, dimensional stability, no veining .
4. High resistance to penetration and burn on, improved Surface finish.
5. Lower binder and catalyst additions and thus lower gas evolution.

As can be seen from the above the desirable properties fall into two key areas 1-4, the physical properties of the materials and 5 the effect of these properties on binder usage.

Properties (1-4)

In the authors opinion it is very difficult to make hard and fast rules in foundries as a lot of the data on which foundry practice is based is either extrapolated graphs (where products or effects cannot be tested at casting temperatures), or based on the conclusions of a foundries practical experience.

This results in a need for foundries to develop a philosophy which overcomes the lack of cold hard facts. If at its simplest we say that in an ideal world where melting, pouring, and moulding is perfect, then if ingate velocity, pouring and solidification time are all zero, then there would be no time to generate defects. Unfortunately of course this is impossible, but it does at least allow us to conclude that, everything that moves in the opposite direction is undesirable.

Given these objectives by making a mould with chromite sand rather than silica sand we can expect due to its higher density, specific heat and conductivity, that the immediate solidified skin which is created during mould filling will be thicker this also means it has a greater resistance to being re-melted during mould filling and being washed away, which in turn infers that the mould can be filled more quickly, this in turn given chromite sands low thermal expansion characteristics, results in less chance of veining, erosion, spalling, and dimensional problems. Likewise this rapid heat abstraction and solidified skin formation, reduces the incidence of penetration and Burn on.

As the above clearly drives us towards our simplistic goals, we concluded that maximising the bulk density of the material should result in significant technical advantages. The only downside in maximising bulk density is the reduction in permeability, table below shows how sieve analysis, afs no, bulk density and permeability are interrelated. We have therefore decided that we should create a number of tailor made HS's aimed at allowing foundries to maximise bulk density for an acceptable reduction in permeability

Table

Gas evolution and resin usage

The table below shows the test data for HS process sand, a typical foundry chromite, and the various samples of HS shown in table?

As you will see the interesting aspect of the study is as you move existing chromite sand from a 2 sieve sand to a 4/5 sieve sand, not only does the bulk density increase and the permeability drop, it also reduces the resin requirement even though the calculated sand surface area has increased, the reason for this is that the improved compaction reduces the size of the voids in the compacted sand and in turn increase the number of contact points with other sand grains hence a stronger sand for less binder. While this means lower binder usage and less gas evolution during casting. It must be remembered that if the

sand mass is denser then there is more resin for a given volume of sand, we have therefore shown in the final column of the table an adjustment for the effect of density on the resin content.

CONCLUSIONS

The HS process project, and the associated research and testing has thrown up a number of issues with regard to the supply and procurement process which currently exists in the industry.

1. There is no definitive or agreed world standard specification for foundry quality chromite sand.
2. Test procedures and technical requirements are often inconsistent or based on habit / past experience or in many instances based on information and products which were defined 50 years ago.
3. There are significant benefits to be gained by maximising bulk density as long as permeability and resin additions are controlled.

We hope that the information and the arguments we have outlined in this paper can be used by the industry as the validity and the basis for the industry and its technical institutions to review recommended acceptance specifications.

We believe the table below should be the minimum requirements, while as a supplier we can also make suggestions for product enhancement. Our recommended test procedures are attached as appendices. Should you wish to see the detailed studies please contact Amcol.

Appendix A- Data
Table 1: Data for “Shake” Test Turbidity method

Operator #	Average Turbidity (NTU)
#1	518
#2	445
#3	378
#4	584
#5	496
#6	427
#7	739
#8	595
#9	412
#10	616
#11	454
#12	415
Average Results	507
Standard Deviation	107.3

Different individuals in the Hoffman Estates Lab tested the sample with the same procedure, and equipment. There is variability in these results, the lowest result seen was 378 NTU and the highest was 739 NTU, the average results is nearly 100 NT less than the average reported in table 1.

Table 8: General Data for Turbidity method utilizing Wrist Action Shaker

Operator #	Average Turbidity (NTU)
#1	465
#2	471
#3	478
#4	434
#5	446
#6	452
#7	456
#8	512
#9	451
#10	459
#11	470
#12	438
Average Results	461
Standard Deviation	20.8

As done previously in table 2, individual users were asked to run the turbidity method again using the wrist action shaker, instead of shaking by hand, it is apparent that the distribution of results is much narrower and the standard deviation is better using this method.

Appendix B- Methods and Procedures

Measurement of Turbidity of Chrome Sand-

Equipment:

500 ml Pyrex Erlenmeyer Flask

Hach 2100N laboratory Turbidity Meter, calibrated with Hach Stab Cal standard solutions of 0, 20, 200, 1000 and 4000 NTU as per manufacturers instructions. Instrument should be recalibrated quarterly.

Burrell – Wrist Action Shaker (amplitude lever set to 10)

Turbidity Free water (Distilled/ De-ionized Water)

Drying oven

Scale- Capable of accurately measuring at least 250 grams

1. Dry a sufficient amount of chrome sand to a constant weight in a drying oven (110 C)
2. Weigh 100g dry chrome sand in a weigh boat and add to 500 ml Flask
3. Weigh 250 grams distilled water into a beaker and add to 500 ml Flask
4. Place Flask into Grip of Wrist Action Shaker and tighten until secure (do not over tighten or risk cracking the neck of the flask) and shake for 1 minute on maximum amplitude (separate lever on side on shaker, set to "10").
5. After shaking 1 minute, allow flask to stand for 30 seconds, after settling seconds pour off turbid water into beaker.
6. Carefully pour water from beaker into clean, dry 30 ml Hach sample vial, secure cap
7. wipe vial with cloth, apply silicone oil to vials as necessary, and insert into Hach
8. Make sure ratio and signal averaging modes are active (lights will be green on these keys), and make sure the units are NTU
9. Record first value displayed by Hach, as the numbers fluctuate due to settling while in instrument