DE BEERS
CANADA
GAHCHO KUÉ PROJECT

June 8, 2012 File: S110-01-09

Chuck Hubert
Senior Environmental Assessment Officer
Mackenzie Valley Environmental Impact Review Board
P.O. Box 938
Yellowknife NT X1A 2N7

Dear Mr. Hubert:

Undertaking #2 - Response to Physical Properties of Fine PK for Gahcho Kué
Project EIR0607-001 Environmental Impact Review Technical Sessions, May 22-25, 2012

De Beers Canada Inc. (De Beers) is pleased to submit the attached Technical Memorandums in response to Undertaking #2 to the Mackenzie Valley Environmental Impact Review Board (MVEIRB). The undertaking was requested at the May 22-25, 2012 Technical Sessions held for the Gahcho Kué Project.

Specifically, Undertaking #2 requested De Beers to get back to Kathy Racher of Wek'èezhii Land and Water Board (WLWB) (indicated incorrectly in the undertaking as MVLWB) on information on physical properties of Fine PK i.e., gravity, size, settle-ability, from each pit.

The attached Technical Memorandum entitled EBA Technical Memorandum - Gahcho Kué Fine PK Laboratory Testing Information (June 6, 2012) provides the response to Undertaking #2.

We trust the response provides the information necessary to fulfill our requirements.

Sincerely,

Veronica Chisholm

Veronica Chisholm
Permitting Manager

Attachment

C: K. Racher, Wek'èezhii Land and Water Board (WLWB)

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TECHNICAL MEMO

ISSUED FOR USE

TO:	Andrew Williams, De Beers	**DATE:**	June 6, 2012
C:	Wayne Corso, JDS Dan Johnson, JDS		
FROM:	Bill Horne	**EBA FILE:**	E14101208

SUBJECT: Gahcho Kué Fine PK Laboratory Testing Information

1.0 INTRODUCTION

The following provides a summary of the laboratory testing information on the fine processed kimberlite (fine PK) in response to a query at the Gahcho Kué Technical Sessions that were held on May 23, 2012

Test results of the Gahcho Kué Fines testing programs are contained in the following documents:

1. De Beers 2002, Note for the Record – Gahcho Kue Slimes Characterization, Compiled by Tomo, October 2002.
2. De Beers 2004, Note for the Record – Gahcho Kué Phase II ODS Slimes Characterization, Compiled by Tomo, October 2004.
3. Patterson & Cooke 2005, Gahcho Kué Ore Dressing Study: Slurry Tests Using 5034 and Hearne Ore, submitted to De Beers.
4. De Beers 2008, Note for the Record – Gahcho Kué Tuzo Slimes Dewatering Test Reports, Compiled by Tomo May 2008.
5. Golder 2011, Technical Memorandum DCN-033 Gahcho Kué EIS Post Submission/Integrated Evaluation of Post Closure Alternatives. Phase 2030: Task 20: Material Characterization.

The documents present fine PK settling tests, mineralogy tests, grain size, specific gravity, soil-water characteristics (SWCC), and hydraulic conductivities. The documents are attached to this memo.

2.0 BACKGROUND

Gahcho Kué fine PK is planned to be disposed of in three areas.

- Area 2 disposal area (3.3 Mt)
- Mined out 5034 pit (1.5 Mt)
- Mined out Hearne pit (3.0 Mt)

A TETRA TECH COMPANY

A comparison was made between the Gahcho Kué site and the EKATI Mine site at the technical sessions. It should be noted that the Gahcho Kué Area 2 disposal area is planned to contain 3.3 Mt of fine PK as opposed to the EKATI Processed Kimberlite Containment Area (PKCA) which has a capacity of 58 Mt. Currently, approximately 40 Mt of fine PK has been placed in the EKATI PKCA.

The source of the ore for the GK disposal areas is as follows:

- Area 2 – majority from 5034 pit, small amount from the Hearne Pit
- Mined out 5034 pit – majority from Hearne Pit, some from the Tuzo Pit
- Mined out Hearne pit – majority from Tuzo Pit

3.0 KEY FINDINGS

The conclusions from the test data reports are as follows:

- Settling 5034 and Hearne material using Magnafloc E10 achieved clear overflow water with turbidity less than 100 NTU. (De Beers 2004).
- Settling rates determined for most Gahcho Kué samples from all 5034 and Hearne samples with 5 and 10 percent solids concentration ranged from 10.0 to 35.8 m/h, with a median settling rate of 23.1 m/h. Settling rates greater than 10 m/h are considered to settle easily (De Beers 2002).
- Settling rates for Tuzo ranged from 7.2 to 18.0 m/h with a median value of 16.2. One sample out of 15 samples from Tuzo had a settling rate less than 10 m/h. (De Beers 2008).
- Tuzo ore samples had a finer slurry particle size distribution than 5034 and Hearne samples. (De Beers 2008).
- The Gahcho Kué ore bodies contain Smectite clay. The natural state of the Smectite clay is generally highly calcium exchanged and has a relatively low exchangeable sodium percentage (ESP). It is expected that colloidally settling slurries will be generated from the ore and water combinations at the natural pH conditions. Good slurry flocculation and settling characteristics are expected. (De Beers 2008, Patterson & Cooke 2005).

4.0 CONCLUSIONS

Based on the test results, it is anticipated that the fine PK will settle adequately within Area 2. Minimal issues may be managed by blending of ores being fed in the plant.

APPENDIX A

GAHCHO KUE SLIMES CHARACTERIZATION (2002)

DE BEERS
A DIAMOND IS FOREVER

NOTE FOR THE RECORD
GAHCHO KUE SLIMES CHARACTERISATION

Compiled by
Phakamele Tomo

15 October 2002

Document No: T05-400130-855

Revision 1.0

Note:
If this copy is no longer in use, return to sender.

DEBTECH

DOCUMENT INFORMATION

REPORT TITLE	GAHCHO KUE SLIMES CHARACTERISATION
AUTHOR	P TOMO
PUBLISH DATE	15 October 2002
REPORT NUMBER	T05-400130-855
PROJECTS & SERVICES AREA	Mineral Processing Water & Environmental Services

MINERAL PROCESSING MANAGER	H Voordewind
PROJETS & SERVICES MANAGER	B Greeff

APPROVAL

Name	Signature	Date
AJ Vietti Senior Researcher DebTech Research		
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Name	Signature	Date
P Tomo Jr Process Engineer DPS Water & Environmental Services		

ELECTRONIC SOURCE DATA

EFFECTIVE DATE	**06 June 2012**
FILE SIZE	**8622 592 Bytes**
FILE NAME	**WES_Report_GahchoKueODS**
APPLICATION	**MS Word 97**

CHANGE HISTORY

Date	CR No	Revision	Description of change
2002-10-15	-	1.0	New document

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LIST OF ABBREVIATIONS

CEC	Cation Exchange Capacity
CTS	Characterisation and Treatment Section within DebTech Projects & Services
ESP	Exchangeable Sodium Percentage
g/t	Grams per tonne
me/100g	Milliequivalant per 100 grams of sample
meq/l	Milliequivalant per litre
mS/cm	MilliSiemens per centimetre
mg/l	Milligrams per litre
NTU	Nephelometric Turbidity Unit
WES	Water and Environmental Services in Knowledge Services
ODS	Ore Dressing Studies Department
ods	Ore dressing study
GRN	
GRN+K	
HK	Hypabyssal Kimberlite
HK2	
HKB	Hypabyssal Kimberlite Breccia
HKg	
HK+B	
HK-GRN	
HK-TKNt	
HK+TKt	
HNHK	
TKSD	
TKtB-HKt	

NOTE FOR THE RECORD

1. INTRODUCTION

Clay analysis and slimes characterisations were performed on Gahcho Kue samples as part of the ore dressing study for Gahcho Kue. The Water and Environmental Services (WES) involvement aims at characterising ore samples to establish expected changes in operating conditions because of changes in ore body.

Fifteen (15) samples for characterisation were received from Gahcho Kue. The descriptions of samples analysed are presented in Table 1. Nine of the samples were taken from 5034 Diamond Drill Hole and the other six samples were taken from Hearne Diamond Drill Holes.

Table 1: Gahcho Kue samples description

Drill Hole ID	Drill Hole #	LR #	Sample Description	Av. Depth (m)
5034 Diamond Drill Hole	MPV-02-076C	LR 1244	GRN	236
		LR 1245	HK2	284
	MPV-02-079C	LR 1246	HK	47
		LR 1247	HKB	112
		LR 1248	HK-GRN	160
Hearne Diamond Drill hole	MPV-02-080C	LR 1249	HK-TKNt	100
		LR 1250	HNHK	231
5034 Diamond Drill Hole	MPV-02-082C	LR 1251	HK+B	105
		LR 1252	GRN+K	189
		LR 1253	HK+TKt	243
Hearne Diamond Drill Hole	MP-02-084C	LR 1254	HK	86
	MPV-02-085C	LR 1255	HK	60
		LR 1256	HKg	142
		LR 1257	TKSD	237
5034 Diamond Drill Hole	MPV-02-087C	LR 1258	TKtB-HKt	153

2. METHODOLOGY

The Characterisation and Treatment Section (CTS) within DebTech Projects & Services screened the samples at –1 mm size fraction.

A portion of screened –1 mm material was sent to the Agricultural Research Council (ARC), Institute of Soil, Climate and Water for mineralogy analysis. The mineralogy analysis includes the following characterisation:

- Total mineral analysis,

- Clay mineral analysis,
- Extractable cation and cation exchange capacity, and
- Particle size distribution

Slimes were generated using the screened –1 mm samples and de-mineralised water from Puréau Fresh Water Company. This water simulates pure/clean lake water expected to be used within treatment plant at Gahcho Kue.

- Typical process water was generated by adding about 2 litres of de-mineralised water in 500 g of crushed drill core.
- The mixture was stirred for 1 hour and then left to settle for 2 hours.
- The decant water was used to generate the slimes for testing using fresh ore samples.
- The slimes were generated at a concentration of 5 and 10 percent solids by mass for each sample tested.
- Slimes characteristics analysis was then performed.

3. MINERALOGY ANALYSIS

The mineralogy analysis was conducted on crushed -1 mm size fraction material. Tabulated results of total mineral, clay mineral and exchangeable cations analysis are presented in Appendix A.

3.1 Total Mineral Analysis

Total mineral analysis indicate minerals present in the –2 mm + 2 μm size fraction of the ore body.

3.1.1 5034 Diamond Drill Hole

Total mineral analysis results of 5034 Diamond Drill Hole samples is presented in Figure 1. The results indicated that the 5034 Diamond Drill Hole samples are composed of smectite, mica, serpentine, pyrophyllite, quartz, gibbsite, feldspar and calcite in the –2 mm + 2 μm size fraction.

The results indicated that smectite dominated the TKtB-HKt and HK+TKt samples from drill holes MPV-02-087C and MPV-02-082C respectively. The smectite content in these samples was 70 and 27 percent respectively. Samples with high smectite content, greater than 20 percent, in the absence of other mitigating factors, tend to cause settling difficulties when in suspension with water.

The feldspar (sodium-rich mineral) was dominant in GRN and HK-GRN samples from drill holes MPV-02-076C and MPV-02-079C and the content in these samples was 50 and 34 percent respectively. Samples with high feldspar content tend to have a high exchangeable sodium percentage (ESP).

The rest of 5034 Diamond Drill Hole samples were dominated by serpentine [$Mg_3Si_2O_5(OH)_4$], which is a greenish, brownish mineral normally known as a source of magnesium. The serpentine content in 5034 Diamond Drill hole samples ranges between 5 and 77 percent.

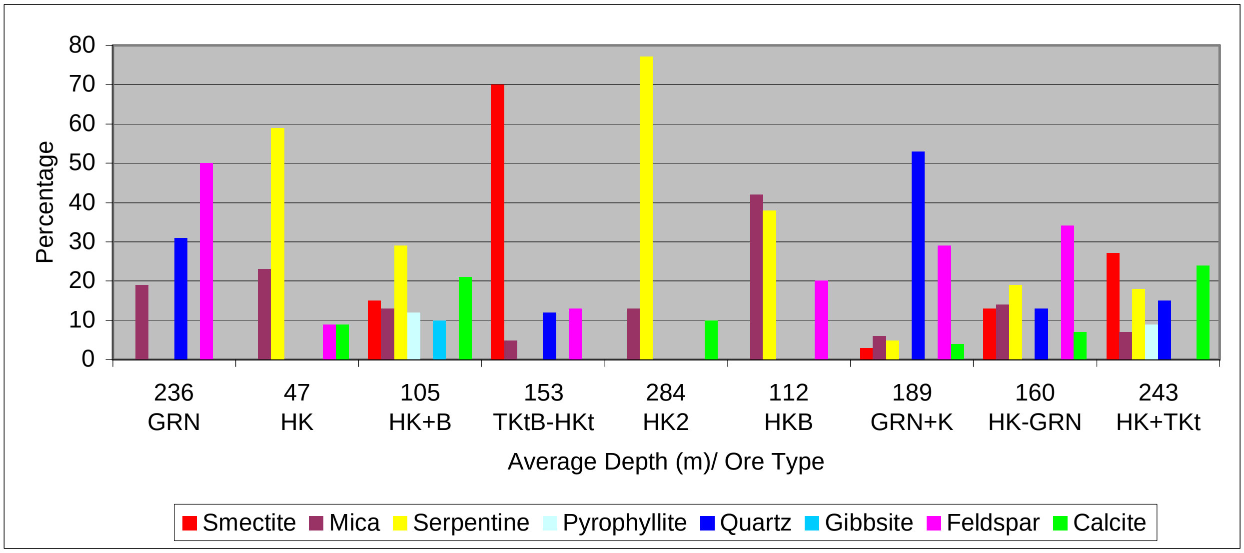


Figure 1: Total mineral analysis of 5034 diamond drill hole samples

3.1.2 Hearne Diamond Drill Hole Samples

Total mineral analysis results of Hearne Diamond Drill Hole samples are presented in Figure 2. The results indicated that the Hearne Diamond Drill Hole samples are composed of smectite, mica, serpentine, pyrophyllite, quartz, feldspar and calcite in the – 2 mm + 2 μm size fraction.

Only HK-TKNt and TKSD samples from Hearne Diamond Drill Hole taken from drill holes MPV-02-080C and MPV-02-085C contained smectite mineral at a content of 58 and 35 percent respectively. The results showed that most of the Hearne Diamond Drill Hole samples are dominated by serpentine.

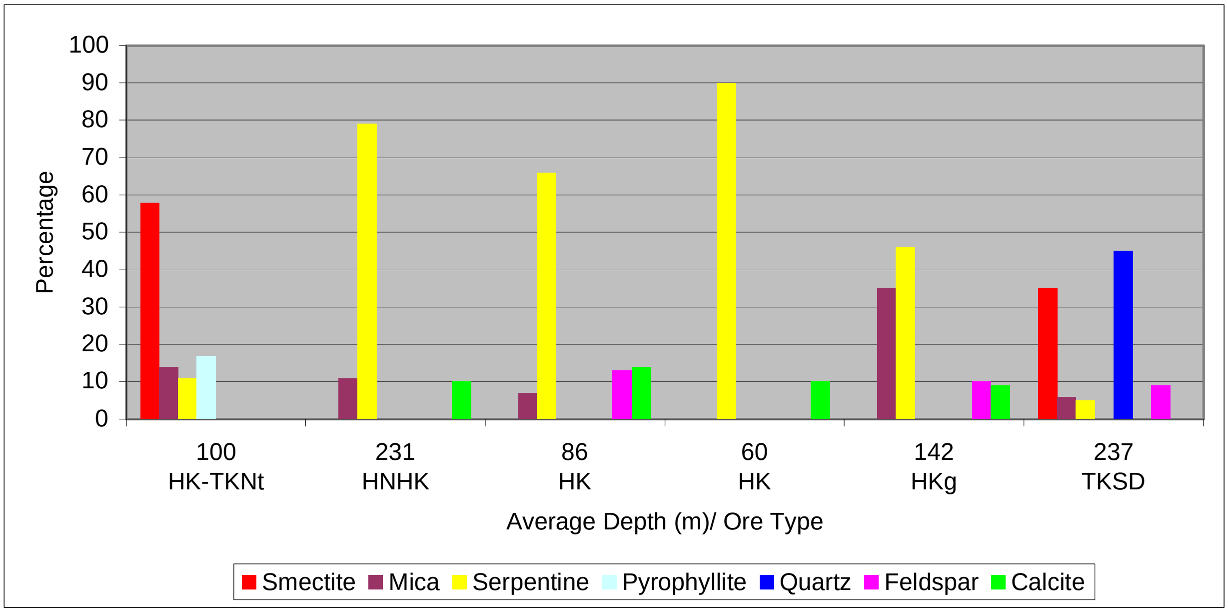


Figure 2: Total mineral analysis of Hearne Diamond Drill Hole samples

3.2 Clay Mineral Analysis

The clay mineral analysis indicates the mineralogy of the minus 2 micron size fraction (or clay fraction).

3.2.1 5034 Diamond Drill Hole Samples

Clay mineral analysis results of 5034 Diamond Drill Hole samples are presented in Figure 3. The results indicate that the 5034 Diamond Drill Hole samples are composed of interstratified, smectite, vermiculite, mica, serpentine, kaolinite, pyrophyllite, quartz, gibbsite, feldspar and calcite. The content of the problematic clay mineral, smectite, and ranges between 14 and 87 percent in the clay fraction of 5034 Diamond Drill Hole samples. This high smectite content may pose settling difficulties when the ore is suspended in water.

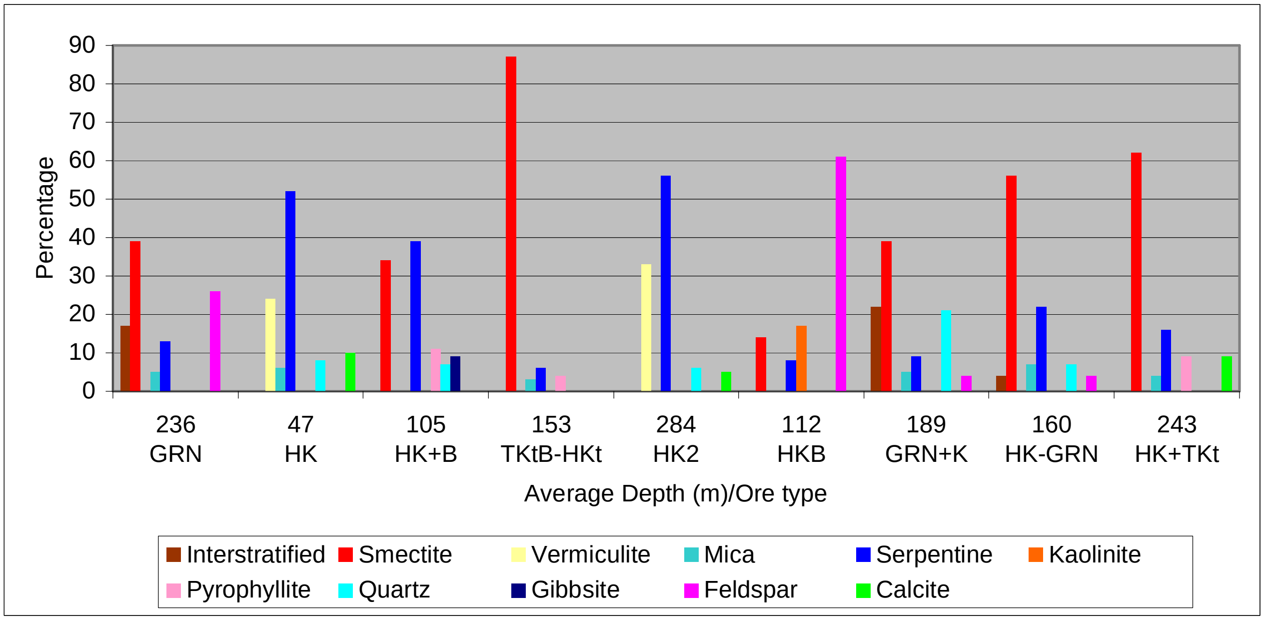


Figure 3: Clay mineral analysis of 5034 Diamond Drill Hole samples

3.2.2 Hearne Diamond Drill Hole Samples

Clay mineral analysis results of Hearne Diamond Drill Hole samples are presented in Figure 4. The results indicate that the Hearne Diamond Drill Hole samples are composed of interstratified, smectite vermiculite, mica, serpentine, pyrophyllite, quartz, feldspar and calcite. The content of the problematic clay mineral, smectite was found to be present in HK-TKNt, HNHK and TKSD at a content of 77, 22 and 86 percent in the clay fraction of Hearne Diamond Drill Hole samples. This high smectite content may pose settling difficulties when the ore is suspended in water.

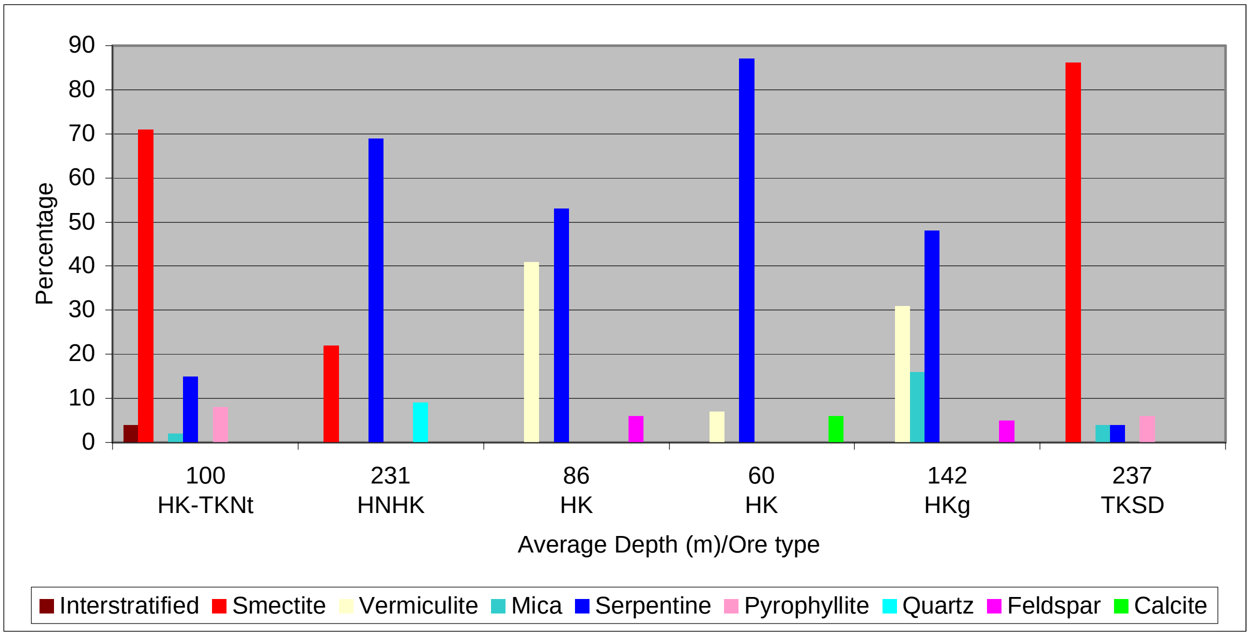


Figure 4: Clay mineral analysis of Hearne Diamond Drill Hole samples

3.3 Extractable Cations and ESP

3.3.1 5034 Diamond Drill Hole

The extractable cation analysis and exchangeable sodium percentage results for 5034 Diamond Drill Hole samples are presented in Figure 5. Extractable cations are often adsorbed on the clay crystal lattice structure and can be exchanged by other cations in solution when in contact with water. The exchangeable sodium percentage (ESP) is an indication of the sodium-exchanged state of the clays in the ore in the dry state (i.e. *in situ*) and is determined from cation extraction test. The ESP is regarded as high if it is in excess of 15 percent and may potentially provide settling problems, while samples with ESP values less than 10 percent are regarded as being easy to settle.

The results indicated that 5034 Diamond Drill Hole samples are characterised by a very low content of sodium exchanged clay and have a high content of extractable calcium. The ESP values of 5034 Diamond Drill Hole samples are below 10 percent for most samples, except for GRN sample. The GRN sample had an ESP value of 11 percent, which is in the medium range.

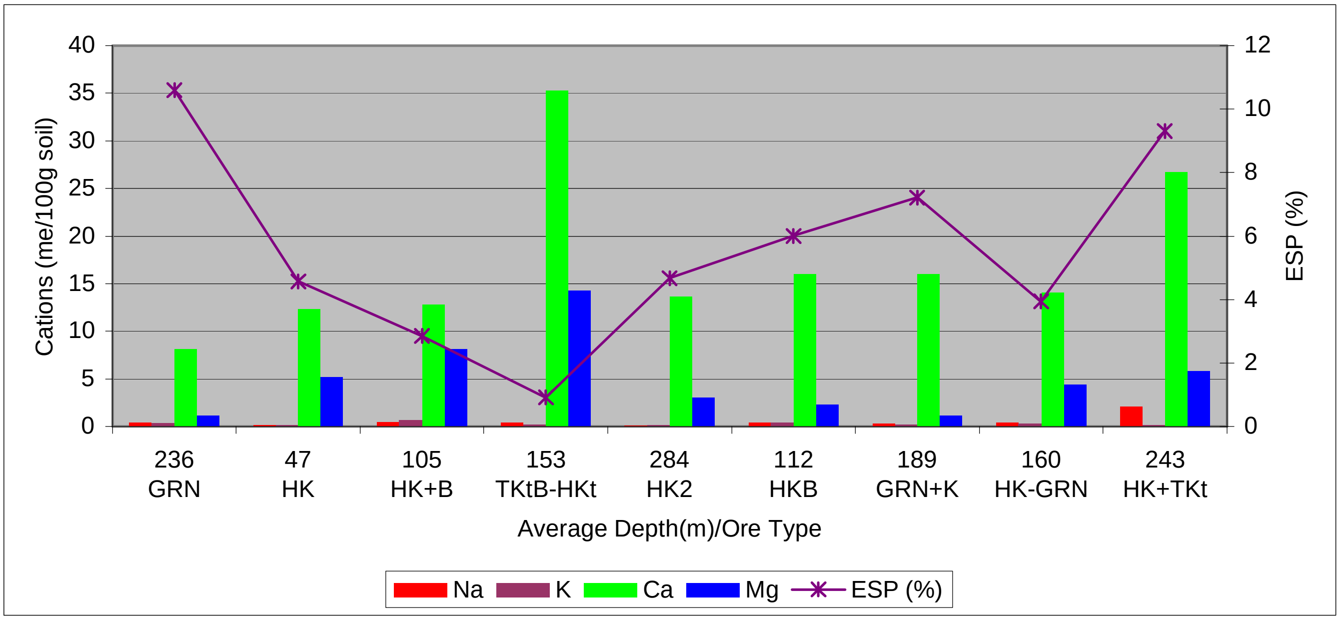
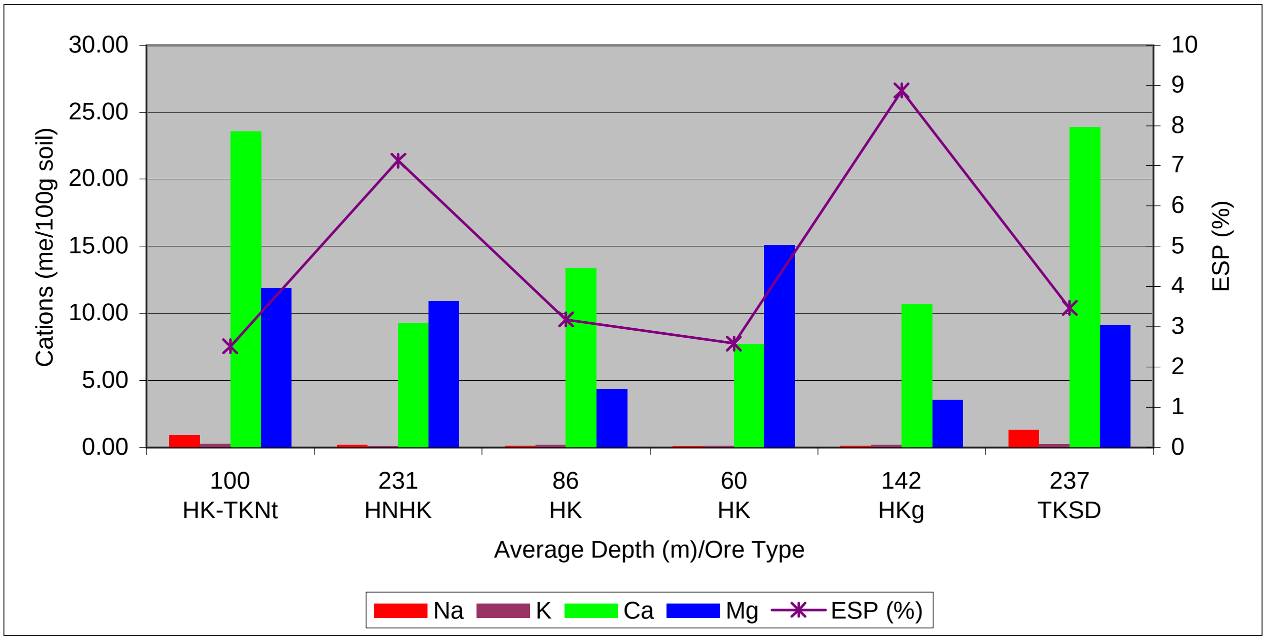


Figure 5: Extractable cations and ESP of 5034 Diamond Drill Hole samples

3.3.2 Hearne Diamond Drill Hole

The extractable cation analysis and exchangeable sodium percentage results for Hearne Diamond Drill Hole samples are presented in Figure 6. The result indicated that Hearne Diamond Drill Hole samples are characterised by a very low content of sodium exchanged clay and have high content of extractable calcium. The ESP values of Hearne Diamond Drill Hole samples are below 10 percent for all samples and indicate that easy settling slurry characteristics can be expected for these samples.



Fi

gure 6: Extractable cations and ESP of Hearne Diamond Drill Hole samples

3.4 Water Analysis

The results of chemical analysis of the de-mineralised water from Puréau Fresh Water Company are presented in Table 2. Samples with SAR value in excess of 15 meq/l are expected to generate non-settling slurries, while the samples with SAR value less than 10 meq/l are expected to generate settling slurries. Partial settling characteristics is expected when the SAR value is between 10 and 15 meq/l.

The Sodium Absorption Ratio (SAR) of the Puréau Fresh Water was calculated from the chemical analysis data as being 0.1 meq/l. This SAR is lower than that of the 5034 process water, however, both water samples has a potential of generating easy settling slurries.

Table 2: Summarised chemical analysis of raw water

Determinant	Puréau Fresh Water	5034 Process Water*
pH	6.7	8.0
Conductivity (mS/m)	4.01	350 µS/cm
Colour (mg/t Pt-Co)	7	
Turbidity (NTU)	0.8	
Total Dissolved Solids (mg/l)	23	240

Nitrate (mg/l N)	0.2	0.8
Alkalinity (mg/l $CaCO_3$)	<5	71
P-Alkalinity (mg/l $CaCO_3$)	<5	
Chloride (mg/l Cl)	8	10.5
Sulphate (mg/l SO_4)	7	80
Fluoride (mg/l F)	<0.2	1.1
Sulphur (mg/l S)	<0.2	28.9
Calcium (mg/l Ca)	3	29.2
Magnesium (mg/l Mg)	<1	13.7
Potassium (mg/l K)	2	8.5
Sodium (mg/l Na)	<1	18.0
SAR (meq/l)	**0.1**	**0.7**

*De Beers Canada provided 5034 process water chemical analyses and no water samples were submitted to DebTech for slimes characterisation. Thus Puréau Fresh water was selected to prepare slurry samples for characterisation

3.5 Slimes Characterisation

Slimes were prepared using -1 mm size fraction of screened samples from Gahcho Kue and de-mineralised water samples from Puréau Fresh. Slimes characterisation was conducted at a feed solids concentration of 5, and 10 percent for each sample.

3.5.1 Slimes Characteristics

5034 Diamond Drill Hole

Slimes characteristics of 5034 Diamond Drill Hole samples are presented in Table 3. Slimes samples with a pH within pH 9 – pH 11 range are regarded to be in a colloidally stable pH range and tend to be difficult to settle. The pH value of 5034 Diamond Drill Hole material was below pH 9 indicating that the slimes would settle readily.

The conductivity of 5034 Diamond Drill Hole slimes samples ranges from 1.07 to 2.38 mS/cm. Experience has shown that slurry samples with conductivity in excess of 3.0 mS/cm are easy to settle.

Particle size distribution graphs are presented in Appendix B. Microtrac X100 size distribution results indicated that the 5034 Diamond Drill Hole slimes samples had ultra-fines ranging from low to medium content as indicated by the minus 22 micron size fraction.

Table 3: Slimes characteristics of 5034 Diamond Drill Hole samples

Ore Type	Sample	Av. Depth	Req. %	Act. RD	Act. %	pH	Conductivity	% -22

		(m)	Solids	(kg/m^3)	Solids		(mS/cm)	micron Fraction
GRN	**LR1244**	236	5	1.033	5.1	8.00	1.61	24.9
			10	1.066	9.9	8.42	1.80	10.2
HK2	**LR1245**	284	5	1.033	5.1	8.53	2.09	12.5
			10	1.067	10.1	8.78	2.14	23.8
HK	**LR1246**	47	5	1.034	5.3	8.46	1.78	23.8
			10	1.066	9.9	8.72	1.92	26.6
HKB	**LR1247**	112	5	1.034	5.3	8.28	1.18	23.8
			10	1.067	10.1	8.74	1.70	15.9
HK-GRN	**LR1248**	160	5	1.033	5.1	8.28	1.54	26.0
			10	1.066	9.9	8.69	1.88	14.0
HK+B	**LR1251**	105	5	1.033	5.1	8.13	1.29	9.7
			10	1.066	9.9	8.36	1.81	22.8
GRN+K	**LR1252**	189	5	1.034	5.3	8.15	2.09	27.5
			10	1.066	9.9	8.86	2.38	29.4
HK+TKt	**LR1253**	243	5	1.033	5.1	8.18	1.07	18.0
			10	1.066	9.9	8.64	1.39	31.4
TKtB-HKt	**LR1258**	153	5	1.034	5.3	8.20	1.38	25.4
			10	1.066	9.9	8.74	2.08	17.9

Hearne Diamond Drill Hole

Slimes characteristics of Hearne Diamond Drill Hole samples are presented in Table 4. The pH value of Hearne Diamond Drill Hole material was below pH 9 indicating that the slimes would settle readily. The conductivity of slimes samples ranged from 1.05 to 2.08 mS/cm.

Microtrac X100 size distribution results indicated that the Hearne Diamond Drill Hole slimes samples had ultra-fines ranging from low to high content as indicated by the minus 22 micron size fraction. A high content of ultra-fines, in excess of 40 percent, was recorded for the HK-TKNt slimes with a 10 percent solids concentration. A high content of ultra-fines, greater than 40 percent, increases the surface area of suspension in water thereby increasing the colloidal stability of the slimes.

Table 4: Slimes characteristics of Hearne Diamond Drill Hole samples

ODS	Sample	Av. Depth (m)	Req. % Solids	Act. RD (kg/m^3)	Act. % Solids	pH	Conductivity (mS/cm)	% -22 micron Fraction
HK-TKNt	**LR1249**	100	5	1.035	5.4	8.26	1.05	29.3
			10	1.067	10.1	8.64	1.98	45.6
HNHK	**LR1250**	231	5	1.034	5.3	8.26	1.19	13.5

			10	1.066	9.9	8.68	2.08	20.7
HK	**LR1254**	86	5	1.034	5.3	8.24	1.16	34.2
			10	1.066	9.9	8.44	1.94	26.8
HK	**LR1255**	60	5	1.034	5.3	8.24	1.13	26.2
			10	1.066	9.9	8.65	1.71	19.9
HKg	**LR1256**	142	5	1.033	5.1	8.14	1.11	35.6
			10	1.066	9.9	8.56	1.68	24.7
TKSD	**LR1257**	237	5	1.033	5.1	8.15	1.65	30.5
			10	1.066	9.9	8.76	1.98	33.5

3.5.2 Flocculant Selection

Flocculant selection was conducted on the 10 percent solids concentration slurry, using E10, 156, 1011, AO17, AD2 and 5250L flocculants. Flocculant were stirred and hydrated in tap water for approximately two hours at a 0.025 percent strength.

Ciba Chemical (Pelichem) produces Magnafloc E10, 156, 1011and 5250L flocculants while Ore Pro Consultant produces the AO17 and AD2 flocculants.

Ten millilitres of slimes sample was dispensed into six test tubes and each test tube was then dosed with 0.1 ml of flocculants. Test tubes are then shaken and observed for floc settling. A flocculant that produced good flocculation and clear water was selected for conducting settling tests.

From the selected flocculants, Magnafloc E10 produced good flocculation and very clear overflow water. Magnafloc E10 was used to perform settling test for the entire Gahcho Kue slimes samples, as it was the most efficient flocculant for settling the material.

3.5.3 Flocculant Dosage and Settling Characteristics

Tabulated data of the flocculant dose and settling characteristics of Gahcho Kue material is presented in Appendix C. The settling curves of the Gahcho Kue slimes are presented in Appendix D.

5034 Diamond Drill Hole Samples

The settling rates and flocculant dosage of 5034 Diamond Drill Hole samples as functions of depth are presented in Figure 7 and 8 respectively. Good settling rates were recorded for the slimes with a 5 and 10 percent solids concentration. As expected, lower settling rates were recorded for TKtB-HKt and HK+TKt samples, potentially due to domination by smectite mineral in the total mineral fraction.

Settling rates for 5034 Diamond Drill Hole samples ranges as follows:

- 5 percent solids concentration slimes: 23.2 m/h – 34.0 m/h
- 10 percent solids concentration slimes: 10.0 m/h – 23.6 m/h

Flocculant dose indicated that a slurry with a 5 percent solids concentration require 4.7 to 11.8 g/t while the 10 percent requires 5.9 to 11.8 g/t. There was a little variation in flocculant consumption for 5 and 10 percent solids concentration slimes of 5034 Diamond Drill Hole material.

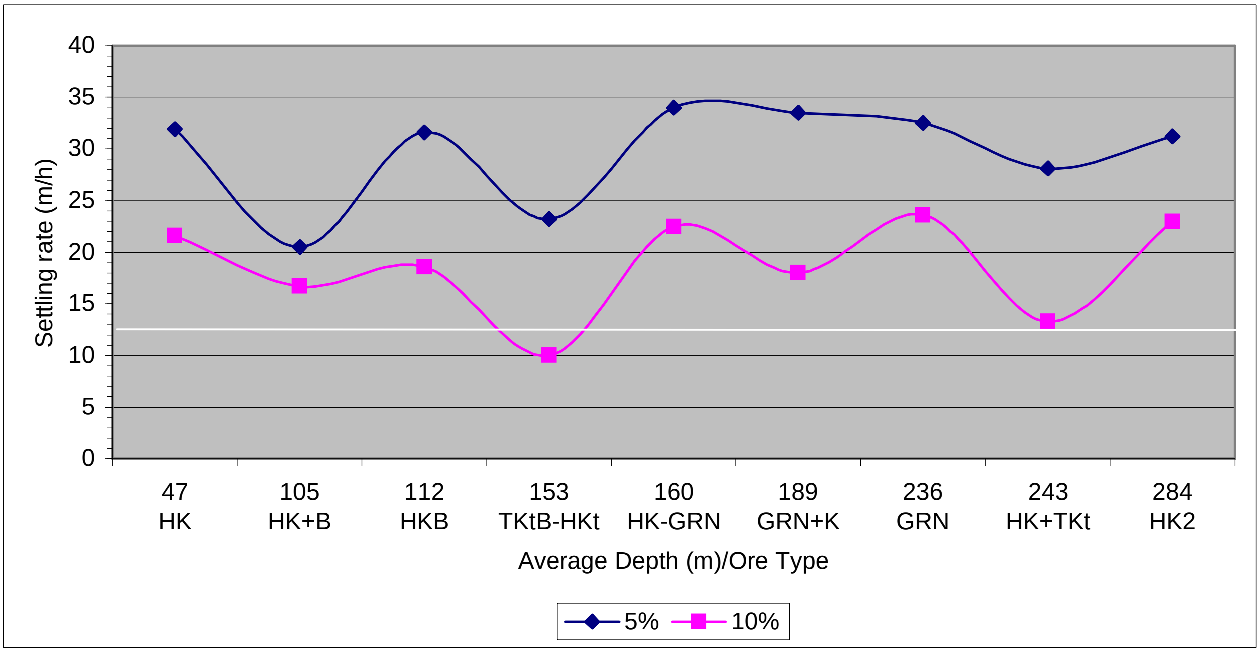


Figure 7: Settling rates of 5034 Diamond Drill Hole samples

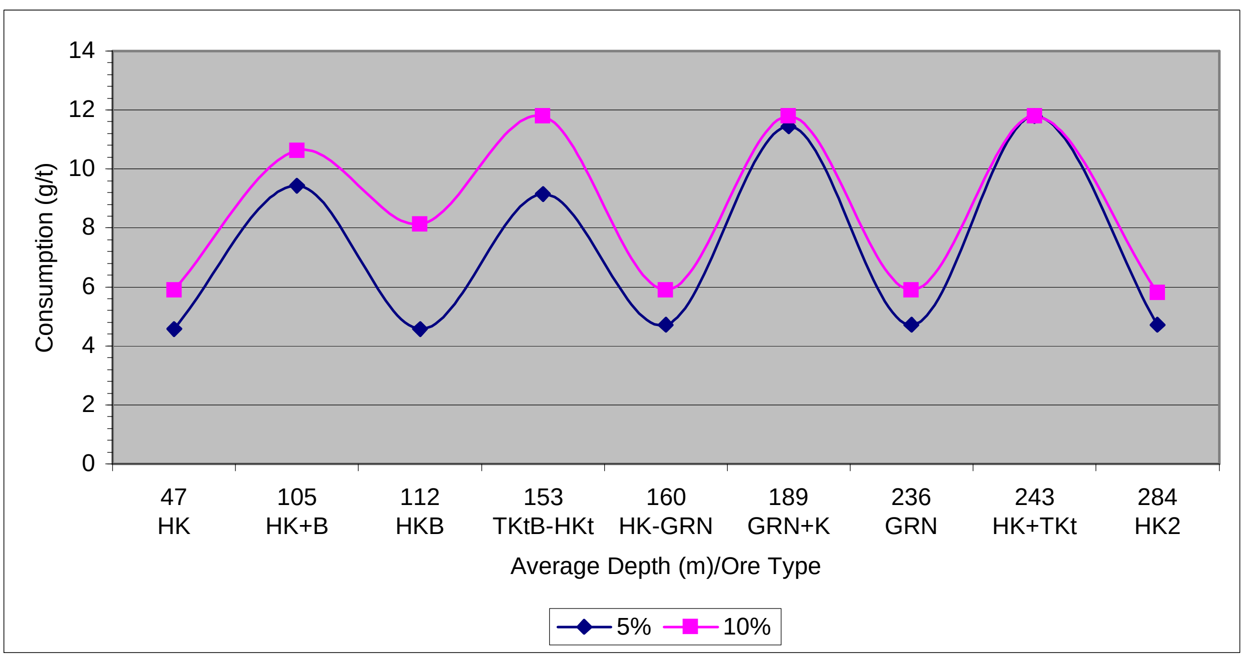


Figure 8: Magnafloc E10 dosages of 5034 Diamond Drill Hole samples

Hearne Diamond Drill Hole Samples

The settling rate and flocculant dosage of Hearne Diamond Drill Hole samples as functions of depth are presented in Figure 9 and 10 respectively. Good settling rates were recorded for the slimes with a 5 and 10 percent solids concentration. Lower settling rates were recorded for HK-TKNt and TKSD samples. These samples were dominated by smectite mineral in the total mineral fraction. Settling rates for 5034 Diamond Drill Hole samples ranges as follows:

- 5 percent solids concentration slimes: 19.7 m/h – 35.8 m/h
- 10 percent solids concentration slimes: 10.4 m/h – 24.8 m/h

Low flocculant doses were required to settle Hearne Diamond Drill Hole samples. The flocculant dose for the Hearne Diamond Drill Hole sample ranges from 6.9 to 13.7 g/t for 5 percent solids slurry and from 7.1 to 11.8 g/t for a 10 percent solids slurry samples.

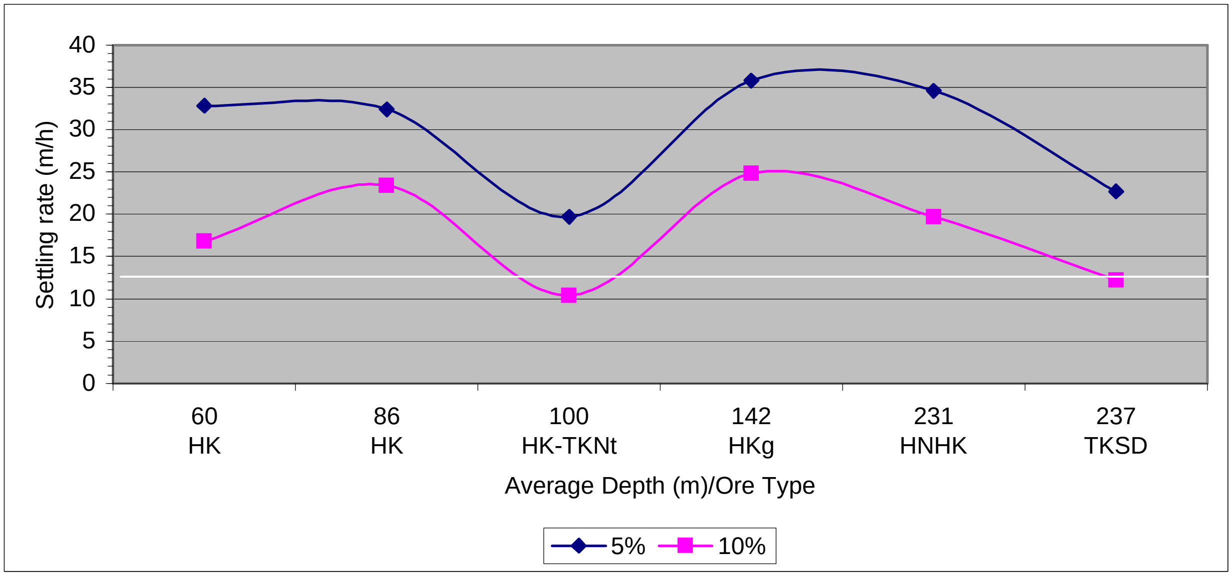


Figure 9: Settling rates of Hearne Diamond Drill Hole samples

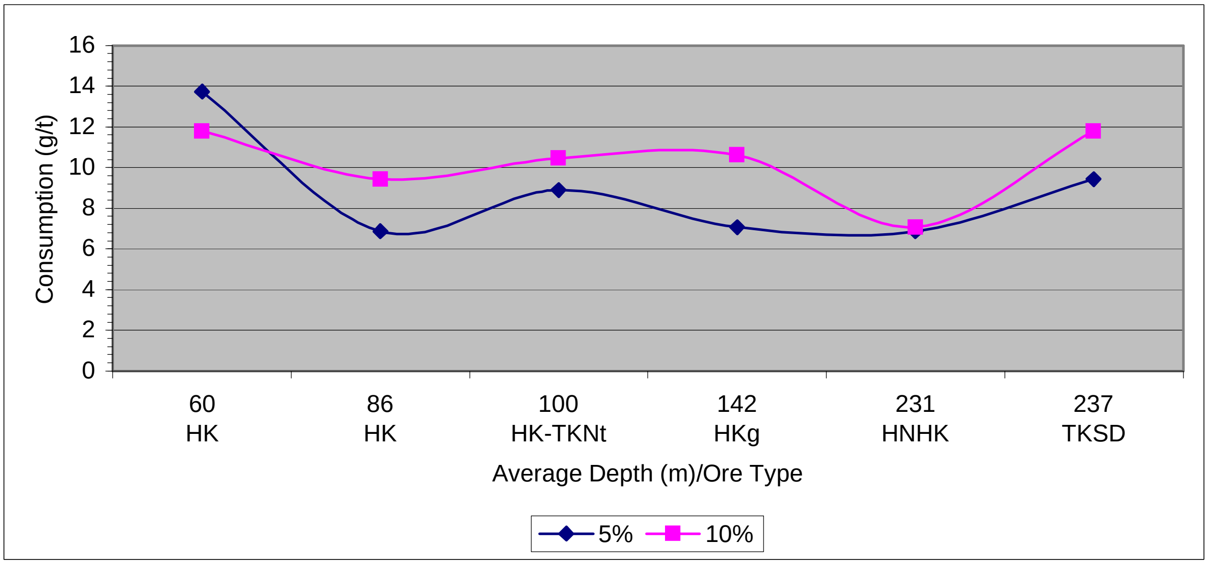


Figure 10: Magnafloc E10 dosages of Hearne Diamond Drill Hole samples

4. CONCLUSIONS

The pH value of Gahcho Kue slimes samples ranges between pH 8.0 and pH 8.8 and these values are typically in the unstable pH region and slurries within this pH range are expected to settle easily.

The ultra-fines content for most of the Gahcho Kue slimes samples ranges from low to medium. Only one sample, HK-TKNt, had a high ultra-fines content in excess of 40 percent. Ultra-fines content in excess of 40 percent increases the surface area of suspension and are responsible for absorbing flocculant.

No coagulation was required to render Gahcho Kue slimes unstable prior to flocculant addition.

A wide range of flocculants were able to bring about flocculation for Gahcho Kue slimes samples. Magnafloc E10 was the most efficient flocculant to use for the Gahcho Kue slimes samples.

Low flocculant dosages, ranging between 4.7 g/t and 13.7 g/t, were recorded for flocculating Gahcho Kue samples.

Good settling rates were determined for most Gahcho Kue slimes samples with 5 and 10 percent solids concentration. The settling rates of Gahcho Kue slimes samples ranges between 10 m/h and 35.8 m/h, with a median settling rate being 23.1 m/h.

Total mineral analysis indicated that Gahcho Kue ore bodies are composed of a wide range of minerals. High smectite content in the TKtB-HKt, HK+TKt, HK-TKNt and TKSD samples has a potential to cause settling problems. This was seen by relative lower settling rates recorded by these samples.

The ESP values of the Gahcho Kue samples are less than 15 percent. Samples with such low ESP values are known to settle easily.

5. RECOMMENDATIONS

- Magnafloc E10 should be used to treat Gahcho Kue slimes samples and should be dosed in two sequential units.
- Feed slurry to the thickener should be in the order of 5 percent solids concentration as some poor settling characteristics were generally observed at 10 percent solids concentration.
- Design settling rate for Gahcho Kue thickening unit should be taken as 23 m/h.

APPENDIX A: MINERALOGY RESULTS

Table A1: Total Mineral Analysis

Sample	ODS	Av. Depth (m)	Smectite	Mica	Serpentine	Pyrophyllite	Quartz	Gibbsite	Feldspar	Calcite
LR1244	GRN	236		19			31		50	
LR1245	HK2	284		13	77					10
LR1246	HK	47		23	59				9	9
LR1247	HKB	112		42	38				20	
LR1248	HK-GRN	160	13	14	19		13		34	7
LR1249	HK-TKNt	100	58	14	11	17				
LR1250	HNHK	231		11	79					10
LR1251	HK+B	105	15	13	29	12		10		21
LR1252	GRN+K	189	3	6	5		53		29	4
LR1253	HK+TKt	243	27	7	18	9	15			24
LR1254	HK	86		7	66				13	14
LR1255	HK	60			90					10
LR1256	HKg	142		35	46				10	9
LR1257	TKSD	237	35	6	5		45		9	
LR1258	TKtB-HKt	153	70	5			12		13	

Table A2: Clay Mineral Analysis

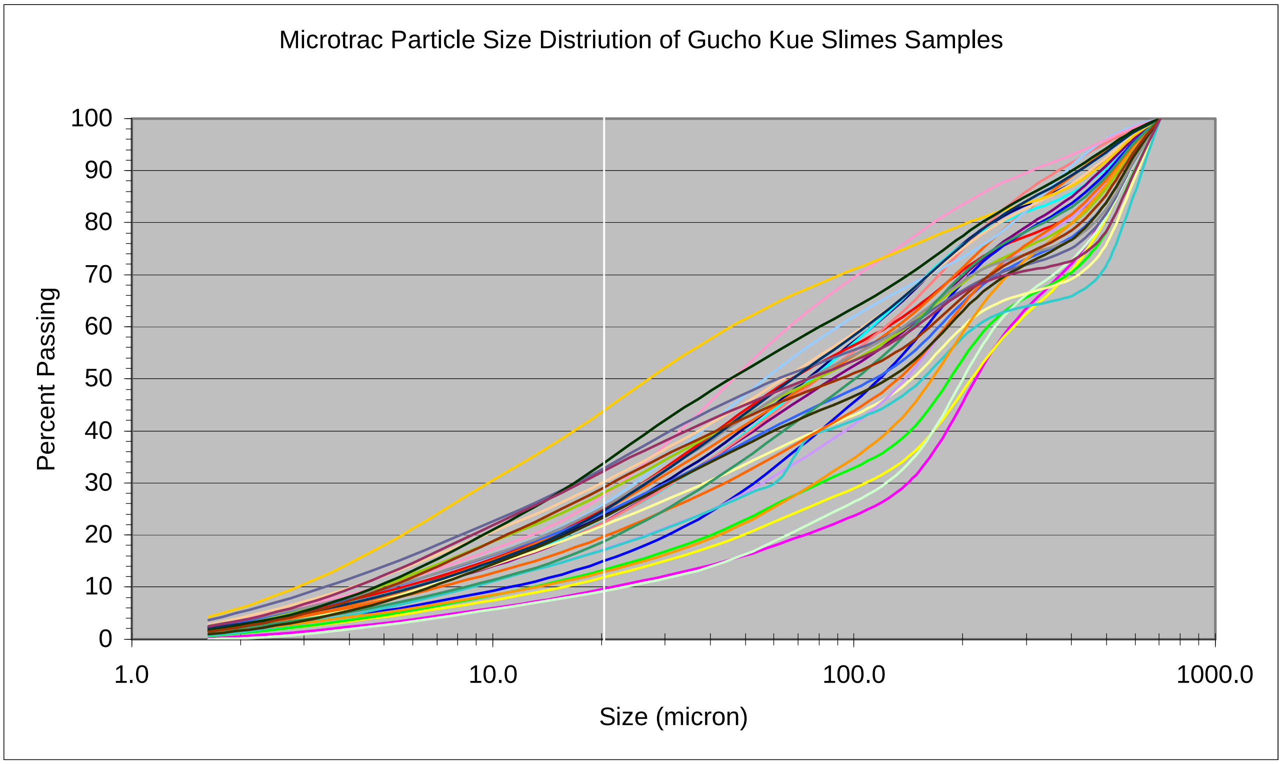
Sample	ODS	Av. Depth (m)	Interstratified	Smectite	Vermiculite	Mica	Serpentine	Kaolinite	Pyrophyllite	Quartz	Gibbsite	Feldspar	Calcite
LR1244	GRN	236	17	39		5	13					26	
LR1245	HK2	284			33		56			6			5
LR1246	HK	47			24	6	52			8			10
LR1247	HKB	112		14			8	17				61	
LR1248	HK-GRN	160	4	56		7	22			7		4	
LR1249	HK-TKNt	100	4	71		2	15		8				
LR1250	HNHK	231		22			69			9			
LR1251	HK+B	105		34			39		11	7	9		
LR1252	GRN+K	189	22	39		5	9			21		4	
LR1253	HK+TKt	243		62		4	16		9				9
LR1254	HK	86			41		53					6	
LR1255	HK	60			7		87						6
LR1256	HKg	142			31	16	48					5	
LR1257	TKSD	237		86		4	4		6				

LR1258	TKtB-HKt	153		87		3	6		4				

Table A3: Extractable Cations and Exchangeable Sodium Percentage

Sample	ODS	Av. Depth (m)	Na	K	Ca	Mg	CEC	ESP (%)
LR1244	GRN	236	0.42	0.34	8.17	1.18	3.96	10.59
LR1245	HK2	284	0.08	0.13	13.63	3.04	1.67	4.68
LR1246	HK	47	0.15	0.17	12.32	5.22	3.19	4.58
LR1247	HKB	112	0.43	0.40	16.00	2.29	7.15	6.00
LR1248	HK-GRN	160	0.40	0.31	14.08	4.39	10.12	3.94
LR1249	HK-TKNt	100	0.88	0.26	23.53	11.88	35.07	2.51
LR1250	HNHK	231	0.17	0.08	9.22	10.91	2.38	7.13
LR1251	HK+B	105	0.51	0.68	12.78	8.15	17.88	2.85
LR1252	GRN+K	189	0.31	0.19	16.00	1.18	4.31	7.22
LR1253	HK+TKt	243	2.07	0.17	26.68	5.81	22.23	9.31
LR1254	HK	86	0.12	0.20	13.33	4.35	3.74	3.18
LR1255	HK	60	0.07	0.12	7.65	15.10	2.67	2.58
LR1256	HKg	142	0.12	0.18	10.67	3.56	1.35	8.87
LR1257	TKSD	237	1.33	0.21	23.89	9.12	38.40	3.47
LR1258	TKtB-HKt	153	0.42	0.21	35.26	14.25	45.70	0.91

APPENDIX B: MICROTRAC X100 SIZE DISTRIBUTION



APPENDIX C: SLIMES SETTLING CHARACTERISTICS DATA

Table C1: Settling Data of 5034 Diamond Drill Hole Samples

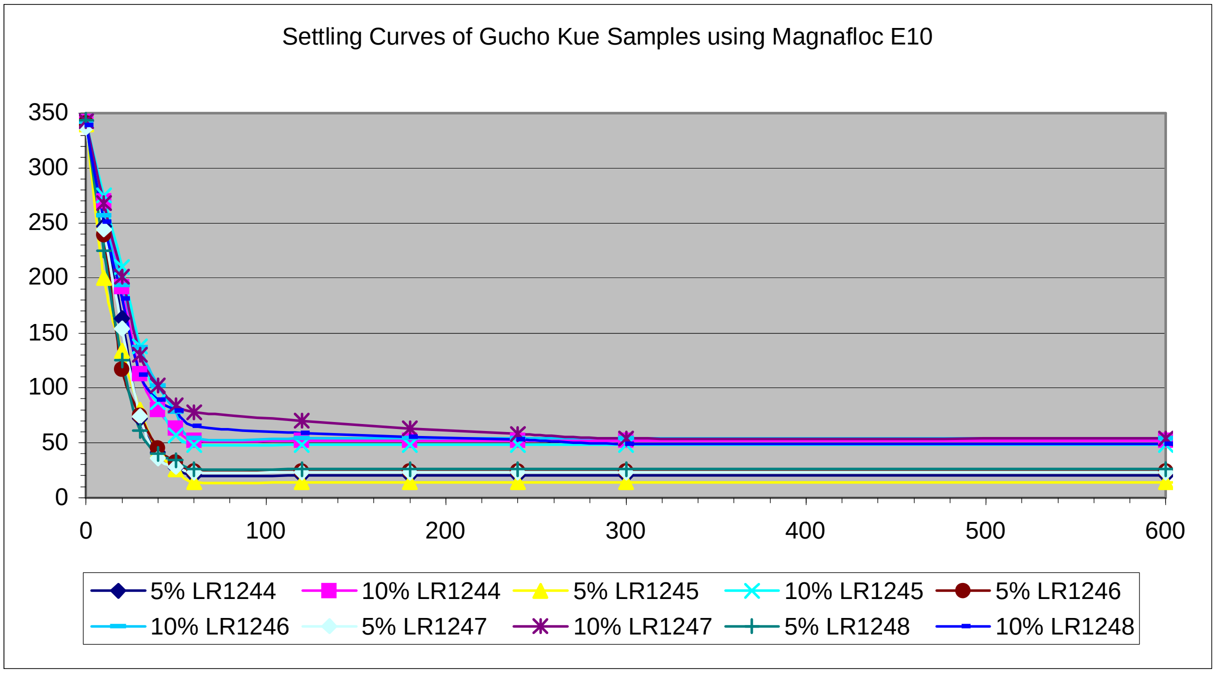
Ore Type	Sample	Av. Depth (m)	Settling Characteristics				
			ml/1000ml	g/t	% Solids	Set. Rate (m/h)	Final Height (mm)
GRN	**LR1244**	236	1.0	4.7	30.12	32.5	20
			2.5	5.9	42.28	23.6	52
HK2	**LR1245**	284	1.0	4.7	29.98	31.2	14
			2.5	5.8	44.36	23.0	48
HK	**LR1246**	47	1.0	4.6	32.18	31.9	24
			2.5	5.9	40.66	21.6	54
HKB	**LR1247**	112	1.0	4.6	42.98	31.6	23
			3.5	8.1	50.34	18.6	54
HK-GRN	**LR1248**	160	1.0	4.7	32.78	34.0	26
			2.5	5.9	52.98	22.5	49
HK+B	**LR1251**	105	2.0	9.4	40.16	20.5	23
			4.5	10.6	54.59	16.7	56
GRN+K	**LR1252**	189	2.5	11.4	38.97	33.5	29
			5.0	11.8	51.10	18.0	60
HK+TKt	**LR1253**	243	2.5	11.8	40.26	28.1	23
			5.0	11.8	58.98	13.3	75
TKtB-HKt	**LR1258**	153	2.0	9.2	30.92	23.2	23
			5.0	11.8	52.81	10.0	78

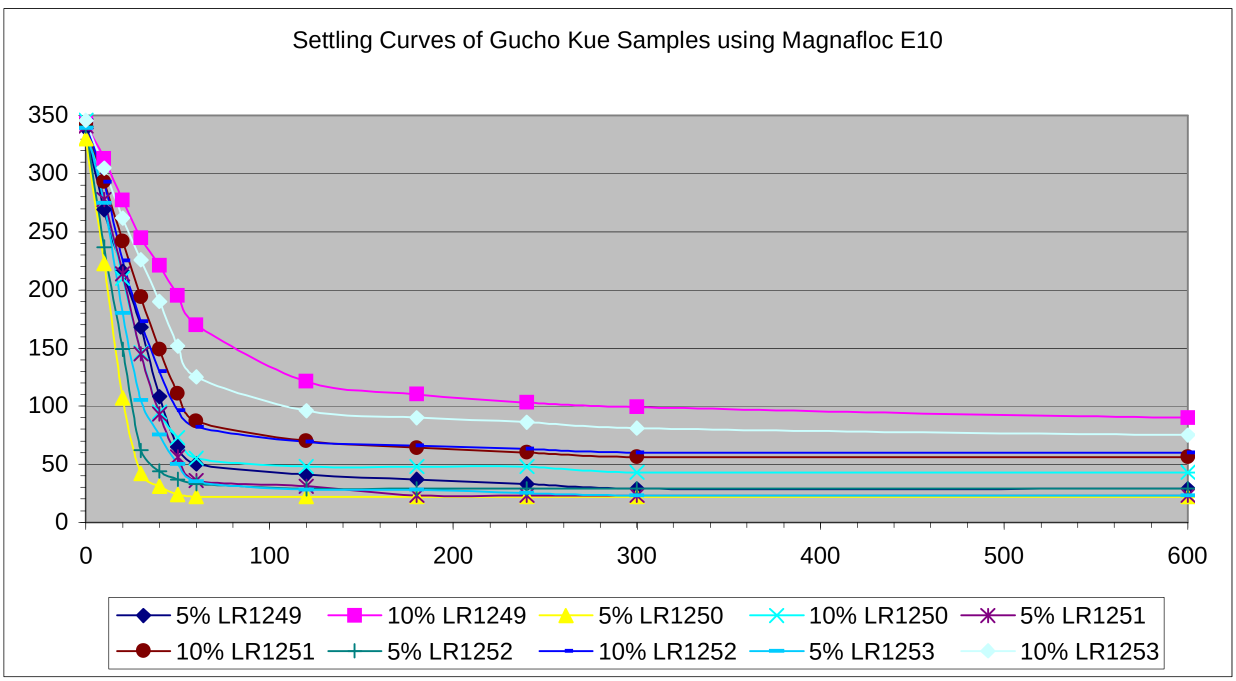
Table C2: Settling Data of Hearne Diamond Drill Hole Samples

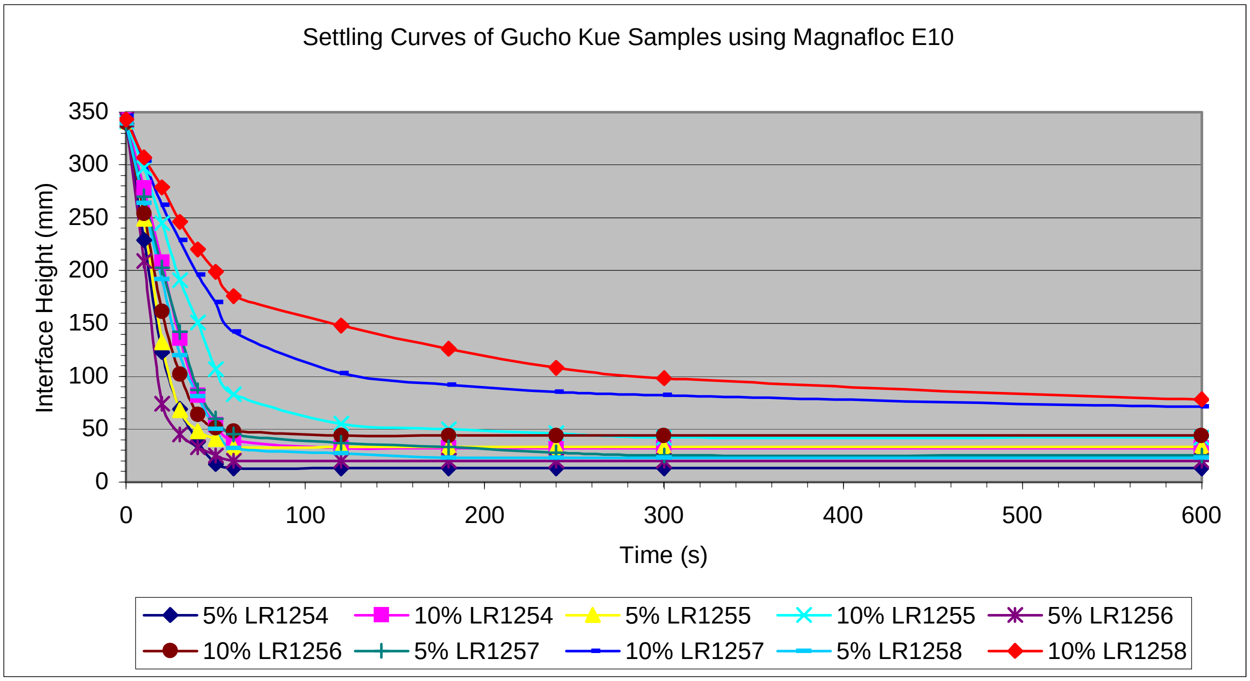
ODS	Sample	Av. Depth (m)	Settling Characteristics				
			ml/1000ml	g/t	% Solids	Set. Rate (m/h)	Final Height (mm)
HK-TKNt	**LR1249**	100	2.0	8.9	30.79	19.7	29
			4.5	10.5	45.98	10.4	78
HNHK	**LR1250**	231	1.5	6.9	43.91	34.6	22
			3.0	7.1	50.68	19.7	43
HK	**LR1254**	86	1.5	6.9	40.18	32.4	13
			4.0	9.4	52.14	23.4	32
HK	**LR1255**	60	3.0	13.7	46.16	32.8	33
			5.0	11.8	59.08	16.8	42
HKg	**LR1256**	142	1.5	7.1	30.78	35.8	20
			4.5	10.6	54.66	24.8	44

TKSD	**LR1257**	237	2.0	9.4	31.08	22.7	25
			5.0	11.8	52.19	12.2	71

APPENDIX D: SLIMES SETTLING CURVE






Settling Curves of Gucho Kue Samples using Magnafloc E10
Interface Height (mm)
350
300
250
200
150
100
50
0
0
100
200
300
400
500
600
Time (s)
5% LR1254
10% LR1254
5% LR1255
10% LR1255
5% LR1256
10% LR1256
5% LR1257
10% LR1257
5% LR1258
10% LR1258

APPENDIX B

GAHCHO KUÉ PHASE II ODS SLIMES CHARACTERIZATION (2004)

DE BEERS
A DIAMOND IS FOREVER

NOTE FOR THE RECORD
GAHCHO KUE PHASE II ODS SLIMES CHARACTERISATION

Compiled by

Phakamele Tomo

01 October 2004

Document No: 2240-900559-PSS-00001-5624

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TABLE OF CONTENTS

ACRONYMS, ABBREVIATIONS AND DEFINITIONS

Acronyms and Abbreviations

AARL	Anglo American Research Laboratory
ARC	Agricultural Research Council – Institute of Soil, Climate & Water
CCC	Critical Coagulation Concentration
ESP	Exchangeable Sodium Percentage
ISO	International Standards Organisation
meq/100g	Milliequivalent per 100 grams of soil
meq/l	Milliequivalent per litre
ODS	Ore Dressing Studies
PSD	Particle Size Distribution
SAR	Sodium Absorption Ration
GTS	Group Technical Support
WES	Water and Environmental Services

Definitions

NOTE FOR THE RECORD

1. INTRODUCTION

This document form part of the slimes characterisation report that was done as part of Gahcho Kue Phase I ODS, Document No. T05-4000130-855. The work included full mineralogical characterisation and initial slimes characterisation of Hearne and 5034 samples. These results are available in a Note for the Record compiled by P Tomo [1].

The above note reported that the Gahcho Kue ore samples generated unstable slurries which were easy to treat. Magnafloc E10 was found to be best flocculant at low flocculant dosages ranging between 4.7 and 13.7 g/t.

The report is about work done as an input data pack to the paste characterisation work to be done at Paterson & Cooke Consulting Engineers in Cape Town.

2. LABORATORY SCALE TEST WORK

2.1 Chemical Analysis

One litre each of raw water and 'typical' process water samples were dispatched to AARL for full chemical analysis. Raw water samples were dispatched as received from De Beers Canada. The "typical" process water was generated using two different ore samples, that Hearne and 5034 ore bodies.

Typical process water was generated as follows:

- Measure up a 20% (by mass) slimes suspension to a total volume of 5 litres using raw water and –1 mm ore material as provided (e.g. 1 kg ore/5litres water);
- Stir the suspension for 20 minutes;
- Allow suspension to settle for 10 minutes;
- Decant the supernatant water; and
- This supernatant water should now be similar to typical thickener overflow (or process water) in chemical composition.

The stability of a clay suspension is influenced by the type of ions dissolved in the water, which in turn influences the types of ions adsorbed onto the clay surfaces, thus the need to perform the chemical analysis.

2.2 Mineralogical Analysis

The mineralogy of Hearne and 5034 ore bodies was analysed and reported previously [1]. The analysis indicated that the ores contained very low levels of sodium exchanged smectite clays.

2.3 Slimes Generation

Slimes samples were generated using Canada raw water and the screened -1 mm and -300 µm ore material for both ore bodies.

2.4 Reagent Preparation

Reagent used during flocculation was the same as the findings of the Gahcho Kue Phase I ODS, which is Magnafloc 10 (formerly E10).

- Flocculant preparation:
  - Flocculants were prepared at a working strength of 0.025 percent;
  - 0.025 grams of dry powders was added;
  - Added the powder to 100 ml of water; and
  - Hydrated the mixture for approximately 2 hours.

Reagents were not allowed to stay overnight and for each day a fresh batch of reagent solution was prepared.

2.5 Slimes Characterisation

The following characterisation tests were conducted:

- Measurement of the pH and electrical conductivity of all slurry samples using the 704 pH-meter and the Yokogawa Model SC82 Conductivity Meter, respectively;
- Particle size distribution (PSD) analysis of the slurry using Microtrac X100 Particle Size Analyser;
- Reagent demand test:
  - The objective of this test was to determine the quantity of reagent (coagulant and flocculant) required for clay particles to aggregate;
  - Using a 100ml of slurry at its natural pH, stirred with a magnetic stirrer, the coagulant at the CCC was added;
  - Flocculant was then added drop-wise until flocculation occurs. The volume of flocculant used was recorded;
- Settling tests:
  - The optimum flocculant doses, which gave the best results in terms of flocculation and supernatant clarity during reagent demand tests, were used for settling tests;
  - For each settling test, a one litre measuring cylinder was filled with slurry at its natural pH;
  - The required flocculant dose was then added and the cylinder again inverted three to four times for thorough mixing;
  - Once the cylinder was set down, the distance settled by the bed level interface was marked off and measured for 10s, 20s, 30s, 40s, 50s, 1min, 2min, 3min, 4min, 5min, 10min, 15min, 20min, 25min , 30min, 40min, 50min and 60min;
  - After 30 minutes, the turbidity of the supernatant was measured using Hach Ratio/XR Turbidimeter as well as the Wedge scale; and
  - The percent solid of the underflow slurry was measured using Mettler LP16 & PM2000 Drier.

3. RESULTS

3.1 Chemical Analysis Results

Summarised chemical analysis results of the water samples from Gahcho Kue are presented in Table 1 and a complete analysis is presented in Appendix A. An analysis of the water in which kimberlitic clay is suspended provides information as to the colloidal nature of the suspension. The stability of a clay suspension is influenced by the type of ions dissolved in the water, which in turn influences the types of ions adsorbed onto the clay surfaces.

The first parameter, which gives indications of the expected colloidal nature of slurry suspension, is the sodium absorption ratio (SAR). The SAR, measured in (meq/l), is a ratio of the concentrations of sodium (monovalent ion), calcium and magnesium (divalent ions) in the suspending water. Waters with a SAR in excess of 15 meq/l are expected to form non-settling suspensions.

The results indicated that the Gahcho Kue raw water and “typical” process water samples had a very low SAR value and thus are expected to generate easy settling slurries when in contact with kimberlitic-clay material.

Table 1: Summarised chemical analysis results of Gahcho Kue water samples

Sample ID	GK Raw Water	Hearne “Typical” Process Water	5034 “Typical” Process Water
pH at 25^{O}C	6.7	6.4	7.1
Conductivity mS/m at 25^{o}C	2	20	20
Calcium as Ca	2	11	11
Magnesium as Mg	0.6	5	4
Sodium as Na	0.6	13	9
SAR (meq/l)	**0.1**	**0.8**	**0.6**
Ionic Strength	**0.0003**	**0.0024**	**0.0024**

3.2 Slimes Characterisation Results

3.2.1 Feed Solids Optimisation

Feed solids concentration optimisation was conducted using a 1 litre cylinder tests. During feed solids optimisation the reagent dosages were kept constant for each test while the feed solid concentration was changed.

The reagent dose for the Hearne feed solids optimisation was kept at 10 g/t and 39 g/t for a minus 1 mm and -300 µm slurry samples respectively. The free settling rate for each feed solids concentration was measured and recorded. Figure 1 presents the settling flux as functions of feed solids concentration for Hearne ore body.

The results indicate that the optimum settling fluxes were achieved at 7.5 and 10 percent feed solids concentration for a minus 1 mm and -300 µm Hearne slurry samples respectively.

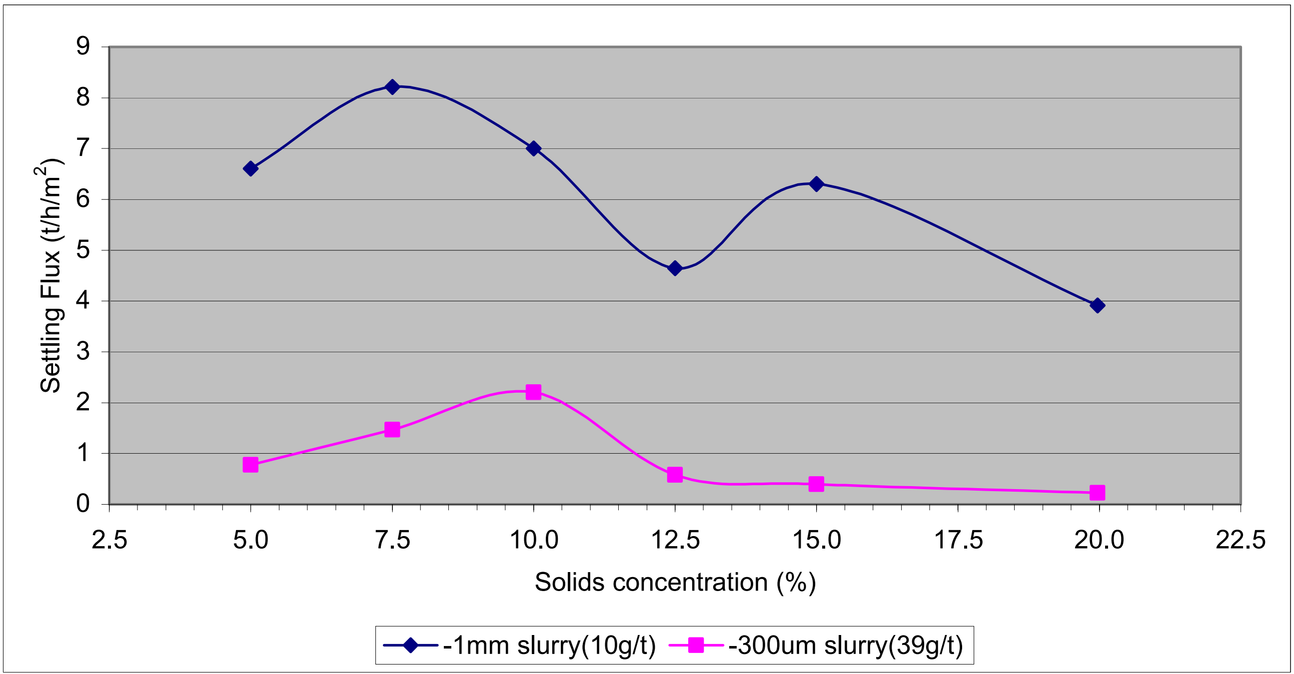


Figure 1: Settling flux as a function of feed solids concentration for Hearne ore body.

The reagent dose for the 5034 feed solids optimisation was kept at 10 g/t and 20 g/t for a minus 1 mm and -300 µm slurry samples respectively. The free settling rate for each feed solids concentration was measured and recorded. Figure 2 presents the settling flux as functions of feed solids concentration for 5034 ore body.

The results indicate that the optimum settling fluxes were achieved at 5 and 7.5 percent feed solids concentration for a minus 1 mm and -300 µm 5034 slurry samples respectively.

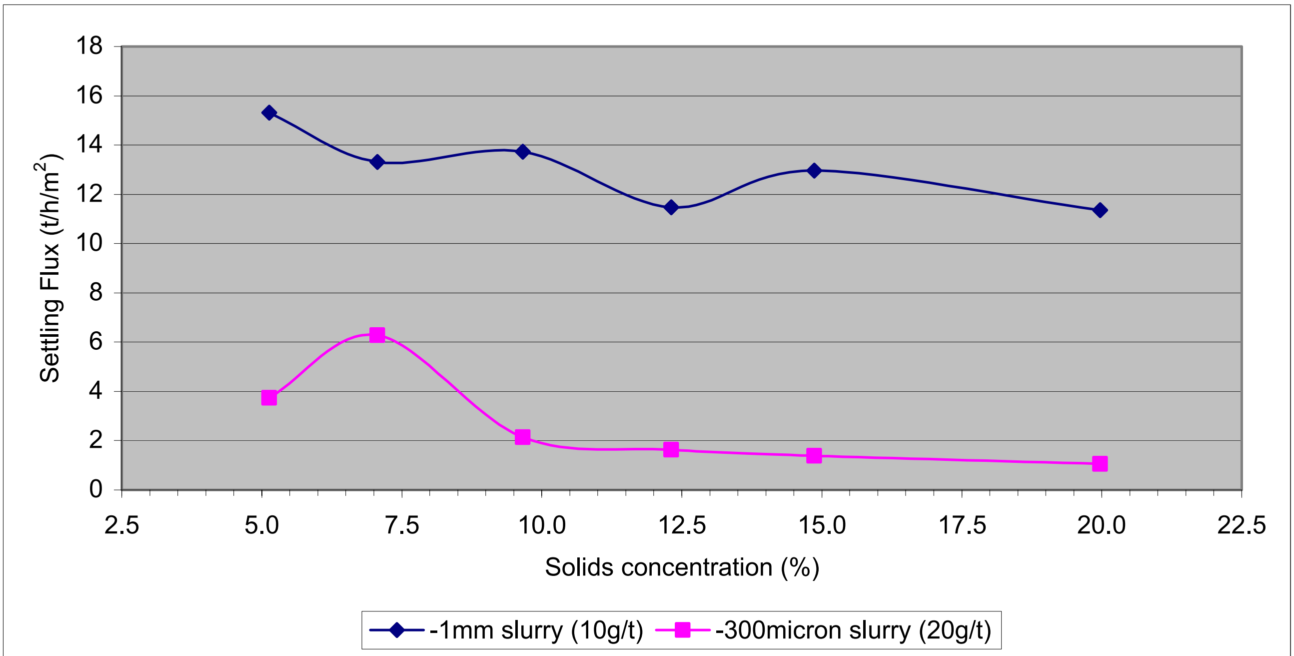


Figure 2: Settling flux as a function of feed solids concentration for 5034 ore body.

3.2.2 Flocculant demand

Flocculant demand was conducted in a beaker test at 5 percent feed solids concentration while varying flocculant dosage.

Figure 3 presents the flocculant demand result for the Hearne slimes samples. The results indicated that a flocculant dose of 5 to 10 g/t will be able to treat the -1mm Hearne slurry efficiently (Fig. 3a). The optimum flocculant dose for treating the -300μm Hearne slurry was ranging at between 28 to 38 g/t (Fig. 3b).

This indicates that a degritted Hearne material would require almost trice the flocculant dosage of treating a co-thickened Hearne material.

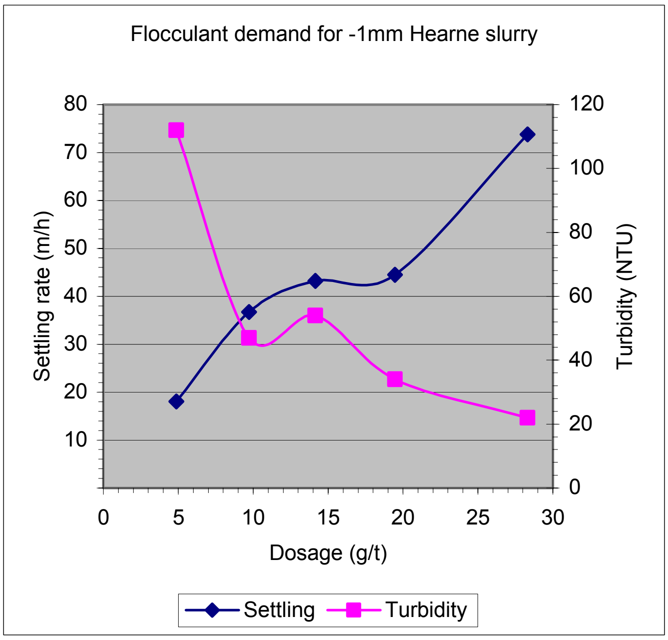


fig 3a

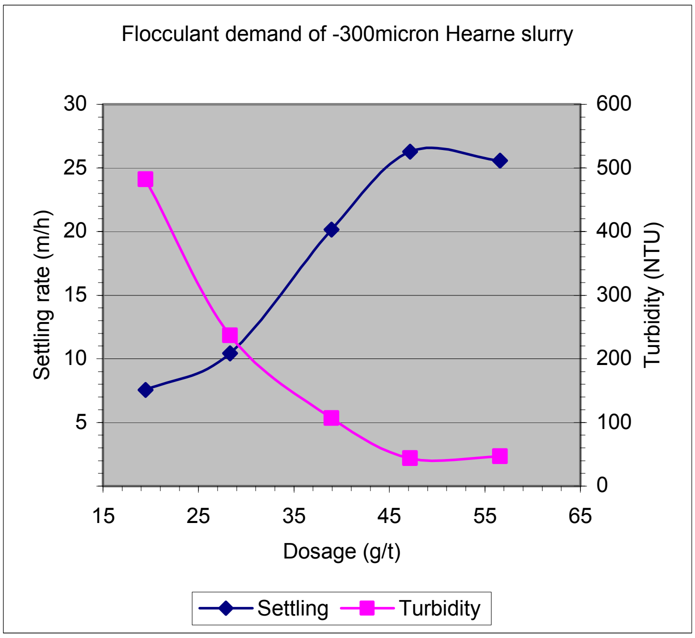


fig 3b

Figure 3: Flocculant demand for Hearne slimes samples (a) -1mm slurry sample, and (b) -300μm slurry sample.

Figure 4 presents the flocculant demand result for the 5034 slimes samples. The results indicated that a flocculant dose of 5 to 10 g/t will be able to treat the -1mm 5034 slurry efficiently (Fig. 4a). The optimum flocculant dose for treating the -300μm 5034 slurry was ranging at between 10 to 20 g/t (Fig. 4b).

This indicates that a degritted 5034 material would require almost twice the flocculant dosage of treating a co-thickened Hearne material.

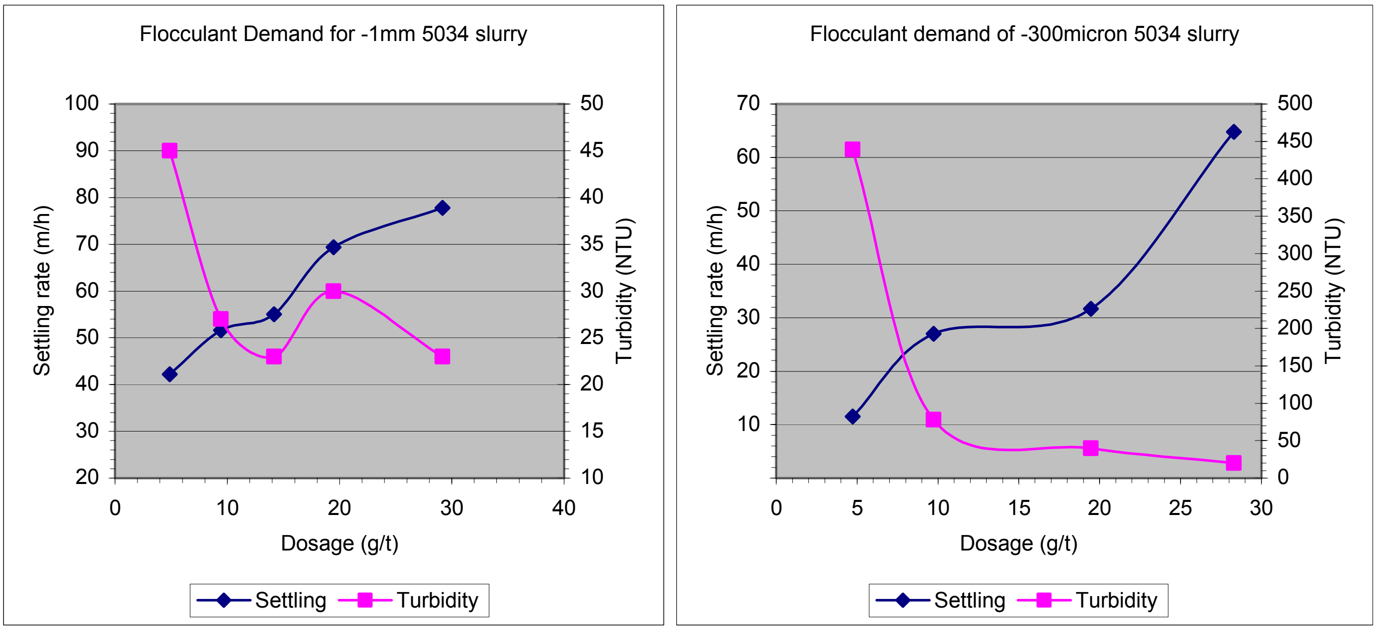


fig 4a ***fig 4b***

Figure 4: Flocculant demand for 5034 slimes samples (a) -1mm slurry sample, and (b) -300µm slurry sample.

3.2.3 Settling data

Settling tests were conducted on the slurry's natural pH and no pH modification tests were conducted. Magnafloc E10 was used for the settling tests of all slimes samples. The settling test results are presented in Table 2.

Good settling results were achieved for all slurry types tested. Very good settling rates higher than 10 m/h and overflow clarities of less than 100 NTU were achieved.

In general, flocculant demand was higher for finer slurry, with dosages of 10 g/t for coarser slurries and 20 – 38 g/t for finer slurry samples. Coarser slurry samples gave rise to higher terminal density of 1.673 and 1.718 t/m^3 for Hearne and 5034 respectively.

Table 2: Settling data of Gahcho Kue slimes samples

Slurry Type		Feed Solids		pH	Cond. (mS/cm)	Dose	Settling Analysis			UF Slurry	
		t/m^3	%			g/t	m/h	t/h/m^2	NTU	%	t/m^3
Hearne	-1mm	1.048	7.4	9.0	0.195	10	20.4	9.48	59	64.6	1.673
	-300µm	1.066	9.9	9.1	0.398	38	10.3	2.24	94	44.2	1.380
5034	-1mm	1.067	10	9.2	0.167	10	20.0	11.40	58	67.1	1.718
	-300µm	1.049	7.5	9.2	0.245	20	18.1	5.39	34	48.3	1.430

4. CONCLUSIONS

Gahcho Kue water was relatively easy to treat when combined with Hearne and 5034 material. This might be due to a very low SAR value of less than 1 meq/l, which is far less than a danger limit of 15 meq/l.

Settling characterisation was conducted to simulate treatment of both co-thickening (-1.5 mm) and degritted (-300 µm) slurries. The optimum settling fluxes at the following feed solids concentration:

	-1.5 mm slurry (Co-thickening)	-300 µm slurry (Degritted)
• Hearne material:	7.5%	10%
• 5034 material:	5%	7.5%

Flocculant demand indicated that degritted slurry would required almost twice the flocculant dosage of treating co-thickened slurry. The optimum flocculant dose for Gahcho Kue material is as follows:

	-1.5 mm slurry (Co-thickening)	-300 µm slurry (Degritted)
• Hearne material:	5 – 10 g/t	28 – 38g/t
• 5034 material:	5 – 10 g/t	10 – 20g/t

Good settling rates higher than10 m/h was achieved for all samples tested. Settling Hearne and 5034 material using Magnafloc E10 achieved clear overflow water with turbidity of less than 100 NTU.

The co-thickened slurry gave rise to high terminal density of approximately 66 percent solids while the de-gritted slurry had a average underflow density of about 46 percent solids. However, with a good raking mechanism and bed compaction, the underflow density can be increased.

5. REFERENCES

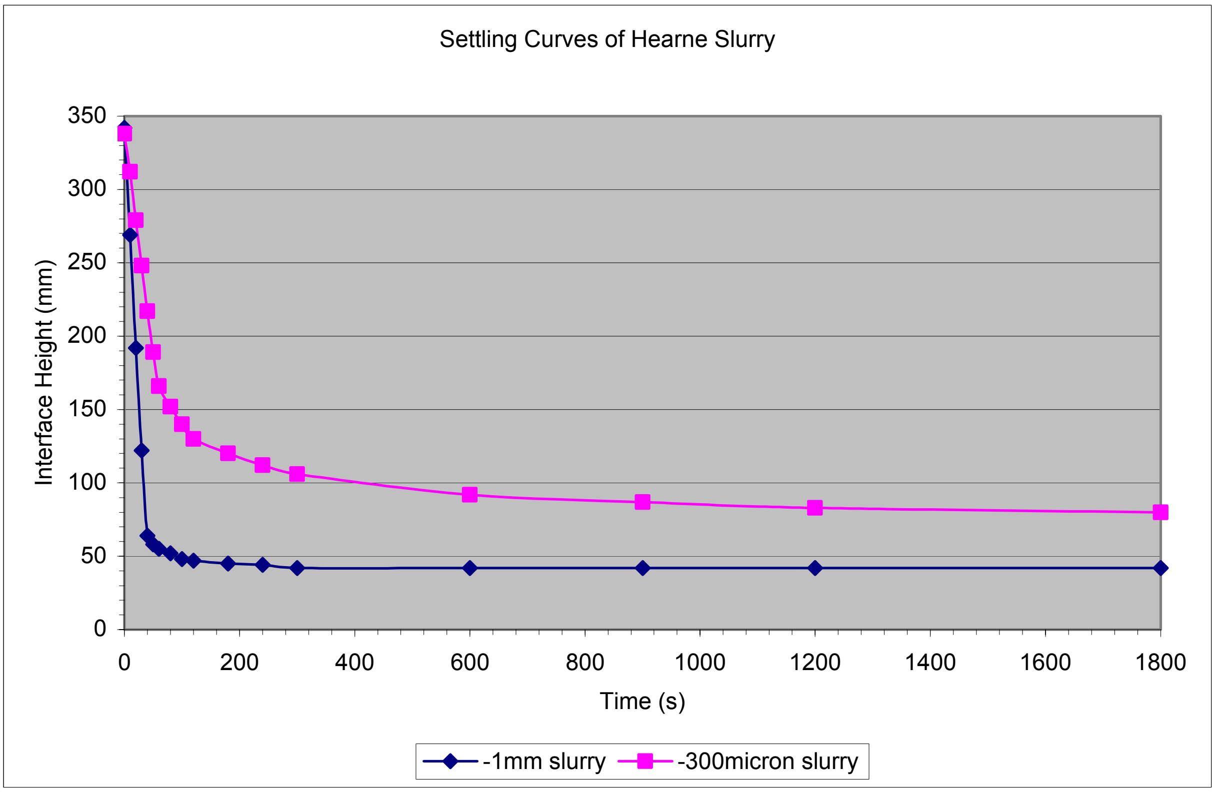
1 Tomo P — *Gahcho Kue Slimes Characterisation*, Note for the Record, Document No. T05-400230-855, October 2002.

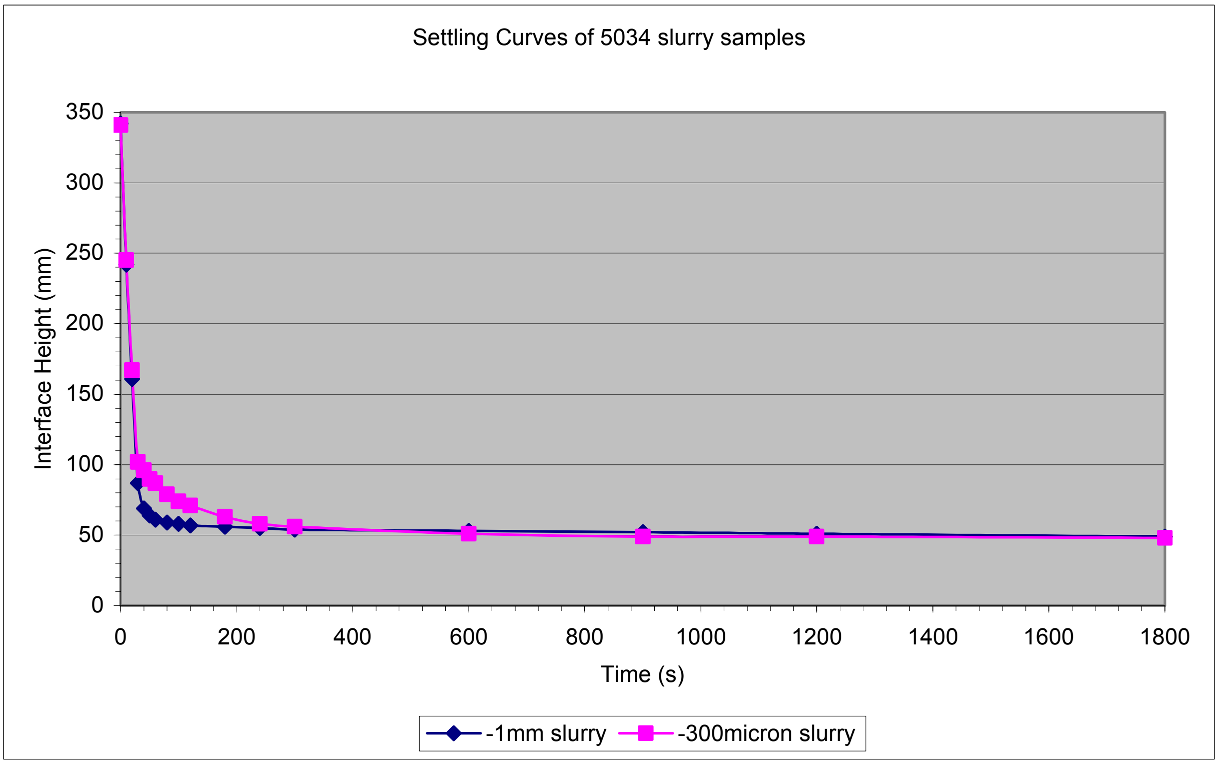
2 Van de Graaff, Patterson RA, (2001) — Explaining the mysteries of salinity, sodicity, SAR and ESP in On-Site Practice in *Proceedings of On-Site ’01 Conference: Advancing On-Site Wastewater Systems* by RA Patterson & MJ Jones (Eds), Published by Lanfax Laboratories, Armidale.

APPENDIX A: WATER ANALYSIS DATA

SAMPLE I.D.	GK Raw Water	Hearne "Typical" Process Water	5034 "Typical" Process Water
pH at 25°C	6.7	6.4	7.1
Conductivity mS/m at 25°C	2	20	20
Total Dissolved Solids at 180°C	<20	92	98
Total Suspended Solids at 105°C	<10	644	441
Alkalinity - mg/l $CaCO_3$ pH 4,5	7	50	58
Ca Hardness as mg/l $CaCO_3$	**5**	**27**	**21**
Mg Hardness as mg/l $CaCO_3$	**2**	**21**	**48**
Total Hardness as mg/l $CaCO_3$	**7**	**48**	**69**
Fluoride as F	<0.04	0.41	0.31
Chloride as Cl	1	26	23
Nitrites as NO_2	<0.5	<0.5	<0.5
Nitrates as NO_3	<0.5	2	<0.5
Nitrates as N	**<0.5**	**1**	**<0.5**
Phosphate as PO4	<0.5	<0.5	<0.5
Sulphate as SO_4	1	8	5
Total Phosphorus as P	<0.5	<0.5	<0.5
Silver as Ag	<0.2	<0.2	<0.2
Aluminium as Al	<0.5	<0.5	<0.5
Calcium as Ca	2	11	11
Chromium as Cr	<0.1	<0.1	<0.1
Copper as Cu	<0.5	<0.5	<0.5
Iron as Fe	<0.5	<0.5	<0.5
Magnesium as Mg	0.6	5	4
Sodium as Na	0.6	13	9
Potassium as K	0.7	7	10
Lead as Pb	<0.1	<0.1	<0.1
Zinc as Zn	<0.5	<0.5	<0.5
Silica as Si	<0.5	4	5
Cation / Anion Balance - % Diff.	**1.09**	**-9.79**	**-15.65**
SAR (meq/l)	**0.1**	**0.8**	**0.6**
Ionic Strength	**0.0003**	**0.0024**	**0.0024**

APPENDIX B: SLIMES SETTLING CURVE





APPENDIX C

GAHCHO KUÉ ORE DRESSING STUDY: SLURRY TESTS USING 5034 AND HEARNE ORE (2005)

P-006

DE BEERS
A DIAMOND IS FOREVER

GAHCHO KUÉ ORE DRESSING STUDY: SLURRY TESTS USING 5034 AND HEARNE ORE

Report Number: DGK-571.R03 Rev 0

March 2005

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SUMMARY

This document presents the slurry test results for the Gahcho Kué ore dressing study conducted by Paterson & Cooke Consulting Engineers (Pty) Ltd (PCCE) for Mr Tomo Phakamele of De Beers Technical Services.

Material Properties Tests

The following table summarises the properties of the two Gahcho Kué ore materials tested.

Material Type	Hearne Ore	5034 Ore
Solids density	2.63 t/m³	2.65 t/m³
d_{90} particle size	1035 μm	1027 μm
d_{85} particle size	930 μm	921 μm
d_{50} particle size	380 μm	369 μm
d_{10} particle size	32 μm	24 μm
Coefficient of sliding friction, μs	0.430	0.465
Average slurry pH	8.9	8.8
Freely settled bed packing concentration, C_{bfree}	40.5%v 64.1%w	40.5%v 64.4%w

Limits of Conventional, High Density and Paste

The following table summarises the classification of the two Gahcho Kué ore slurry samples according to PCCE's standard definitions.

Hearne Ore			
	Conventional slurry	High density slurry	Paste
Yield stress range	0 Pa < τ_y < 0.7 Pa	0.7 Pa < τ_y < 100 Pa	100 Pa < τ_y
Concentration range	0 < C_w < 64.1%w	64.1%w < C_w < 76.1%m	76.1% < C_w
Approximate Slump	No slump	10.0 inch < slump < 12.0 inch	slump < 10.0 inch
5034 Ore			
	Conventional slurry	High density slurry	Paste
Yield stress range	0 Pa < τ_y < 8.9 Pa	8.9 Pa < τ_y < 100 Pa	100 Pa < τ_y
Concentration range	0 < C_w < 64.4%w	64.4%w < C_w < 74.4%m	74.4% < C_w
Approximate Slump	No slump	9.9 inch < slump < 12.0 inch	slump < 9.9 inch

TERMS OF REFERENCE

This work has been conducted by Paterson & Cooke Consulting Engineers (Pty) Ltd for Mr P Tomo of De Beers Technical Services under Order Number PO-0070907. The proposal for this work was presented in PCCE Proposal DGK-571.P02 "Gahcho Kué Ore Dressing Study: Rheological Characterisation and Flow Behaviour Tests" dated 20 October 2004.

CONTENTS

DOCUMENT DISTRIBUTION AND REVISION HISTORY

Rev	Date	Distribution / Revisions	Prepared	Reviewed	Client Approval
0	31/03/2005	Issued to Mr P Tomo from De Beers Technical Services	FvS	AP/WG	-

NOMENCLATURE

A	cross sectional area	m^2
C	solids concentration	
C_{bfree}	freely settled solids packing volumetric concentration	%
C_{bmax}	maximum solids packing volumetric concentration	%
C_v	volumetric solids concentration	%
C_w	mass solids concentration	%
d	particle size	m
d_{50}	particle size at which 50% of the particles by mass are smaller than d_{50}	m
D	internal pipe diameter	m
f	friction factor	
g	acceleration due to gravity	m/s^2
k	hydraulic pipe roughness	m
K	fluid consistency index	$Pa.s^n$
K_B	Bingham viscosity	Pa.s
L	length	m
M	mass flow rate	kg/s
n	flow behaviour index	
P	pressure	Pa
Q	volumetric flow rate	m^3/s
Re	Reynolds number	
S	relative density	
T	temperature	°C
V_{dep}	stationary deposition velocity	m/s
V_m	mean mixture velocity	m/s
γ	shear rate	s^{-1}
Γ	pseudo or bulk shear rate (8V/D)	s^{-1}
ρ	density	kg/m^3
τ_o	pipe wall shear stress	Pa
τ_y	mixture yield stress	Pa
μ_s	coefficient of sliding friction between solid particle and pipe wall	
μ	viscosity	Pa.s

Subscripts

b	bed
m	mixture (slurry), mass
N	Newtonian
NN	non-Newtonian
s	solids
v	volumetric
w	conveying fluid

1. INTRODUCTION

1.1 Background

Mr Phakamele Tomo is managing the ore dressing studies for De Beers Canada proposed Gahcho Kué project. The Gahcho Kué project is located approximately 300 km northeast of Yellowknife in the Northwest Territories.

The study is currently at pre-feasibility level. Paterson & Cooke Consulting Engineers (PCCE) submitted proposal DGK-571.P02 which allowed for pilot scale thickening, crushing of existing ore to -1.5 mm, and rheology characterisation of the Hearne and 5034 ore bodies.

This report presents the rheological characterisation of the Hearne and 5034 ore bodies. No further crushing was required as all the material delivered to the PCCE laboratory was less than1.5 mm.

1.2 Test Work Scope

The following test work has been conducted to obtain design information for the Gahcho Kué ore dressing study using the Hearne and 5034 ore:

1.2.1 Material property tests

The material property tests include the following:

- Solids specific gravity
- Particle size analysis
- Slurry pH
- Solids freely settled concentration
- Coefficient of sliding friction between solids and pipe wall
- Particle micrographs (using an electron microscope).

1.2.2 Slump test

A standard 300 mm high, 12-inch slump cone was used for all the tests.

1.2.3 Viscometer tests

The rheology of the Hearne and 5034 ore was determined using PCCE's Rheolab MC 1 rotational rheometer.

1.2.4 Clay Behavioural Analysis

The behaviour of the varying clay mineral content in each sample was assessed by Paterson & Cooke Consulting Scientists (Pty) Ltd (PCCS). The results are presented in Appendix E.

1.3 Units and Abbreviations

SI units are used for this document. The following abbreviations are used:

%w - solids percentage by mass
%v - solids percentage by volume.

1.4 Definitions

Appendix A presents a list of hydrotransport terms and definitions used in this report.

The following definitions, agreed upon during extensive discussions with De Beers Group Mines personnel, are used in this report:

- **Vehicle** is the mixture formed by the combination of water in the slurry and all solids finer than 75 µm.
- **Slimes** is all material finer than 300 µm.
- **Grits** is all material sized between 300 µm and 1.5 mm.
- **Slurry** is considered to be a mixture of slimes and grits.

Figure 1 and Figure 2 present the relationship between slurry density, solids mass concentration and solids volume concentration for the Hearne and 5034 ore respectively. Appendix B shows this data in tabular form.

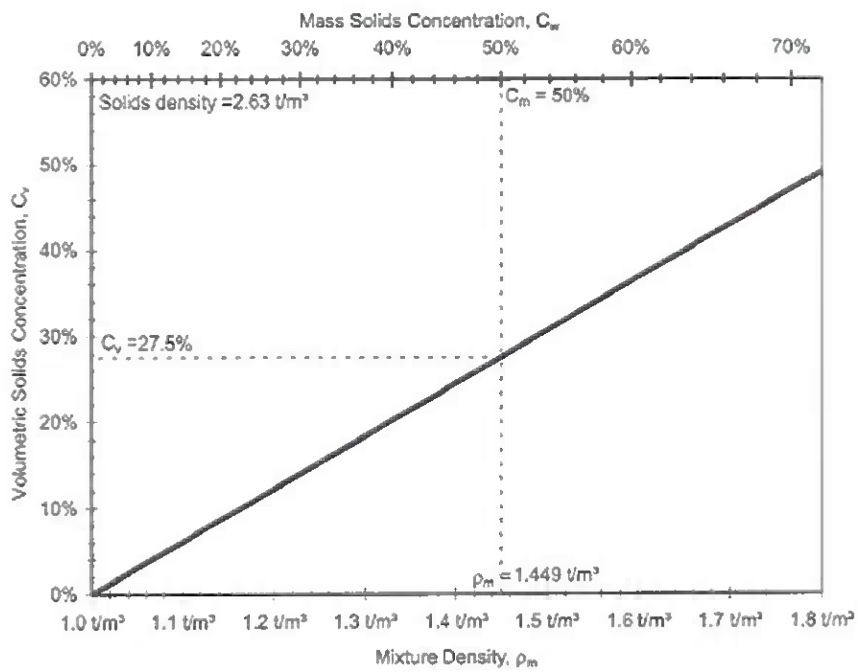


Figure 1: Relationship between ρ_m, C_v and C_w for Hearne Ore

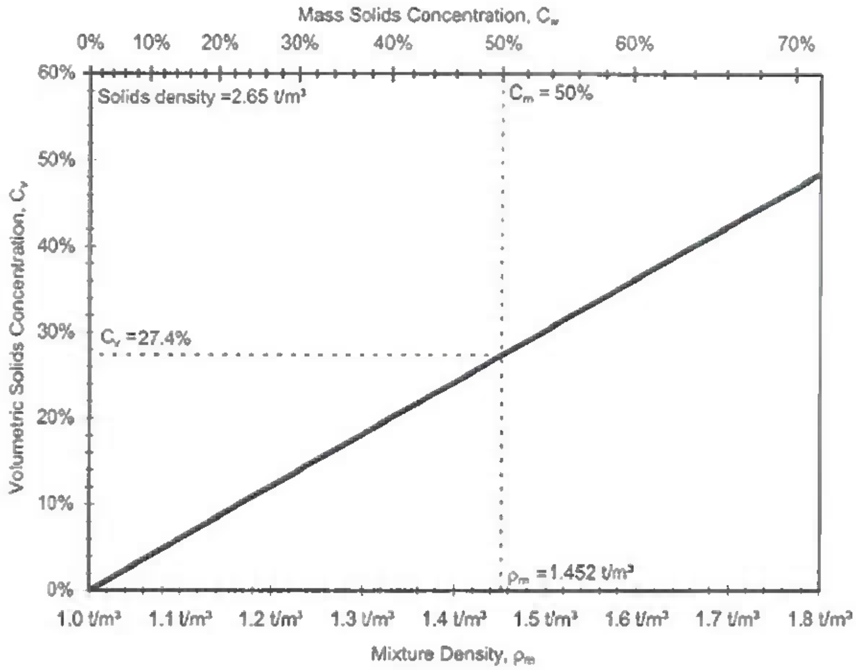


Figure 2: Relationship between ρ_m, C_v and C_w for 5034 Ore

1.5 Samples Supplied for the Test Work

Hearne and 5034 ore samples were delivered to PCCE's Laboratory on 24 January 2005, as shown in Table I.

Table I: Sample Delivery and Description

Delivery Date	Sample Type	Description
24 January 2005	Hearne Ore	9 x 50 litre blue loose lid drums each containing -1.5 mm dry ore material
	5034 Ore	9 x 50 litre blue loose lid drums each containing -1.5 mm dry ore material
	Process water	2 x 210 litre blue loose lid drums each containing approximately 200 litres of process water

Mr T Phakamele of De Beers Technical Services visited the laboratory the week starting 24 January 2005 and supplied PCCE with Magnafloc 10 used to flocculate the Hearne and 5034 ore.

1.6 Sample Preparation

The Hearne and 5034 ore arrived as a dry crushed sample. Each ore was prepared to produce representative slurry.

The following procedure describes the method used to prepare batches of flocculated slurry and slimes samples for the rheological characterisation tests:

(i) Prepare a flocculent solution using Magnafloc 10 at a dosage of 0.25%w. The solution was left overnight to hydrate.
(ii) Suitable quantities of water and solids to form 40 litres of mixture at a mass solids concentration of 10%w are placed in a 50 litre drum agitated using an impeller.
(iii) The impeller speed is varied to achieve "just off the bottom" suspension of the solids in the drum.
(iv) The mixture is blended for 30 seconds.
(v) Flocculent is added at a dosage of 10 g/t of dry solids.
(vi) The mixture is blended for 30 seconds and then allowed to settle over night.
(vii) The following day the supernatant water is decanted from the mixture and stored for later use as make up water.

The thickened settled mixture is stored in drums for the material properties and rheological characterisation tests. During the pipe loop and rheology tests one litre samples were collected for particle size distribution analysis.

2. MATERIAL PROPERTY TESTS

The tests described below were conducted to determine material properties of the samples. The results are summarised in Table II.

2.1 Solids Specific Gravity, S_s

The specific gravity of the material is determined using the method specified in ASTM D854-02 "Standard Test Method for Specific Gravity of Soils by Water Pycnometer"

2.2 Particle Size Analysis

The particle size distribution is determined by a combination of dry sieving (+75 µm fraction) and hydrometer analysis (-75 µm fraction) according to the method detailed in ASTM D 422-63 "Standard Test Method for Particle Size Analysis of Soils".

Appendix C presents the particle size distribution test data files. Figure 3 shows the average particle size distribution measured for the Hearne and 5034 ore for samples taken during the rheological characterisation tests. There is very little difference between the two ore types. The 5034 ore is slightly finer than the Hearne ore.

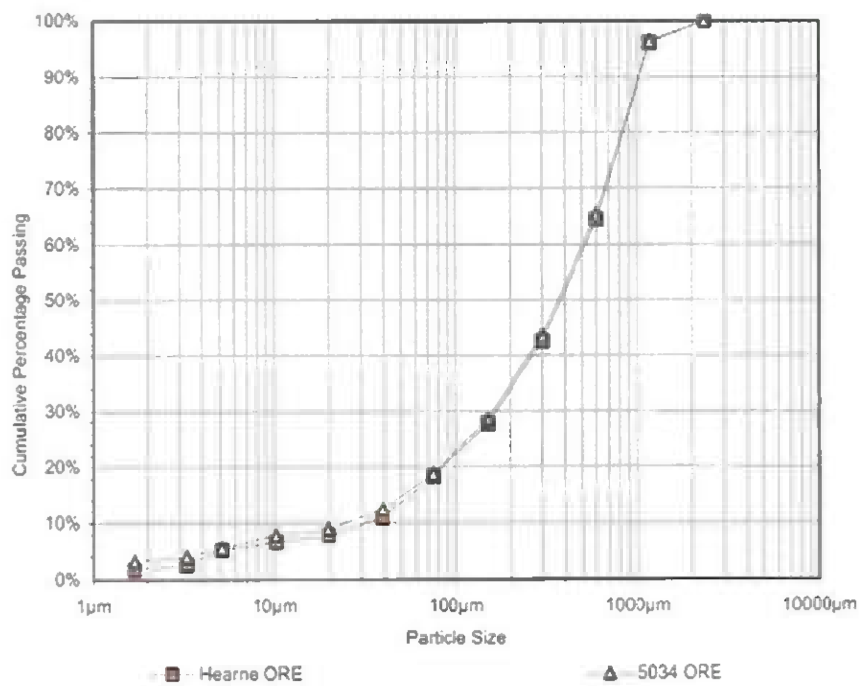


Figure 3: Particle Size Distribution of Hearne and 5034 Material

2.3 Slurry pH

The pH of the slurry is measured using a calibrated hand held pH meter.

2.4 Coefficient of Sliding Friction

The coefficient of sliding friction between the solids and the pipeline wall is measured using a tilting tube apparatus.

2.5 Freely Settled Bed Packing Concentration, C_{bfree}

The freely settled bed packing concentration by volume is calculated from the volume of the freely settled bed formed by a known volume of solids. A slurry sample is allowed to settle for 24 hours in a measuring flask. The actual solids volume is determined from the dry mass of material and the solids density.

2.6 Particle Micrographs

Figure 4 to Figure 7 show particle micrographs of the Hearne and 5034 ore at different magnifications respectively. The particles have sharp angular shapes typical for crushed or milled rock. Referring to the micrographs there is no visual difference between the two ore types.

Table II: Gahcho Kué Ore Dressing Study Material Properties

Material Type	**Hearne Ore**	**5034 Ore**
Solids density	2.63 t/m³	2.65 t/m³
d_{90} particle size	1035 µm	1027 µm
d_{85} particle size	930 µm	921 µm
d_{50} particle size	380 µm	369 µm
d_{10} particle size	32 µm	24 µm
Coefficient of sliding friction, µs	0.430[1]	0.465[1]
Average slurry pH	8.9	8.8
Freely settled bed packing concentration, C_{bfree}	40.5%v 64.1%w	40.5%v 64.4%w

Notes:

1. Applicable for grits fraction of slurry only

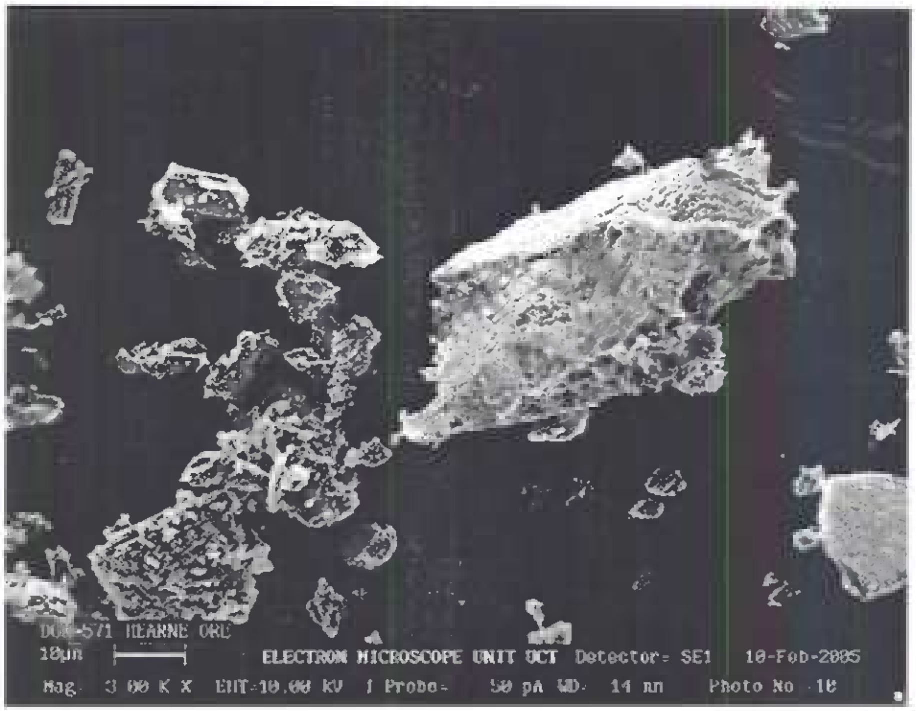


Figure 4: Particle Micrograph – Hearne Ore (High Magnification)

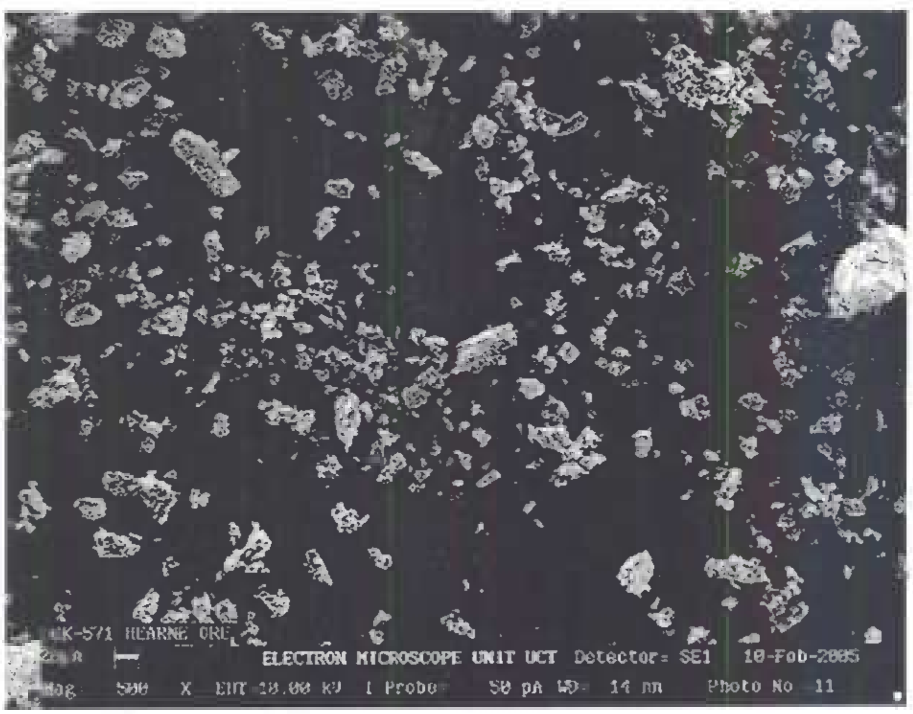


Figure 5: Particle Micrograph – Hearne Ore (Low Magnification)

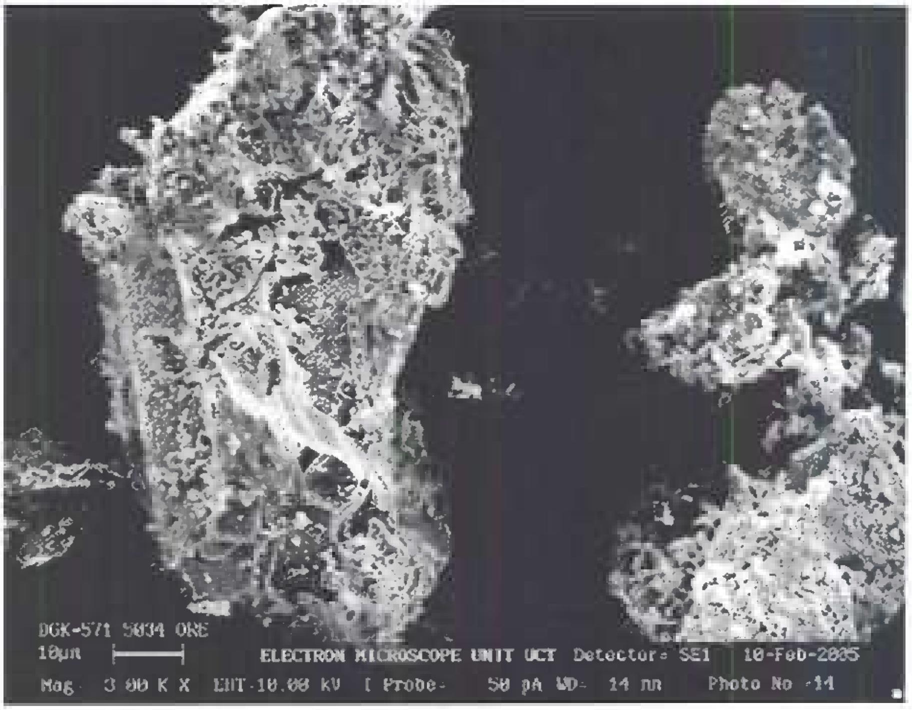


Figure 6: Particle Micrograph -- 5034 Ore (High Magnification)

Figure 7: Particle Micrograph – 5034 Ore (Low Magnification)

3. SLUMP TESTS

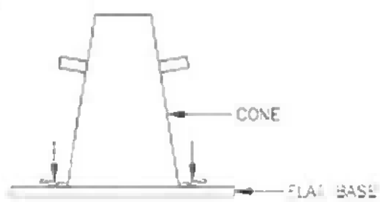
3.1 General

The slump test measures the consistency of the paste and is a good quality control measure for paste. Slump tests are conducted using the method specified in ASTM, C 143/C 143M "Standard Test Method for Slump of Hydraulic-Cement Concrete". A standard 300 mm high (12-inch) slump cone was used for all the tests.

The procedure to measure the slump of paste is as follows:

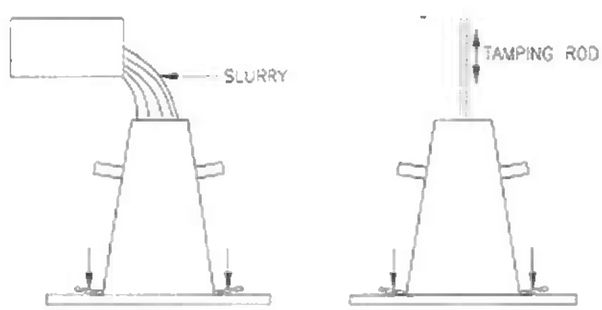
Step 1: Position the cone

- Wet the inside of the cone surface and the wooden base plate.
- Position the cone in the centre of the wooden base.
- Place feet firmly on the slump cone foot tabs.



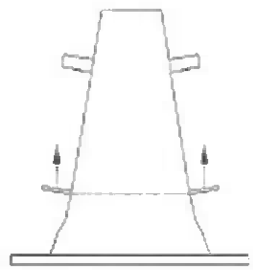
Step 2: Place slurry in the cone

- Fill the cone in three layers of slurry.
- Tamp each layer 25 times using a tamping rod, spreading the strokes uniformly across the cross-section of each layer. If after adding the final layer, the slurry level is below the top of the cone, fill the cone with slurry and level off the excess slurry.



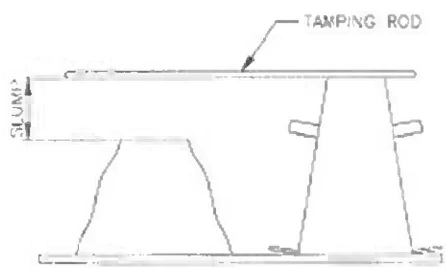
Step 3: Remove slump cone

- Remove any slurry surrounding the cone base to avoid any interference with the slumping slurry.
- Lift the cone slowly vertically. It should take about 5 seconds to raise the cone completely.



Step 4: Record slump

- The difference in millimetres between the top of the cone and the displaced original centre of the top of the slurry sample defines the slump distance.



3.2 Test Data

Figure 8 shows the slump data as a function of the mass solids concentration for the Hearne ore. The concentration range tested varied from 75.3 %w (270 mm slump, 10.6 inch) to 78.3 %w (148 mm slump, 5.8 inch). There is a significant change in slump for a small change in mass solids concentration. For concentrations lower than 75.3 %w the slurry was too dilute to measure slump. Table III presents the data in tabular format.

Figure 9 shows the slump data as a function of the mass solids concentration for the 5034 ore. The concentration range tested varied from 73.2 %w (265 mm slump, 10.4 inch) to 76.9 %w (177 mm slump, 7.0 inch). There is a significant change in slump for a small change in mass solids concentration. For concentrations lower than 73.2 %w the slurry was too dilute to measure slump. Table IV presents the data in tabular format.

Figure 10 shows a comparison between the Hearne ore and the 5034 ore slump test data. For the same mass solids concentration the Hearne ore gives a higher slump value compared to the 5034 ore sample.

Table III: Slump Test Data for the Hearne Ore

Test Number	Slump		Solid mass concentration	Picture
001	148 mm	5.8 inch	78.3 %w	
002	224 mm	8.8 inch	77.8 %w	
003	237 mm	9.3 inch	77.2 %w	
004	254 mm	10.0 inch	76.1 %w	
005	270 mm	10.6 inch	75.3 %w	

Table IV: Slump Test Data for the 5034 Ore

Test Number	Slump Height		Mass solids concentration	Picture
001	177 mm	7.0 inch	76.9 %w	
002	200 mm	7.9 inch	76.5 %w	
003	239 mm	9.4 inch	76.0 %w	
004	252 mm	9.9 inch	74.4 %w	
005	265 mm	10.4 inch	73.2 %w	

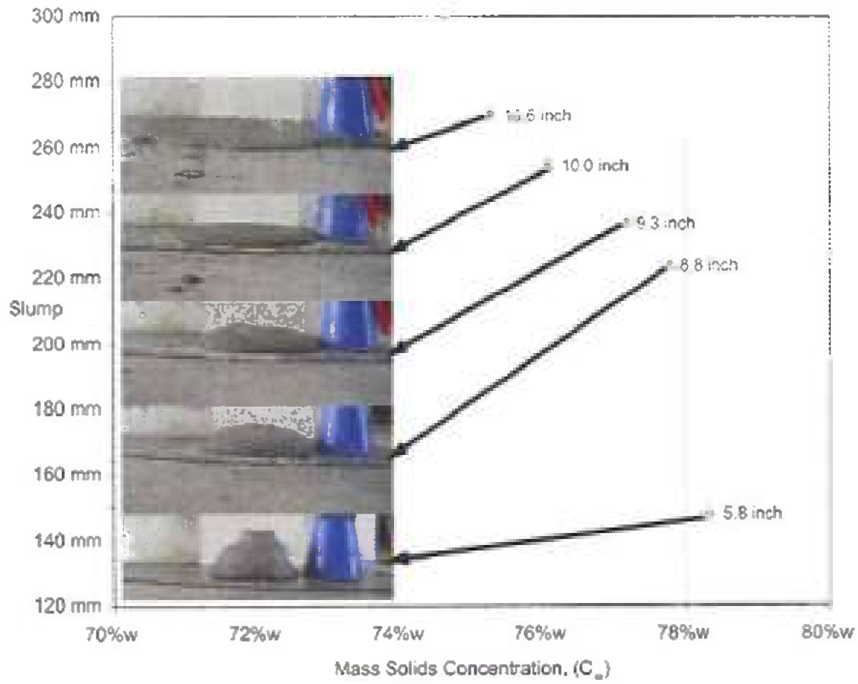


Figure 8: Slump versus C_w for Hearne Ore

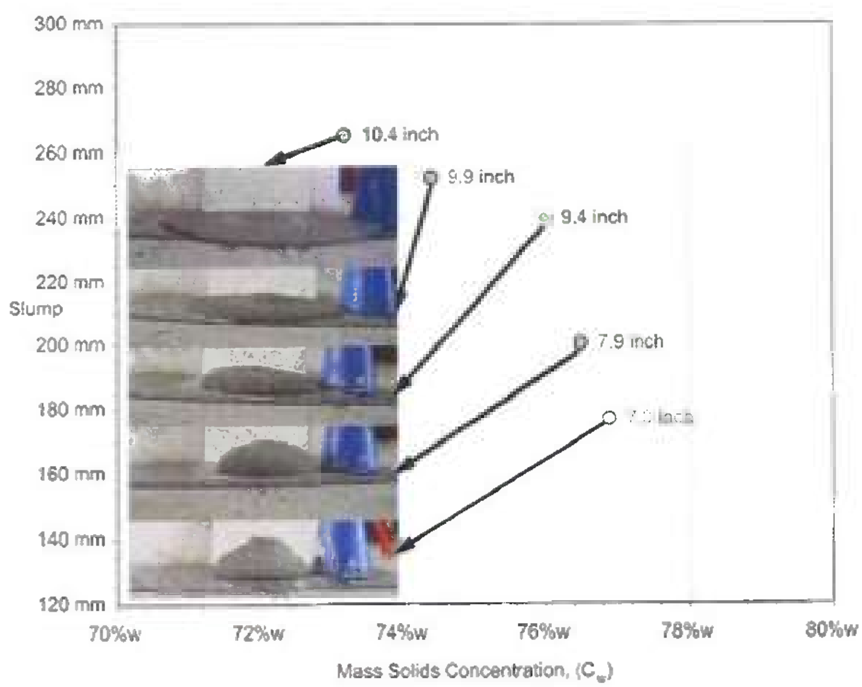


Figure 9: Slump versus C_w for 5034 Ore

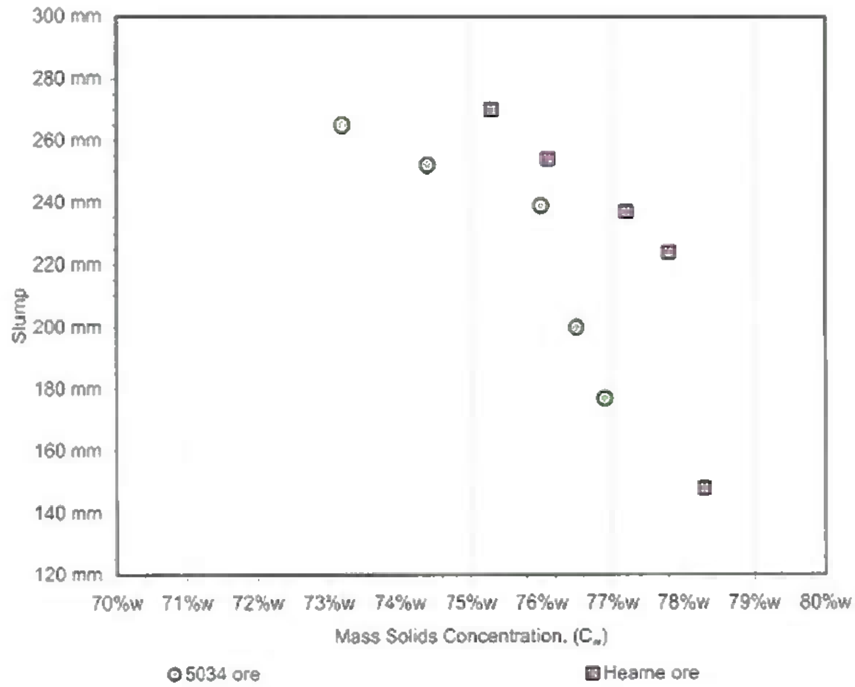


Figure 10: Comparison between 5034 and Hearne Ore Slump Test Data

4. VISCOMETER TESTS

4.1 Objective

The objective of the viscometer tests is to rheologically characterise the Hearne and 5034 ore slurry.

4.2 Test Equipment

PCCE's Rheolab MC 1 rotational rheometer, as shown in Figure 11, was used for the test work.

Figure 11: Rheolab MC 1 Rotational rheometer

4.3 Instrument Calibration

The rotational rheometer is calibrated regularly using oils with a known viscosity as shown in Figure 12.

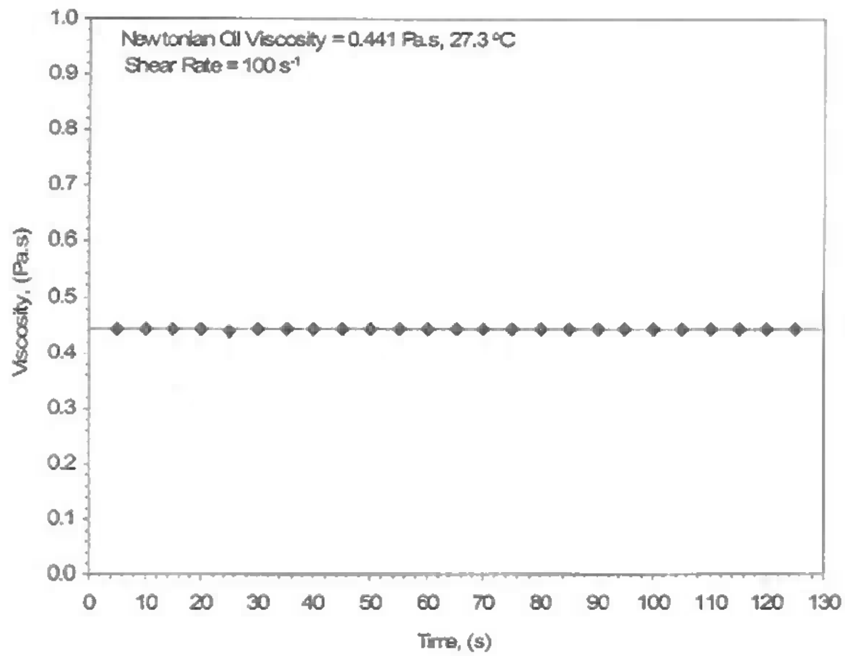


Figure 12: Newtonian Oil Viscosity at a Fixed Temperature Compared with the Rheometer Output.

4.4 Test Procedure

The output from the rheometer is a rheogram, a plot showing the relationship between wall shear stress and shear rate.

The rotational rheometer test sequence to produce a rheogram is as follow:

(i) Select the correct measuring system. The Z2/3 measuring system (DIN53018 standard) was used for the ore samples.
(ii) Fill the cup with a representative sample of slurry to the designated mark.
(iii) Place the cup on the laboratory jack centred below the viscometer bob.
(iv) Slowly raise the jack so that the bob completely penetrates the slurry sample.
(v) Fix the cup to the viscometer using the designated mounting screw.
(vi) Use the software from the rotational rheometer to produce a rheogram of the slurry sample.

4.5 Measured Test Data

Appendix D presents the rheometer test data files. Each data file contains the following:

- Date, sample name and measuring system used for the tests
- Measured values of density and pH
- Measured values of shear stress, shear rate and viscosity
- A rheogram (plot of wall shear stress versus shear rate).

4.6 Viscometer Test Results

Figure 13 shows a rheogram of the Hearne ore data for mass solids concentrations ranging from 73.3%w to 78.3%w. The average test temperature and pH was 24.4 °C and 8.9 respectively. Figure 14 shows a rheogram of the 5034 ore data for mass solids concentrations ranging from 68.4%w to 76.9%w. The average test temperature and pH was 23.2 °C and 8.8 respectively.

Figure 15 and Figure 16 presents a comparison between the Hearne and 5034 ore data at 73.1%w and 76.0%w respectively. In both cases the 5034 data set are higher compared to the Hearne ore data set for approximately the same mass solids concentration.

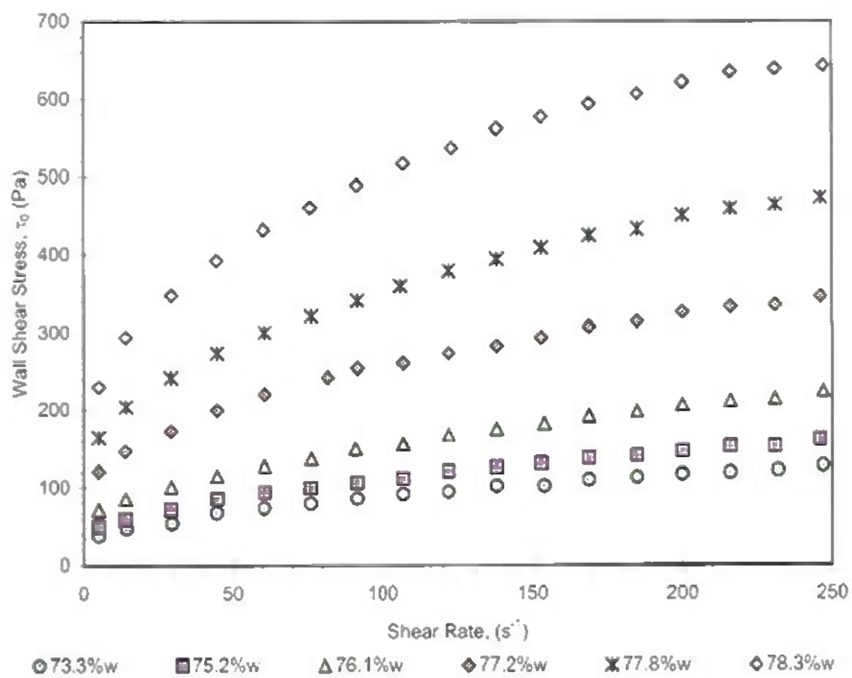


Figure 13: Rheogram Showing Hearne Ore Data

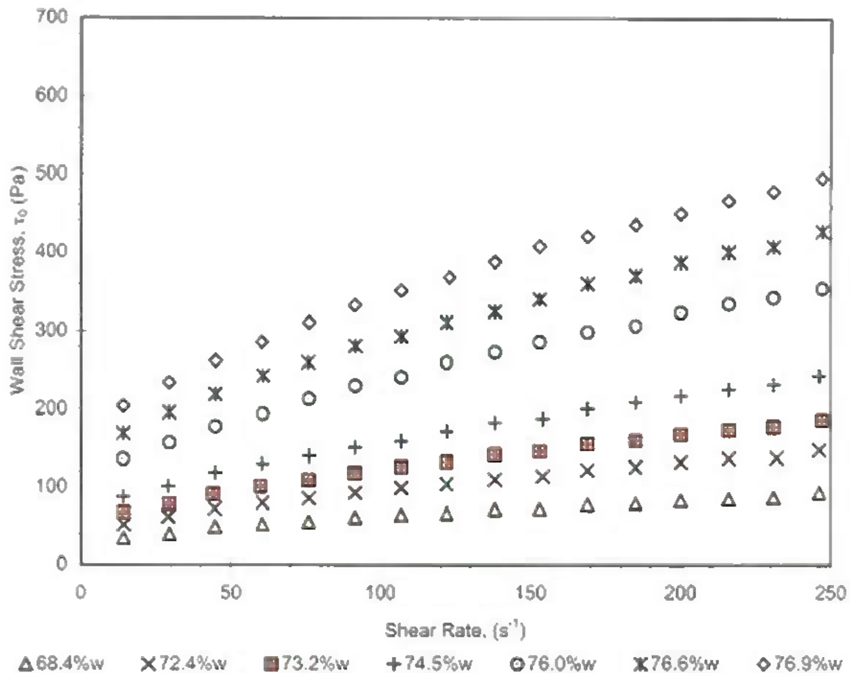


Figure 14: Rheogram Showing 5034 Ore Data

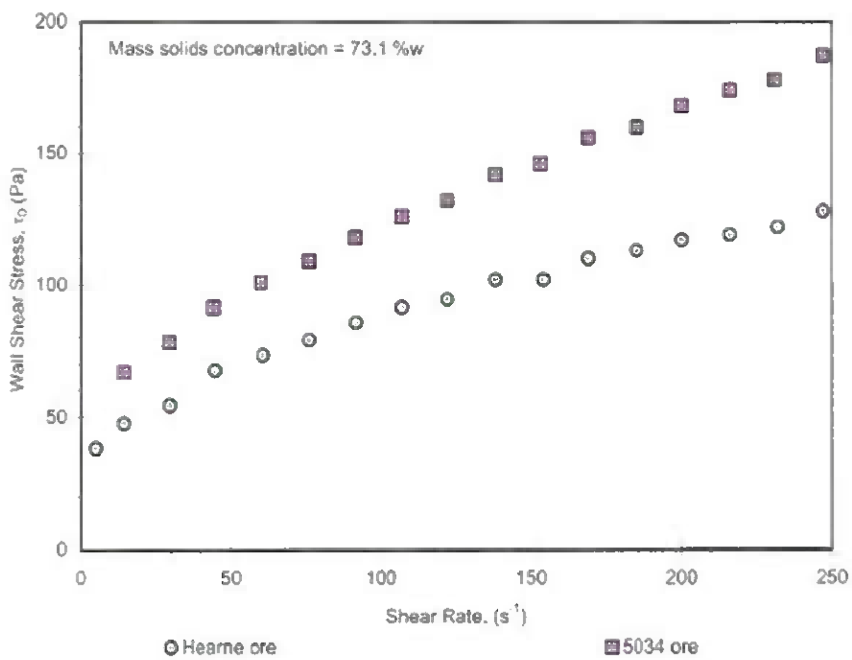


Figure 15: Rheogram Comparing Hearne and 5034 Ore Data at 73.1%w

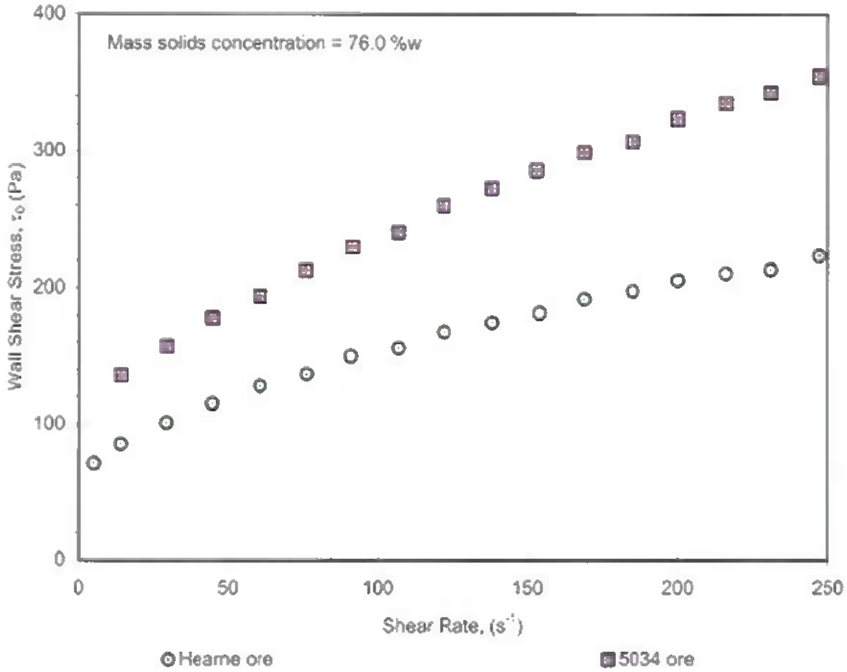


Figure 16: Rheogram Comparing Hearne and 5034 Ore Data at 76.0%w

4.7 Rheological characterisation

4.7.1 Hearne ore

The Hearne ore slurry was analysed as a Bingham plastic slurry, i.e. the rheology of the slurry is defined using a Bingham yield stress and plastic viscosity.

Figure 17 presents the plastic viscosity as a function of the mass solids concentration. Figure 18 presents the Bingham yield stress as a function of the mass solids concentration. There is good agreement between the correlation for Bingham yield stress and plastic viscosity compared to the data points. At 70%w and higher the slurry rheology increases significantly for a small change in solids mass concentration.

The formulas to calculate the rheological parameters for the Hearne ore are presented in Table V.

Table V: Hearne Ore Rheological Parameters

Bingham Plastic Model	
Applicable concentration range 72%w $< C_w <$ 0.79%w	
Plastic Viscosity	**Yield Stress**
The plastic viscosity of the slurry is calculated using the formula: $K_B = \mu_w + 350.0\ C_w^{22.40}$ where μ_w = viscosity of water at 25 °C (0.000894 Pa.s)	The yield stress of the fluid is calculated using the formula: $\tau_y = 2970\ x\ 10^2\ C_w^{29.30}$
The mass solids concentration is calculated using the formula: $C_m = \frac{Slurry\ wet\ mass}{Slurry\ dry\ mass}$	

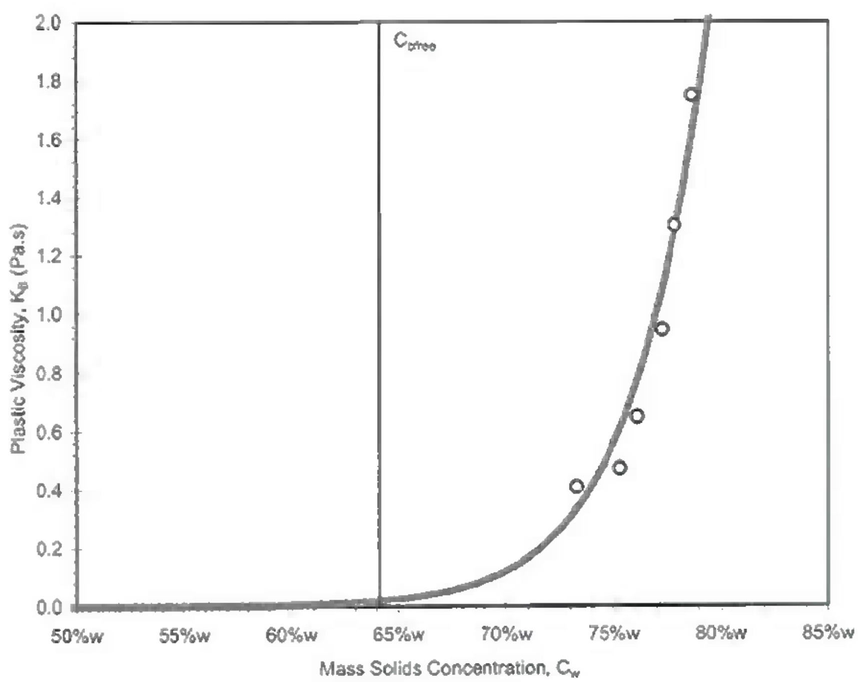


Figure 17: Plastic Viscosity as a Function of Mass Solids Concentration: Hearne Ore

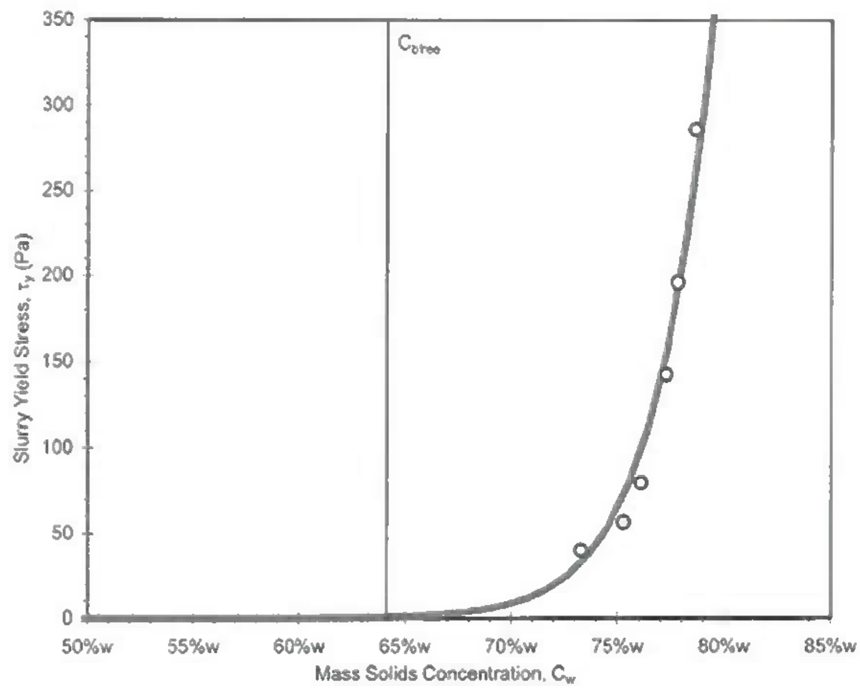


Figure 18: Yield Stress as a Function of Mass Solids Concentration: Hearne Ore

4.7.2 5034 ore

The 5034 ore slurry was analysed as a Bingham plastic slurry, i.e. the rheology of the slurry is defined using a Bingham yield stress and plastic viscosity.

Figure 19 and Figure 20 presents the slurry plastic viscosity and Bingham yield stress as a function of the mass solids concentration respectively. There is good agreement between the correlation for yield stress and plastic viscosity compared to the data points. At above 68%w the slurry rheology increases significantly for a small change in solids mass concentration.

The formulas to calculate the rheological parameters for the 5034 ore are presented in Table VI.

Table VI: 5034 Ore Rheological Parameters

<table>
<tr><th colspan="2">Bingham Plastic Model</th></tr>
<tr><td colspan="2">Applicable concentration range 68%w < C_w < 0.78%w</td></tr>
<tr><th>Plastic Viscosity</th><th>Yield Stress</th></tr>
<tr><td>The plastic viscosity of the slurry is calculated using the formula:
$K_B = \mu_w + 60.000\ C_w^{14.700}$
where
μ_w = viscosity of water at 25 °C (0.000894 Pa.s)</td><td>The yield stress of the fluid is calculated using the formula:
$\tau_y = 13800\ C_w^{16.700}$</td></tr>
<tr><td colspan="2">The mass solids concentration is calculated using the formula:
$C_m = \frac{Slurry\ wet\ mass}{Slurry\ dry\ mass}$</td></tr>
</table>

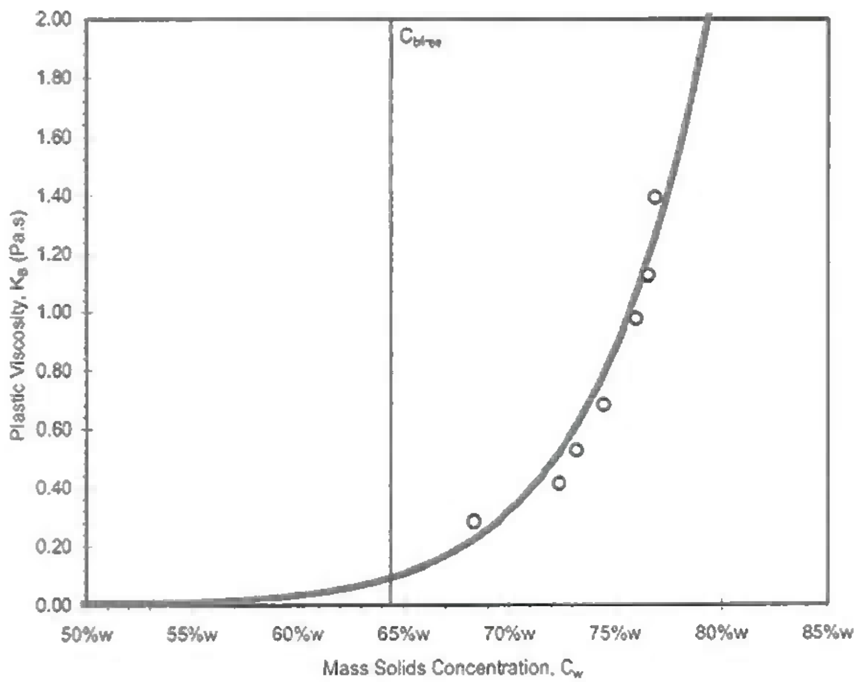


Figure 19: Plastic Viscosity as a Function of Mass Solids Concentration: 5034 Ore

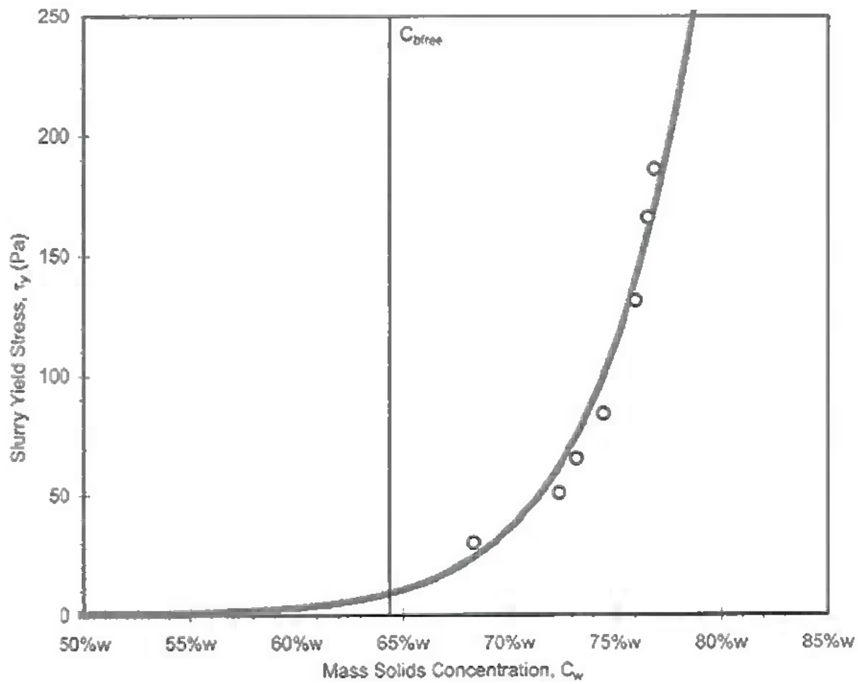


Figure 20: Yield Stress as a Function of Mass Solids Concentration: 5034 Ore

5. LIMITS OF CONVENTIONAL, HIGH DENSITY AND PASTE

The transition from a conventional reject slurry to a high density slurry is determined by the freely settled particle concentration. The transition from high density slurry to paste is based on the yield stress.

PCCE considers the following classifications for the Gahcho Kué ore dressing study:

- The limit for conventional rejects is considered to be less than 64.1%w for the Hearne ore and 64.4%w for the 5034 ore. This value corresponds to C_{bfree} determined for each ore type. The Bingham yield stress at this concentration is approximately 0.7 Pa for the Hearne ore and 8.9 Pa for the 5034 ore. For concentrations higher than this the slurry yield stress begins to increase significantly for a small increase in concentration.

- High density slurry can be considered for mass solids concentrations greater than C_{bfree} up to mass solids concentration at which the slurry yield stress equals 100 Pa. For a slurry yield stress of 100 Pa the mass solids concentration for the Hearne ore would be 76.1%w and 74.4%w for the 5034 ore.

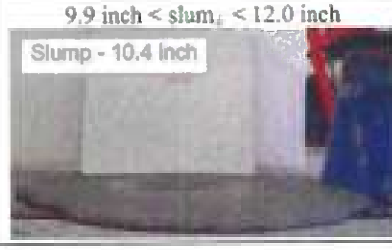
- PCCE considers slurries with a yield stress greater than 100 Pa to be a paste. This definition of paste behaviour has reasonably general acceptance.

Table VII summarizes the slurry classification for the Gahcho Kué ore rejects.

Figure 21 and Figure 22 shows the transition concentrations on the yield stress graph for the Hearne and 5034 ore.

Table VII: Gahcho Kué Ore Rejects Slurry Classification

Hearne Ore			
Parameter	**Conventional slurry**	**High density slurry**	**Paste**
Yield stress range	0 Pa < τ_y < 0.7 Pa	0.7 Pa < τ_y < 100 Pa	100 Pa < τ_y
Concentration range	0 < C_w < 64.1%w	64.1%w < C_w < 76.1%m	76.1% < C_w
Approximate Slump	No slump	10.0 inch < slump < 12.0 inch 	slump < 10.0 inch 

5034 Ore			
Parameter	**Conventional slurry**	**High density slurry**	**Paste**
Yield stress range	0 Pa < τ_y < 8.9 Pa	8.9 Pa < τ_y < 100 Pa	100 Pa < τ_y
Concentration range	0 < C_w < 64.4%w	64.4%w < C_w < 74.4%m	74.4% < C_w
Approximate Slump	No slump	9.9 inch < slump < 12.0 inch 	slump < 9.9 inch 

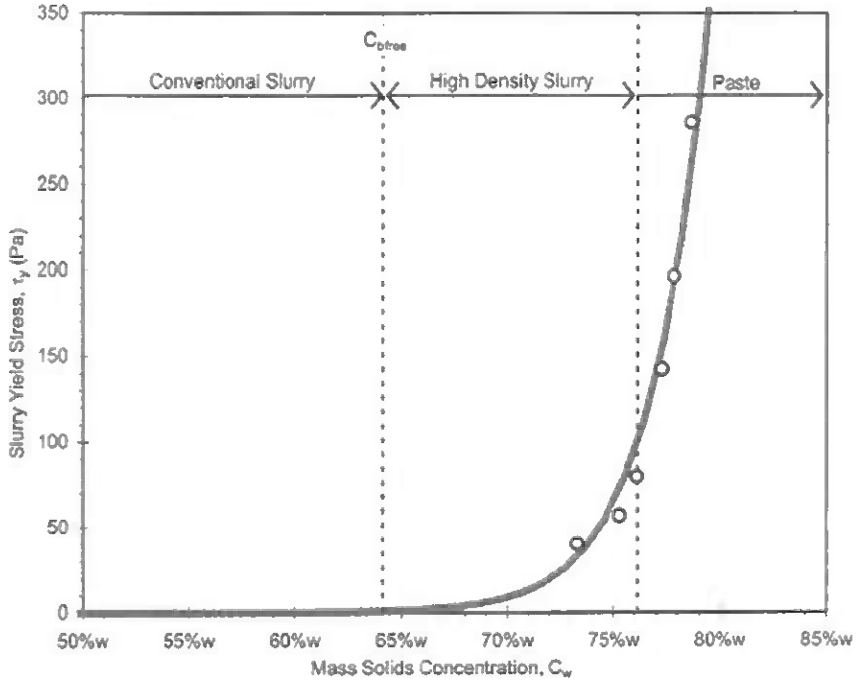


Figure 21: Slurry Classification for Hearne Ore

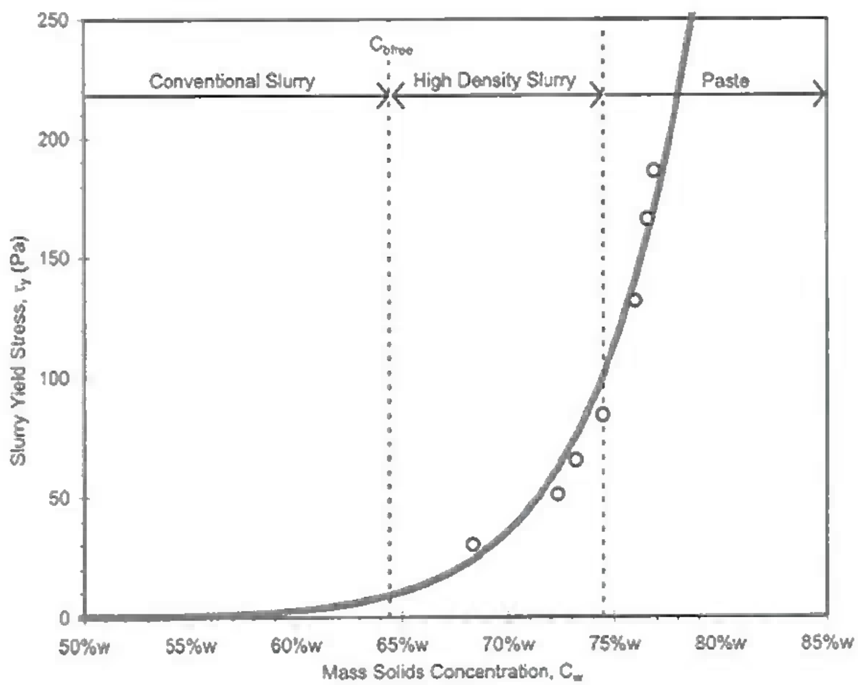


Figure 22: Slurry Classification for 5034 Ore

6. SUMMARY OF FINDINGS

- There is almost no difference between the particle size distribution of the Hearne and 5034 ore.
- For the same mass solids concentration the Hearne ore gives a higher slump value compared to the 5034 ore sample.
- The 5034 ore gives a higher wall shear stress value for the same shear rate compared to the Hearne ore for the same mass solids concentration.
- Both the Hearne and 5034 ore were analysed as Bingham plastic slurries.
- The Gahcho Kué ore rejects slurry classification is presented in Table VII.
- The colloidal analysis in Appendix E of the two ore types confirmed that the natural state of the Gacho Kué materials fall within a favourable colloidally unstable (settling) condition extending across the entire pH range. Good slurry flocculation and settling characteristics are expected.

Sent via e-mail

F van Sittert (PrTech Eng)
31 March 2005

H Myburgh

APPENDIX A

DEFINITION OF TERMS AND BASIC RELATIONS

1. BASIC TERMS

1.1 Vehicle, Load and Slurry

The vehicle is the conveying medium - i.e. water, sea water or fine particle slurries.

The load is the transported material.

The slurry is a mixture of solid particles and fluid ranging from suspensions of coarse, fast-moving particles, possibly with bed load, to suspensions of fine highly concentrated particles moving slowly. The solid and liquid phases do not react chemically with each other.

1.2 Suspended Load

This term is used to describe mixtures or parts of mixtures in which none of the solid load is carried along the bed. The particles are considered to be individually visible (at least microscopically).

1.3 Bed Load

The bed load is defined as that part of the solid load which either is in contact with the pipe invert or in contact with particles which are themselves in contact with the pipe invert. The bed load is supported by the pipe either directly or by granular contact. The bed load may be transported as a sliding bed, rolling particles, layers of rolling particles or a combination of sliding and rolling. The bed load may also be stationary or move sporadically.

1.4 Saltation

Saltation is a term used to describe the motion of particles which are carried in the fluid by a series of leaps and jumps. The particles are picked up by fluid turbulence and deposited further on downstream, on the bottom of the pipe or on the bed load layer and the process is continually repeated. At very low velocities the bed formation tends to be rippled and most saltation occurs from the crest of the ripples.

1.5 Homogeneous Mixture

A homogeneous mixture is a solid-liquid mixture which remains homogeneous when quiescent for a long period of time. Particle size will usually be less than 30 µm, although the size will depend on the relative density of the particles and the solids concentration.

1.6 Pseudo-Homogeneous Flow

Pseudo-homogeneous flow is defined as that flow regime which behaves as single-phase homogeneous flow at high mean mixture velocities, but becomes heterogeneous at lower mean mixture velocities. Pseudo-homogeneous flow can arise with virtually any slurry if the transport velocity is high enough to suspend particles reasonably uniformly by turbulence. The distribution of solid particles is uniform across the pipe section.

1.7 Heterogeneous Flow

In heterogeneous flow the concentration of solid particles across the pipe section is non-uniform and for particles of relative density greater than unity the concentration of solid particles increases towards the pipe invert.

1.8 Mixed Regime Flow

As a result of transporting a range of solid particle sizes simultaneously, more than one regime can exist at a time. For example, large particles may be carried with a heterogeneous concentration gradient in a homogeneous carrier consisting of fluid and fine particles.

1.9 Dense Phase Flow

Dense phase flow is defined to exist when the dominant mechanism supporting the particles in the mixture is interparticle contact. The mixture is essentially a settling mixture in which the solids concentration is close to or equal to the freely settled concentration across the whole of the pipe section.

1.10 Paste Flow

Paste mixtures contain a high percentage of fine particles which form a non-Newtonian vehicle. Typically the vehicle yield stress dominates the flow behaviour. Larger particles may be present but do not significantly contribute to the pipeline friction losses. Paste mixtures are generally operated in laminar flow due to the excessive amount of energy required to achieve turbulent flow.

1.11 Mean Mixture Velocity, V_m

The mean mixture velocity is the average flow rate, Q_m divided by the pipe cross-sectional area, A.

1.12 Stationary Deposit Velocity, V_{dep}

The stationary deposit velocity is the mean mixture velocity at and below which part of the bed load becomes stationary.

If the mean mixture velocity is below the stationary deposit velocity, solids will deposit on the bottom of the pipeline to form a bed over which solids will be transported at a velocity equal to the stationary deposit velocity. However, because the effective flow area is reduced, the pressure gradient increases and the throughput decreases.

1.13 Delivered Volumetric Concentration, C_{vd}

The delivered volumetric concentration is the ratio of the solids flow rate, Q_s to the mixture flow rate, Q_m, ie:

$$C_{vd} = \frac{Q_s}{Q_m}.$$

In this report C_{vd} is commonly denoted as C_v.

1.14 Delivered Weight Concentration, C_{wd}

The ratio of the solids mass flow rate, M_s to the mixture mass flow rate, M_m is the delivered mass (or weight) concentration:

$$C_{wd} = \frac{M_s}{M_m} = C_{vd}\frac{S_s}{S_m}.$$

1.15 Slurry Relative Density, S_m

The slurry relative density is the ratio of the mass of slurry to the mass of an equivalent volume of clear water:

$$S_m = S_w + C_v(S_s - S_w).$$

1.16 In-situ Concentration, C_{vt}

The volumetric concentration in the pipe is known as the in-situ, spatial or transport volumetric concentration and is defined as the ratio of volume of solids, ∇_s in the pipe to the volume of mixture, ∇_m being transported in the pipe:

$$C_{vt} = \frac{\nabla_s}{\nabla_m}.$$

1.17 Particle Shape Factor, S_f

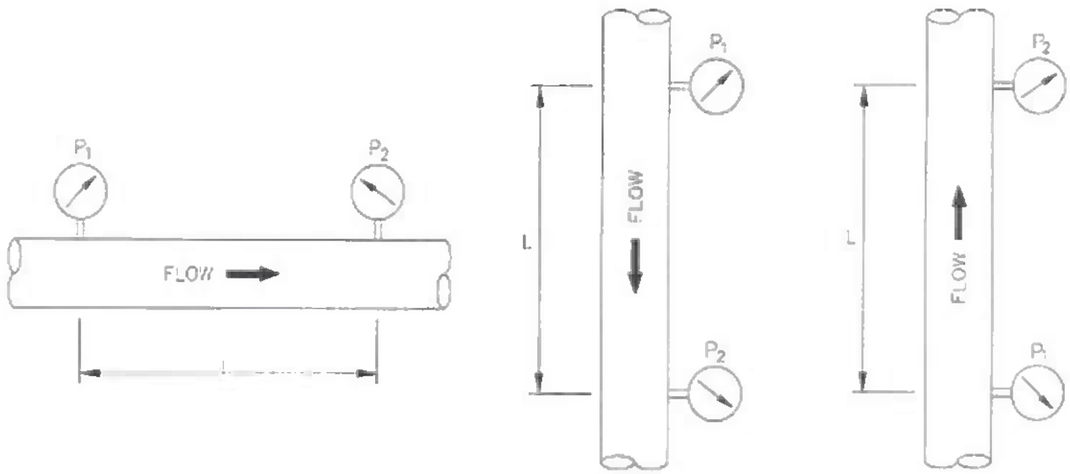
The particle shape factor is defined as the ratio of the settling velocity of a particle to the settling velocity of an equivalent diameter sphere (i.e. a sphere of the same density and mass as the particle) in water :

$$S_f = \frac{\textit{Particle settling velocity}}{\textit{Sphere settling velocity}}.$$

1.18 Pressure Gradient

The pipeline pressure gradient is defined as the change in pipeline pressure per unit length along the pipe axis in the direction of flow, i.e.

$$\frac{\Delta P}{\Delta L} = \frac{P_1 - P_2}{L}.$$



2. RHEOLOGY TERMS

2.1 Rheology

Rheology is the science dealing with flow and deformation of matter. Within the context of slurry pipeline systems, rheology is defined as the viscous characteristics of a fluid or homogenous solid-liquid mixture. There are two terms in this definition that are important:

- The term viscous indicates that laminar flow is being considered (where viscous forces dominate) as opposed to turbulent flow (where inertial forces dominate). Thus, it is important to note that rheology refers to laminar flow phenomenon only.
- The term homogenous indicates that the solid particles are uniformly distributed across the pipe section.

2.2 Rheogram

A plot of shear stress versus shear rate for laminar flow conditions is called a rheogram.

2.3 Pseudo-Shear Diagram

A pseudo-shear diagram is a plot of pipe wall shear stress versus the bulk or pseudo-shear rate for laminar flow conditions. The pseudo-shear rate is defined as:

$$\Gamma = \frac{8\,V_m}{D} \quad ,$$

where Γ = pseudo-shear rate (s^{-1})
D = internal pipe diameter (m).

In laminar flow provided that there is no slip, the data will be co-incident irrespective of tube diameter.

2.4 Newtonian Fluids and Mixtures

Isaac Newton, the originator of the science of rheology, postulated that the relationship between shear stress and shear rate in a fluid is linear, i.e.:

$$\tau = \mu\,\gamma \quad ,$$

where τ = shear stress (Pa)
γ = shear rate (s^{-1})
μ = constant of proportionality known as the dynamic coefficient of viscosity (Pa.s).

Any fluid or mixture that obeys this relationship in laminar flow is considered to be Newtonian and the viscosity is sufficient to characterise the flow. Rheograms for Newtonian fluids and mixtures pass through the origin and the slope of the line is the viscosity.

2.5 Non-Newtonian Fluids and Mixtures

A non-Newtonian fluid or mixture has one or more of the following characteristics:

- a non-linear rheogram
- the rheogram does not pass through the origin
- the rheogram varies with time (i.e. dependant on the shear history).

2.5.1 Time independent mixtures

There are a large number of models that may be used to characterise time independent non-Newtonian mixtures. The most suitable model for most mineral slurry applications is the generalised yield pseudoplastic or Herschel-Bulkley model:

$$\tau = \tau_y + K\,\gamma^n \quad ,$$

where τ_y = yield stress (Pa)
K = fluid consistency index ($Pa.s^n$)
n = flow behaviour index.

Rheological models that can be described by the generalised yield pseudo plastic model are summarised in the table below.

Model	Yield Stress	Flow Behaviour Index	Constitutive Equation
Newtonian	$\tau_y = 0$	$n = 1$	$\tau = \mu\gamma$
Bingham plastic	$\tau_y > 0$	$n = 1$	$\tau = \tau_y + K\gamma$
Pseudo plastic	$\tau_y = 0$	$n < 1$	$\tau = K\gamma^n$
Yield pseudo plastic	$\tau_y > 0$	$n < 1$	$\tau = \tau_y + K\gamma^n$
Dilatant	$\tau_y = 0$	$n > 1$	$\tau = K\gamma^n$
Yield dilatant	$\tau_y > 0$	$n > 1$	$\tau = \tau_y + K\gamma^n$

The Bingham model (n = 1) is widely used to characterise non-Newtonian mineral slurries. The Bingham model is a two parameter rheological model, i.e.:

$$\tau = \tau_y + K_B \gamma \ ,$$

where K_B = Bingham fluid consistency index (Pa.s).

The **apparent viscosity** is defined as the slope of a line drawn from the origin to a point on the rheogram corresponding to a specific shear rate. For a Bingham mixture, the apparent viscosity decreases with increasing shear rate.

Shear thinning refers to a decrease in the apparent viscosity with an increase in shear rate, while **shear thickening** refers to an increase in the apparent viscosity with an increase in shear rate.

2.5.2 *Time dependent mixtures*

A mixture that exhibits a reversible time-dependant decrease in apparent viscosity when sheared at a constant rate is said to be **thixotrophic**. The change in apparent viscosity is due to a structural breakdown of the mixture due to shearing. The structure is re-established if the mixture is left in a quiescent state. This is not common for mineral slurries.

Rheomalaxis is an irreversible decrease in apparent viscosity during shearing. Many flocculated mineral slurries exhibit rheomalaxis behaviour when initially sheared, but the usually apparent viscosity stabilises quickly and the slurries can be treated as time independent.

2.6 Rheological Characterisation of Tube Viscometer Data

The Herschel-Bulkley equation is used to describe the relationship between shear stress and shear rate for laminar flow. The shear stress in pipe flow is directly proportional to the distance from the centre of the pipe and the pressure gradient. The shear stress at the centre of the pipe is zero and reaches a maximum at the pipe wall. This linear relation of the shear stress with the radius of the pipe is valid regardless of the nature of the fluid.

For pipe flow the shear rate (i.e. velocity gradient) is a function of radial position, shear stress and fluid rheology so the Herschel-Bulkley model cannot be directly applied to pipeline flow.

To relate the slurry rheology to pipeline flow, the following assumptions are made:

(i) the flow is steady
(ii) the mixture is homogenous
(iii) there is no slip at the pipe wall
(iv) there is no velocity gradient at the centre of the pipe
(v) the tube is sufficiently long that end effects are negligible.

Using these assumptions, the following equation relating flow rate to shear stress at the pipe wall is developed:

$$\frac{8V_m}{D} = \frac{4n}{\tau_o^3}\left(\frac{1}{K}\right)^{\frac{1}{n}}\left(\tau_o - \tau_y\right)^{\frac{n+1}{n}}\left[\frac{\left(\tau_o - \tau_y\right)^2}{3n+1} + 2\tau_y\frac{\left(\tau_o - \tau_y\right)}{2n+1} + \frac{\tau_y^2}{n+1}\right] ,$$

where τ_o = shear stress at the pipe wall (Pa).

This equation is fitted to the measured pseudo-shear data to determine the rheological parameters (τ_y, K and n).

APPENDIX B – RELATIONSHIP BETWEEN ρ_m, C_v and C_w

Test Name	Solids Density	Page Number
5034 Ore	2.65 t/m^3	B.2
Hearne Ore	2.63 t/m^3	B.3

Material Type:	5034 Ore	
Solids Density:	2.65 t/m^3	
Water Density:	1.00 t/m^3	
Slurry Density	Volumetric solids concentration, C_v	Mass solids concentration, C_w
1.000 t/m^3	0.0%	0.0%
1.025 t/m^3	1.5%	3.9%
1.050 t/m^3	3.0%	7.6%
1.075 t/m^3	4.5%	11.2%
1.100 t/m^3	6.1%	14.6%
1.125 t/m^3	7.6%	17.8%
1.150 t/m^3	9.1%	20.9%
1.175 t/m^3	10.6%	23.9%
1.200 t/m^3	12.1%	26.8%
1.225 t/m^3	13.6%	29.5%
1.250 t/m^3	15.2%	32.1%
1.275 t/m^3	16.7%	34.6%
1.300 t/m^3	18.2%	37.1%
1.325 t/m^3	19.7%	39.4%
1.350 t/m^3	21.2%	41.6%
1.375 t/m^3	22.7%	43.8%
1.400 t/m^3	24.2%	45.9%
1.425 t/m^3	25.8%	47.9%
1.450 t/m^3	27.3%	49.8%
1.475 t/m^3	28.8%	51.7%
1.500 t/m^3	30.3%	53.5%
1.525 t/m^3	31.8%	55.3%
1.550 t/m^3	33.3%	57.0%
1.575 t/m^3	34.8%	58.6%
1.600 t/m^3	36.4%	60.2%
1.625 t/m^3	37.9%	61.8%
1.650 t/m^3	39.4%	63.3%
1.675 t/m^3	40.9%	64.7%
1.700 t/m^3	42.4%	66.1%
1.725 t/m^3	43.9%	67.5%
1.750 t/m^3	45.5%	68.8%
1.775 t/m^3	47.0%	70.1%
1.800 t/m^3	48.5%	71.4%
1.825 t/m^3	50.0%	72.6%
1.850 t/m^3	51.5%	73.8%
1.875 t/m^3	53.0%	74.9%
1.900 t/m^3	54.5%	76.1%
1.925 t/m^3	56.1%	77.2%
1.950 t/m^3	57.6%	78.2%
1.975 t/m^3	59.1%	79.3%
2.000 t/m^3	60.6%	80.3%

Material Type:	Hearne Ore	
Solids Density:	2.63 t/m³	
Water Density:	1.00 t/m³	
Slurry Density	Volumetric solids concentration, C_v	Mass solids concentration, C_w
1.000 t/m³	0.0%	0.0%
1.025 t/m³	1.5%	3.9%
1.050 t/m³	3.1%	7.7%
1.075 t/m³	4.6%	11.3%
1.100 t/m³	6.1%	14.7%
1.125 t/m³	7.7%	17.9%
1.150 t/m³	9.2%	21.0%
1.175 t/m³	10.7%	24.0%
1.200 t/m³	12.3%	26.9%
1.225 t/m³	13.8%	29.6%
1.250 t/m³	15.3%	32.3%
1.275 t/m³	16.9%	34.8%
1.300 t/m³	18.4%	37.2%
1.325 t/m³	19.9%	39.6%
1.350 t/m³	21.5%	41.8%
1.375 t/m³	23.0%	44.0%
1.400 t/m³	24.5%	46.1%
1.425 t/m³	26.1%	48.1%
1.450 t/m³	27.6%	50.1%
1.475 t/m³	29.1%	52.0%
1.500 t/m³	30.7%	53.8%
1.525 t/m³	32.2%	55.5%
1.550 t/m³	33.7%	57.3%
1.575 t/m³	35.3%	58.9%
1.600 t/m³	36.8%	60.5%
1.625 t/m³	38.3%	62.1%
1.650 t/m³	39.9%	63.6%
1.675 t/m³	41.4%	65.0%
1.700 t/m³	42.9%	66.4%
1.725 t/m³	44.5%	67.8%
1.750 t/m³	46.0%	69.1%
1.775 t/m³	47.5%	70.4%
1.800 t/m³	49.1%	71.7%
1.825 t/m³	50.6%	72.9%
1.850 t/m³	52.1%	74.1%
1.875 t/m³	53.7%	75.3%
1.900 t/m³	55.2%	76.4%
1.925 t/m³	56.7%	77.5%
1.950 t/m³	58.3%	78.6%
1.975 t/m³	59.8%	79.7%
2.000 t/m³	61.3%	80.7%

APPENDIX C – PARTICLE SIZE DISTRIBUTION RESULTS

NINHAM SHAND
GEOTECHNICAL LABORATORY
BRADFORD CLOSE AIRPORT INDUSTIA
TEL (021) 934 2052 FAX (021) 934 8161

TEST REPORT FOR PARTICLE SIZE ANALYSIS AND ATTERBERG LIMITS OF SOILS

TEST REFERENCE : ASTM D 422 - 63 (1990)
TEST REFERENCE : ASTM D854-58
TEST REFERENCE : TMH1 A2-A4 (1986)

Test Instruction No.:	NS CT 05 - 000348	Certification Date :	2005/02/16
Project No.:	09200/5/XY/R25	Date of Sampling :	NA
Client Name:	PATTERSON & COOKE	Date Sample received:	2005/02/09
Project Name :	DGK-571	Date Test Commenced:	2005/02/14
Order Number :	2430	Date test Completed:	2005/02/15
Sample reference No :		Tested By:	J Thapelo
Sample No.:	5034 ORE		
Depth:	NA		
Visual Description :	Kimberlite ore		

I. Sieve Analysis

Sieve Size (mm)	Percentage Passing
75.0	100
37.5	100
26.5	100
19	100
13.2	100
9.5	100
6.7	100
4.75	100
2.36	100
1.18	97
0.600	59
0.300	39
0.150	26
0.075	18

II. Hydrometer Analysis

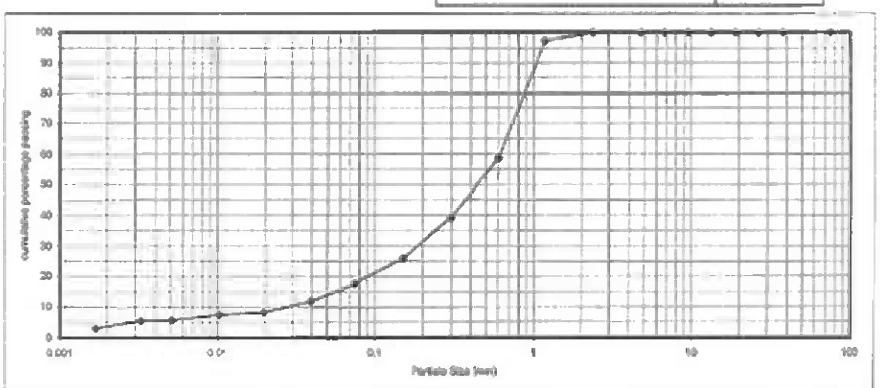
Diameter of particle (mm)	Percentage of soil suspension (%)
0.0392	12
0.0198	8
0.0103	7
0.0052	5
0.0033	5
0.0017	3

III. Atterberg Limits

Liquid Limit	
Plastic Index	NA
Linear Shrinkage	

IV. Specific Gravity	2.712

Tabulated Summary	Percentage
Gravel : Percentage retained on4.75 mm	0
Sand : Percentage passing 4.75mm and retained 0.075mm	82
Silt : Percentage passing0.075mm and retained 0.002mm	14
Clay : Percentage passing 0.002mm	4



Remarks
1. Testing in compliance with ASTM D 422-63(1990)
2. Test results relate only to sample tested

Authorized Signatory

NINHAM SHAND
GEOTECHNICAL LABORATORY
BRADFORD CLOSE AIRPORT INDUSTIA
TEL (021) 934 2052 FAX (021) 934 8161

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Order Number :	2430	Date test Completed:	2005/02/15
Sample reference No.:		Tested By:	J Thapelo
Sample No :	5034 ORE / 001		
Depth:	NA		
Visual Description :	Kimberlite ore		

I. Sieve Analysis

Sieve Size (mm)	Percentage Passing
75.0	100
37.5	100
26.5	100
19	100
13.2	100
9.5	100
6.7	100
4.75	100
2.36	100
1.18	96
0.600	67
0.300	44
0.150	28
0.075	18

II. Hydrometer Analysis

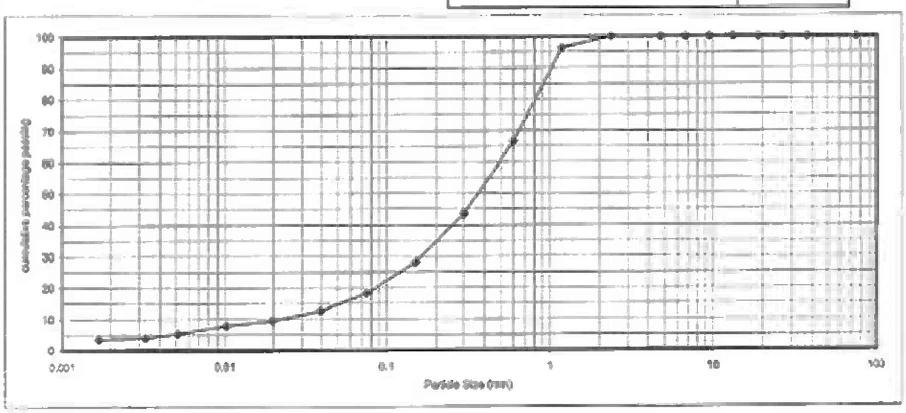
Diameter of particle (mm)	Percentage of soil suspension (%)
0.0392	13
0.0197	10
0.0102	8
0.0052	5
0.0033	4
0.0017	4

III. Atterberg Limits

Liquid Limit	
Plastic Index	NA
Linear Shrinkage	

IV. Specific Gravity	2.62

Tabulated Summary	Percentage
Gravel : Percentage retained on4.75 mm	0
Sand : Percentage passing 4.75mm and retained 0.075mm	82
Silt : Percentage passing0.075mm and retained 0.002mm	14
Clay : Percentage passing 0.002mm	4



Remarks
1. Testing in compliance with ASTM D 422-63(1990)
2. Test results relate only to sample tested.

Authorized Signatory

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Order Number :	2430	Date test Completed:	2005/02/15
Sample reference No.:		Tested By:	J Thapelo
Sample No.:	5034 ORE / 004		
Depth:	NA		
Visual Description :	Kimberlite ore		

I. Sieve Analysis

Sieve Size (mm)	Percentage Passing
75.0	100
37.5	100
26.5	100
19	100
13.2	100
9.5	100
6.7	100
4.75	100
2.36	100
1.18	97
0.600	72
0.300	49
0.150	33
0.075	22

II. Hydrometer Analysis

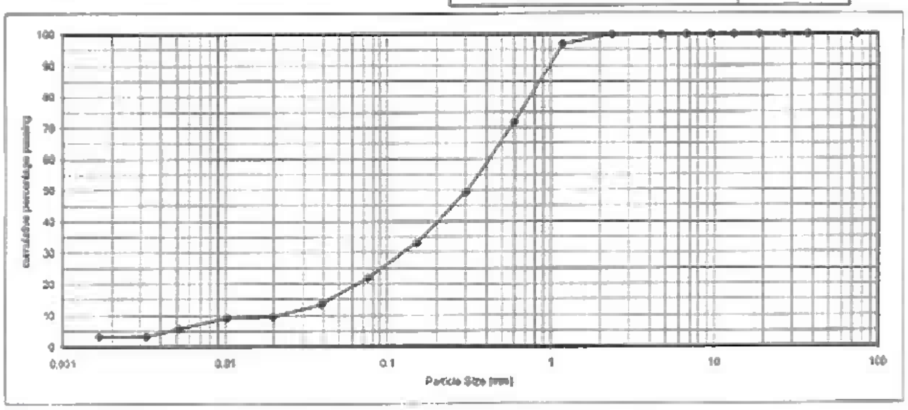
Diameter of particle (mm)	Percentage of soil suspension (%)
0.0391	14
0.0197	10
0.0102	9
0.0051	6
0.0033	3
0.0017	3

III. Atterberg Limits

Liquid Limit	
Plastic Index	NA
Linear Shrinkage	

IV. Specific Gravity	2.609

Tabulated Summary	Percentage
Gravel : Percentage retained on4.75 mm	0
Sand : Percentage passing 4.75mm and retained 0.075mm	78
Silt : Percentage passing0.075mm and retained 0.002mm	19
Clay : Percentage passing 0.002mm	3



Remarks
1. Testing in compliance with ASTM D 422-63(1990)
2. Test results relate only to sample tested.

Authorized Signatory

NINHAM SHAND
GEOTECHNICAL LABORATORY
BRADFORD CLOSE AIRPORT INDUSTIA
TEL (021) 934 2052 FAX (021) 934 8161

TEST REPORT FOR PARTICLE SIZE ANALYSIS AND ATTERBERG LIMITS OF SOILS

TEST REFERENCE : ASTM D 422 - 63 (1990) **TEST REFERENCE : ASTM D854-58**

TEST REFERENCE : TMH1 A2-A4 (1986)

Test Instruction No.:	NS CT 05 - 000348	Certification Date :	2005/02/16
Project No.:	09200/5/XY/R25	Date of Sampling :	NA
Client Name	PATTERSON & COOKE	Date Sample received:	2005/02/09
Project Name	DGK-571	Date Test Commenced:	2005/02/14
Order Number :	2430	Date test Completed:	2005/02/15
Sample reference No.:		Tested By:	J Thapelo
Sample No.:	5034 ORE / 007		
Depth:	NA		
Visual Description :	Kimberlite ORE		

I. Sieve Analysis

Sieve Size (mm)	Percentage Passing
75.0	100
37.5	100
26.5	100
19	100
13.2	100
9.5	100
6.7	100
4.75	100
2.36	100
1.18	95
0.600	65
0.300	42
0.150	27
0.075	18

II. Hydrometer Analysis

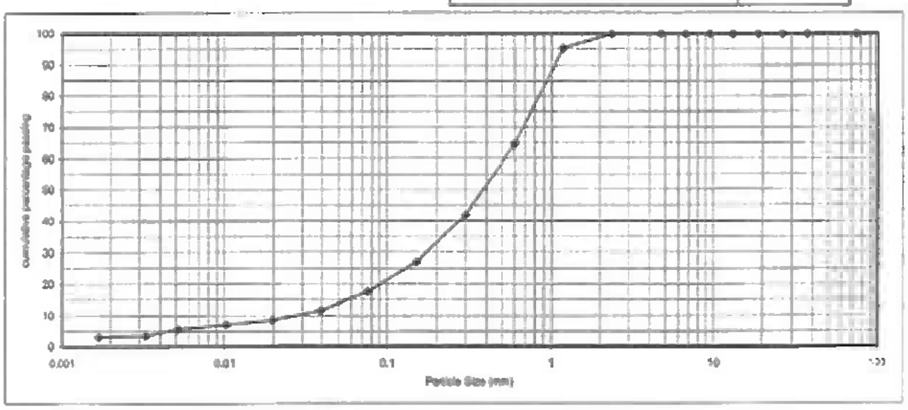
Diameter of particle (mm)	Percentage of soil suspension (%)
0.0393	12
0.0198	9
0.0103	7
0.0052	6
0.0033	4
0.0017	3

III. Atterberg Limits

Liquid Limit	
Plastic Index	NA
Linear Shrinkage	

IV. Specific Gravity	2.643

Tabulated Summary	Percentage
Gravel : Percentage retained on4.75 mm	0
Sand : Percentage passing 4.75mm and retained 0.075mm	83
Silt : Percentage passing0.075mm and retained 0.002mm	14
Clay : Percentage passing 0.002mm	4



Remarks
1. Testing in compliance with ASTM D 422-63(1990)
2. Test results relate only to sample tested.

Authorized Signatory

NINHAM SHAND
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BRADFORD CLOSE AIRPORT INDUSTIA
TEL (021) 934 2052 FAX (021) 934 8161

TEST REPORT FOR PARTICLE SIZE ANALYSIS AND ATTERBERG LIMITS OF SOILS

TEST REFERENCE : ASTM D 422 - 63 (1990) **TEST REFERENCE : ASTM D854-58**
TEST REFERENCE : TMH1 A2-A4 (1986)

Test Instruction No.:	NS CT 05 - 000348	Certification Date :	2005/02/16
Project No.:	09200/5/XY/R25	Date of Sampling :	NA
Client Name:	PATTERSON & COOKE	Date Sample received:	2005/02/09
Project Name :	DGK-571	Date Test Commenced:	2005/02/14
Order Number :	2430	Date test Completed:	2005/02/16
Sample reference No.:		Tested By:	J Thapelo
Sample No.:	Hearne ORE		
Depth:	NA		
Visual Description :	Kimberlite ore		

I. Sieve Analysis

Sieve Size (mm)	Percentage Passing
75.0	100
37.5	100
26.5	100
19	100
13.2	100
9.5	100
6.7	100
4.75	100
2.36	100
1.18	99
0.600	64
0.300	43
0.150	29
0.075	18

II. Hydrometer Analysis

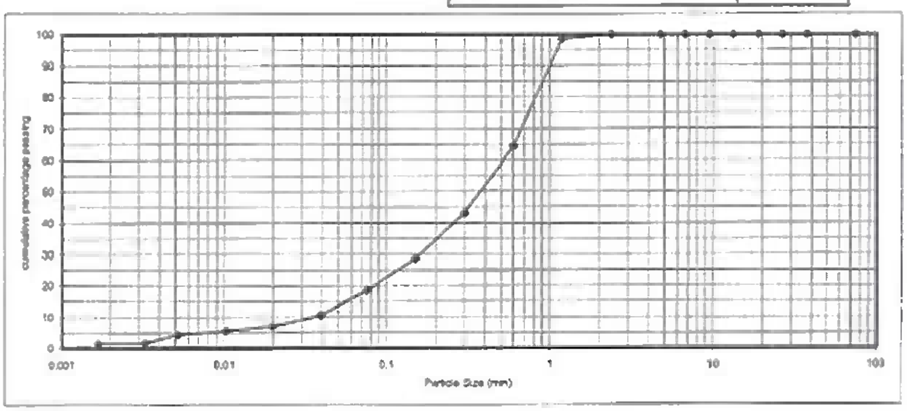
Diameter of particle (mm)	Percentage of soil suspension (%)
0.0394	11
0.0199	7
0.0103	6
0.0052	4
0.0033	2
0.0017	1

III. Atterberg Limits

Liquid Limit	
Plastic Index	NA
Linear Shrinkage	

IV. Specific Gravity	2.818

Tabulated Summary	Percentage
Gravel : Percentage retained on4.75 mm	0
Sand : Percentage passing 4.75mm and retained 0.075mm	82
Silt : Percentage passing0.075mm and retained 0.002mm	17
Clay : Percentage passing 0.002mm	1



Remarks
1. Testing in compliance with ASTM D 422-63(1990) and TMH 1 A2-A4(1986)
2. Test results relate only to sample tested.

Authorized Signatory

NINHAM SHAND
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TEST REPORT FOR PARTICLE SIZE ANALYSIS AND ATTERBERG LIMITS OF SOILS

TEST REFERENCE : ASTM D 422 - 63 (1990) **TEST REFERENCE : ASTM D854-58**

TEST REFERENCE : TMH1 A2-A4 (1986)

Test Instruction No.:	NS CT 05 - 000348	Certification Date :	2005/02/16
Project No.:	09200/5/XY/R25	Date of Sampling :	NA
Client Name:	PATTERSON & COOKE	Date Sample received:	2005/02/09
Project Name :	DGK-571	Date Test Commenced:	2005/02/14
Order Number :	2430	Date test Completed:	2005/02/15
Sample reference No.:		Tested By:	J Thapelo
Sample No.:	Hearne ORE - 002		
Depth:	NA		
Visual Description :	Kimberlite ore		

I. Sieve Analysis

Sieve Size (mm)	Percentage Passing
75.0	100
37.5	100
26.5	100
19	100
13.2	100
9.5	100
6.7	100
4.75	100
2.36	100
1.18	96
0.600	67
0.300	46
0.150	30
0.075	20

II. Hydrometer Analysis

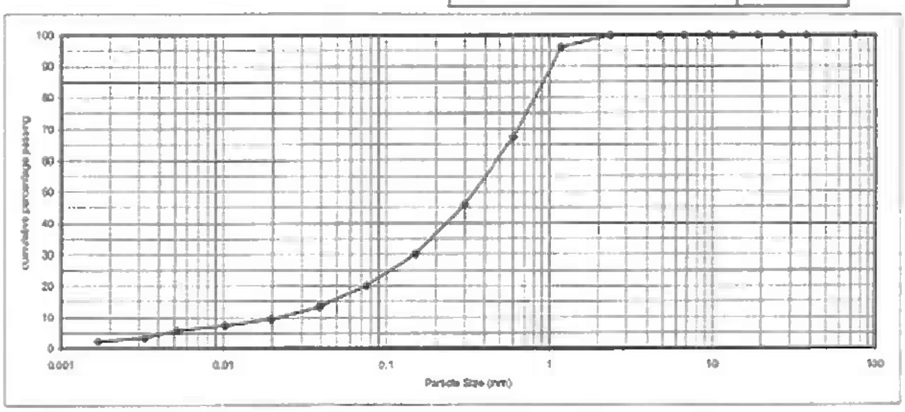
Diameter of particle (mm)	Percentage of soil suspension (%)
0.0391	13
0.0197	10
0.0103	7
0.0051	6
0.0033	4
0.0017	2

III. Atterberg Limits

Liquid Limit	
Plastic Index	NA
Linear Shrinkage	

IV. Specific Gravity	2.618

Tabulated Summary	Percentage
Gravel : Percentage retained on4.75 mm	0
Sand : Percentage passing 4.75mm and retained 0.075mm	80
Silt : Percentage passing0.075mm and retained 0.002mm	17
Clay : Percentage passing 0.002mm	3



Remarks
1. Testing in compliance with ASTM D 422-63(1990) and TMH 1 A2-A4(1986)
2. Test results relate only to sample tested.

Authorized Signatory

NINHAM SHAND
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BRADFORD CLOSE AIRPORT INDUSTIA
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TEST REPORT FOR PARTICLE SIZE ANALYSIS AND ATTERBERG LIMITS OF SOILS

TEST REFERENCE : ASTM D 422 - 63 (1990) **TEST REFERENCE : ASTM D854-58**

TEST REFERENCE : TMH1 A2-A4 (1986)

Test Instruction No.:	NS CT 05 - 000348	Certification Date :	2005/02/16
Project No.:	09200/5/XY/R25	Date of Sampling :	NA
Client Name:	PATTERSON & COOKE	Date Sample received:	2005/02/09
Project Name :	DGK-571	Date Test Commenced:	2005/02/14
Order Number :	2430	Date test Completed:	2005/02/15
Sample reference No.:		Tested By:	J Thapelo
Sample No.:	Hearne ORE - 004		
Depth:	NA		
Visual Description :	Kimberlite ore		

I. Sieve Analysis

Sieve Size (mm)	Percentage Passing
75.0	100
37.5	100
26.5	100
19	100
13.2	100
9.5	100
6.7	100
4.75	100
2.36	100
1.18	94
0.600	60
0.300	38
0.150	24
0.075	16

II. Hydrometer Analysis

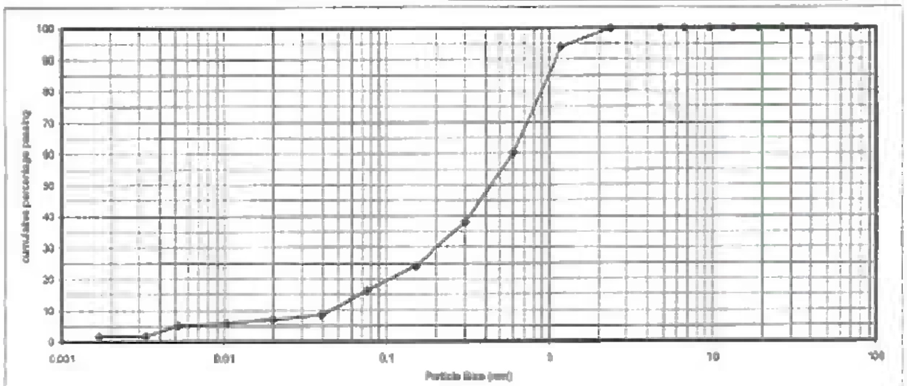
Diameter of particle (mm)	Percentage of soil suspension (%)
0.0398	9
0.0199	7
0.0103	6
0.0052	5
0.0033	2
0.0017	2

III. Atterberg Limits

Liquid Limit	
Plastic Index	NA
Linear Shrinkage	

IV. Specific Gravity	2.653

Tabulated Summary	Percentage
Gravel : Percentage retained on4.75 mm	0
Sand : Percentage passing 4.75mm and retained 0.075mm	84
Silt : Percentage passing0.075mm and retained 0.002mm	14
Clay : Percentage passing 0.002mm	2



Remarks
1. Testing in compliance with ASTM D 422-63(1990)
2. Test results relate only to sample tested.

Authorized Signatory

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BRADFORD CLOSE AIRPORT INDUSTIA
TEL (021) 934 2052 FAX (021) 934 8151

TEST REPORT FOR PARTICLE SIZE ANALYSIS AND ATTERBERG LIMITS OF SOILS

TEST REFERENCE : ASTM D 422 - 63 (1990)
TEST REFERENCE : ASTM D854-58
TEST REFERENCE : TMH1 A2-A4 (1986)

Test Instruction No.:	NS CT 05 - 000348	Certification Date	2005/02/16
Project No.:	09200/S/XY/R25	Date of Sampling	NA
Client Name:	PATTERSON & COOKE	Date Sample received	2005/02/09
Project Name:	DGK-571	Date Test Commenced	2005/02/14
Order Number:	2430	Date test Completed	2005/02/15
Sample reference No.:		Tested By	J Thapelo
Sample No.:	Hearne ORE - 006		
Depth:	NA		
Visual Description:	Kimberlite ore		

I. Sieve Analysis

Sieve Size (mm)	Percentage Passing
75.0	100
37.5	100
26.5	100
19	100
13.2	100
9.5	100
6.7	100
4.75	100
2.36	100
1.18	96
0.600	66
0.300	43
0.150	28
0.075	19

II. Hydrometer Analysis

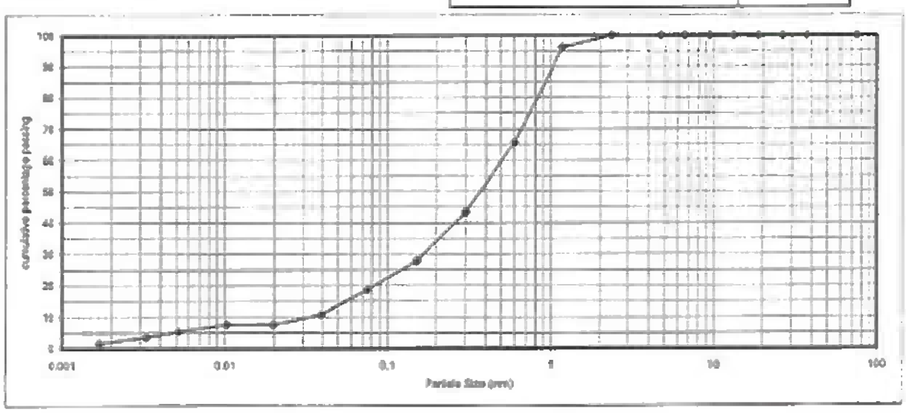
Diameter of particle (mm)	Percentage of soil suspension (%)
0.0393	11
0.0198	8
0.0102	8
0.0052	5
0.0033	4
0.0017	2

III. Atterberg Limits

Liquid Limit	
Plastic Index	NA
Linear Shrinkage	

IV. Specific Gravity	2.643

Tabulated Summary	Percentage
Gravel : Percentage retained on4.75 mm	0
Sand : Percentage passing 4.75mm and retained 0.075mm	81
Silt : Percentage passing0.075mm and retained 0.002mm	16
Clay : Percentage passing 0.002mm	3



Remarks
1. Testing in compliance with ASTM D 422-63(1990)
2. Test results relate only to sample tested.

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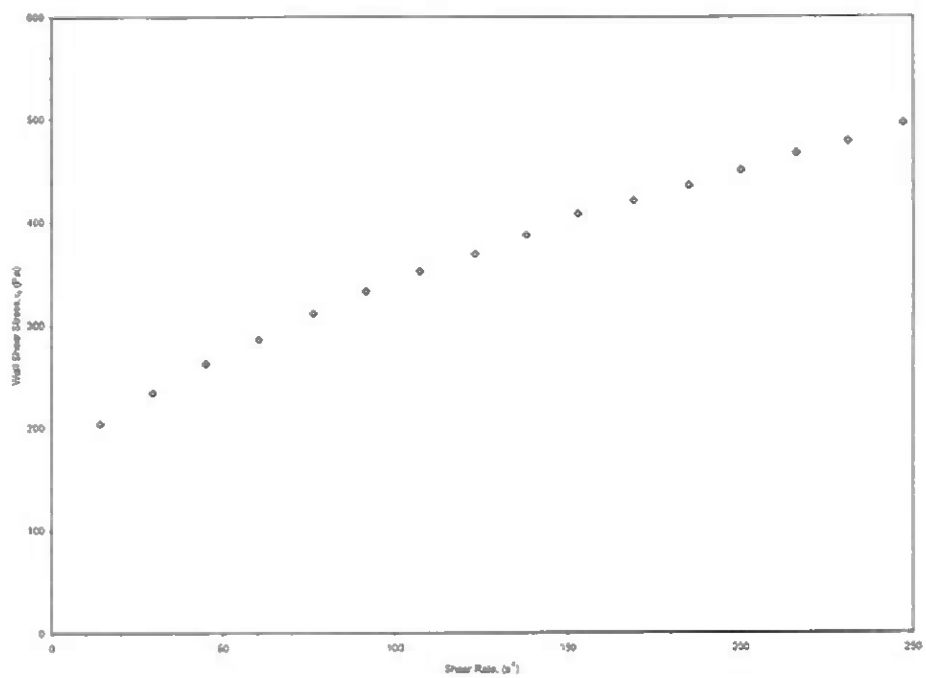
APPENDIX D – RHEOMETER TEST DATA

Test Number	Material Type	Mass Solids Concentration	Page Number
001	5034 Ore	76.9 %w	D.2
002		76.5 %w	D.3
003		76.0 %w	D.4
004		74.4 %w	D.5
005		73.2 %w	D.6
006		72.3 %w	D.7
007		68.3 %w	D.8

Test Number	Material Type	Mass Solids Concentration	Page Number
001	Hearne Ore	78.3 %w	D.9
002		77.8 %w	D.10
003		77.2 %w	D.11
004		76.1 %w	D.12
005		75.3 %w	D.13
006		73.3 %w	D.14

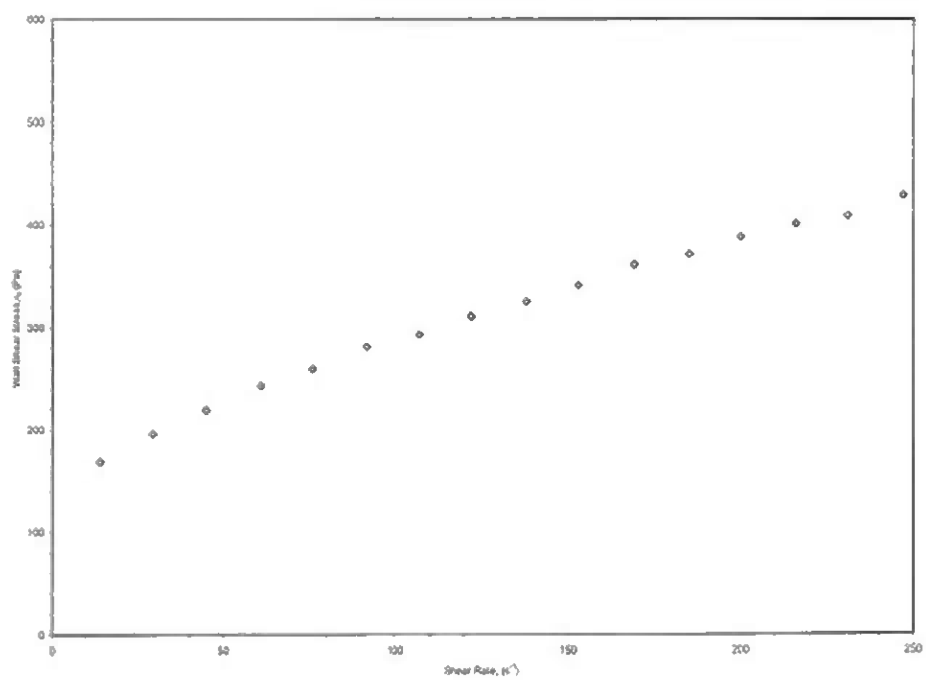
Data Series Information	
Name:	5034-001 1
Sample:	1
Operator:	HM
Remarks:	
Number of Intervals	4
Application:	US200/32 V2.30 21001513-33024
Device:	MC1+ SN679534
Measurement Date:	2005/02/04
Measurement Time:	11:05 AM
Measuring Systems:	Z2/3-DIN
Calculating Constants	
- Csr:	0.28386508
- Css:	21.5
- Start Delay Time [s]:	0.496
- Measurement Type:	2
Interval:	1
Number of Data Points	0
Time Setting:	2 Meas. Pts., Reject Meas. Pt. Duration 3 s
Measuring Profile: Shear Rate	d(gamma)/dt = 0 ... 5 1/s Lin, Continuous Ramp
Interval:	4
Number of Data Points	20
Time Setting:	20 Meas. Pts. Meas. Pt. Duration 4 s
Measuring Profile: Shear Rate	d(gamma)/dt = 300 ... 5 1/s Lin, Continuous Ramp

Meas. Pts.	Shear Rate	Shear Stress	Viscosity	Mass Solids Concentration	Temperature
	[1/s]	[Pa]	[mPa·s]	[%w]	[°C]
1	247	496	2,010	76.9	25.5
2	231	479	2,070	76.9	25.5
3	216	467	2,170	76.9	25.5
4	200	450	2,250	76.9	25.5
5	185	436	2,360	76.9	25.5
6	169	421	2,490	76.9	25.5
7	153	408	2,660	76.9	25.5
8	138	388	2,810	76.9	25.5
9	123	369	3,010	76.9	25.5
10	107	352	3,290	76.9	25.5
11	91.4	333	3,640	76.9	25.5
12	76.1	311	4,080	76.9	25.5
13	60.4	286	4,740	76.9	25.5
14	45	262	5,830	76.9	25.5
15	29.4	234	7,950	76.9	25.5
16	14	204	14,600	76.9	25.5



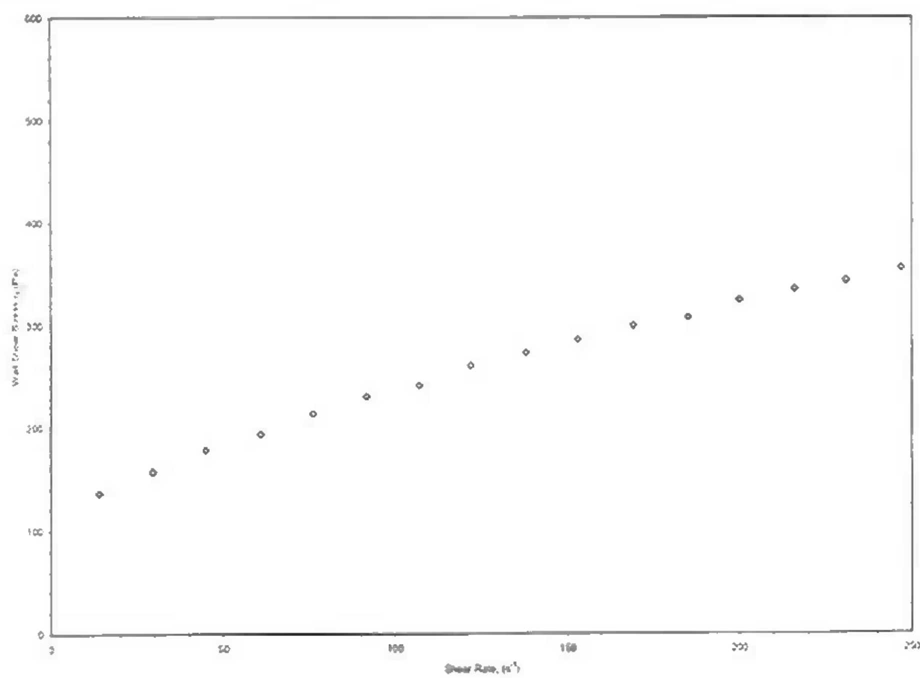
Data Series Information	
Name	5034-002 1
Sample:	1
Operator:	HM
Remarks:	
Number of Intervals:	4
Application:	US200/32 V2.30 21001513-33024
Device:	MC1+ SN679534
Measurement Date:	2005/02/04
Measurement Time:	12:39 PM
Measuring Systems:	Z 2/3-DIN
Calculating Constants:	
- Csr:	0.28396508
- Css:	21.5
- Start Delay Time [s]:	2.354
- Measurement Type:	2
Interval:	4
Number of Data Points:	20
Time Setting	20 Meas. Pts.
	Meas. Pt. Duration 4 s
Measuring Profile:	
Shear Rate	d(gamma)/dt = 300 ... 5 1/s Lin. Continuous Ramp

Meas. Pts.	Shear Rate	Shear Stress	Viscosity	Mass Solids Concentration	Temperature
	[1/s]	[Pa]	[mPa·s]	[%w]	[°C]
1	247	428	1,740	76.6	25.5
2	231	408	1,760	76.6	25.5
3	216	401	1,860	76.6	25.5
4	200	388	1,940	76.6	25.5
5	185	371	2,010	76.6	25.5
6	169	361	2,130	76.6	25.5
7	153	341	2,230	76.6	25.5
8	138	325	2,360	76.6	25.5
9	122	311	2,540	76.6	25.5
10	107	293	2,730	76.6	25.6
11	91.6	281	3,070	76.6	25.6
12	75.8	260	3,430	76.6	25.6
13	60.8	243	4,000	76.6	25.6
14	44.9	219	4,890	76.6	25.6
15	29.4	196	6,650	76.6	25.6
16	14	169	12,100	76.6	25.6



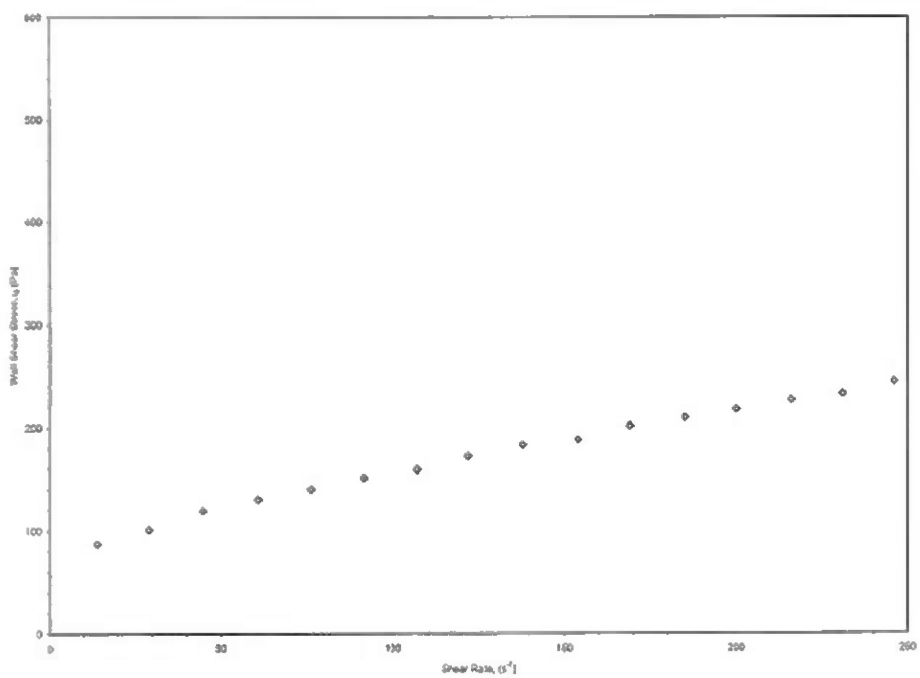
Data Series Information	
Name:	5034-003 1
Sample:	3
Operator:	HM
Remarks:	
Number of Intervals:	4
Application:	US200/32 V2.30 21001513-33024
Device:	MC1+ SN679534
Measurement Date:	2005/02/04
Measurement Time:	01:50 PM
Measuring Systems:	Z 2/3-DIN
Calculating Constants:	
- Csr:	0.28396508
- Css:	21.5
- Start Delay Time [s]:	0.455
- Measurement Type:	2
Interval:	4
Number of Data Points:	20
Time Setting:	20 Meas. Pts. Meas. Pt. Duration 4 s
Measuring Profile:	
Shear Rate	d(gamma)/dt = 300 ... 5 1/s Lin, Continuous Ramp

Meas. Pts.	Shear Rate	Shear Stress	Viscosity	Mass Solids Concentration	Temperature
	[1/s]	[Pa]	[mPa·s]	[%w]	[°C]
1	247	356	1,440	76.0	25.9
2	231	343	1,480	76.0	25.9
3	216	335	1,550	76.0	25.9
4	200	324	1,620	76.0	25.9
5	185	307	1,660	76.0	25.9
6	169	299	1,760	76.0	25.9
7	153	286	1,870	76.0	25.9
8	138	273	1,980	76.0	25.9
9	122	260	2,130	76.0	25.9
10	107	241	2,250	76.0	25.9
11	91.6	230	2,510	76.0	25.9
12	76	213	2,800	76.0	25.9
13	60.7	194	3,200	76.0	25.9
14	44.9	178	3,970	76.0	25.9
15	29.5	157	5,320	76.0	25.9
16	14	136	9,740	76.0	25.9



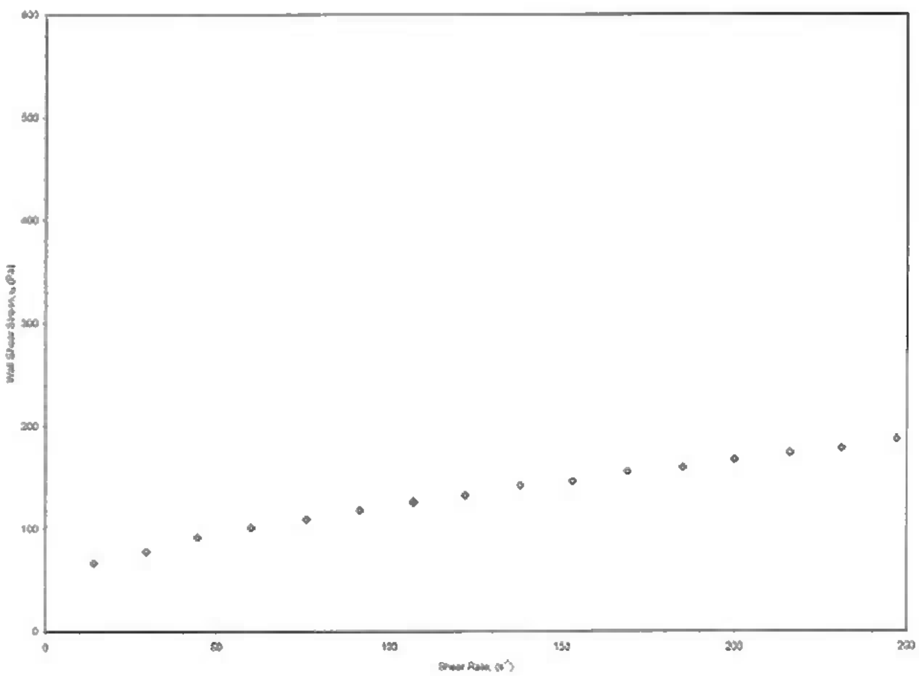
Data Series Information	
Name:	5034-004 1
Sample:	4
Operator:	HM
Remarks:	
Number of Intervals:	4
Application:	US200/32 V2.30 21001513-33024
Device:	MC1+ SN678534
Measurement Date:	2005/02/04
Measurement Time:	03:09 PM
Measuring Systems:	Z 2/3-DIN
Calculating Constants:	
- Csr:	0.28396508
- Css:	21.5
- Start Delay Time (s):	1.733
- Measurement Type:	2
Interval:	4
Number of Data Points:	20
Time Setting:	20 Meas. Pts.
	Meas. Pt. Duration 4 s
Measuring Profile:	
Shear Rate	d(gamma)/dt = 300 ... 5 1/s Lin, Continuous Ramp

Meas. Pts.	Shear Rate	Shear Stress	Viscosity	Mass Solids Concentration	Temperature
	[1/s]	[Pa]	[mPa·s]	[%w]	[°C]
1	246	244	960	74.5	25.8
2	231	232	1,000	74.5	25.8
3	216	226	1,050	74.5	25.8
4	200	217	1,090	74.5	25.8
5	185	209	1,130	74.5	25.8
6	169	201	1,190	74.5	25.8
7	154	188	1,220	74.5	25.8
8	138	183	1,320	74.5	25.8
9	122	172	1,410	74.5	25.8
10	107	159	1,490	74.5	25.8
11	91.5	151	1,650	74.5	25.8
12	76.1	140	1,840	74.5	25.8
13	60.6	130	2,140	74.5	25.8
14	44.8	119	2,650	74.5	25.8
15	29.1	101	3,460	74.5	25.8
16	14	87.3	6,250	74.5	25.8



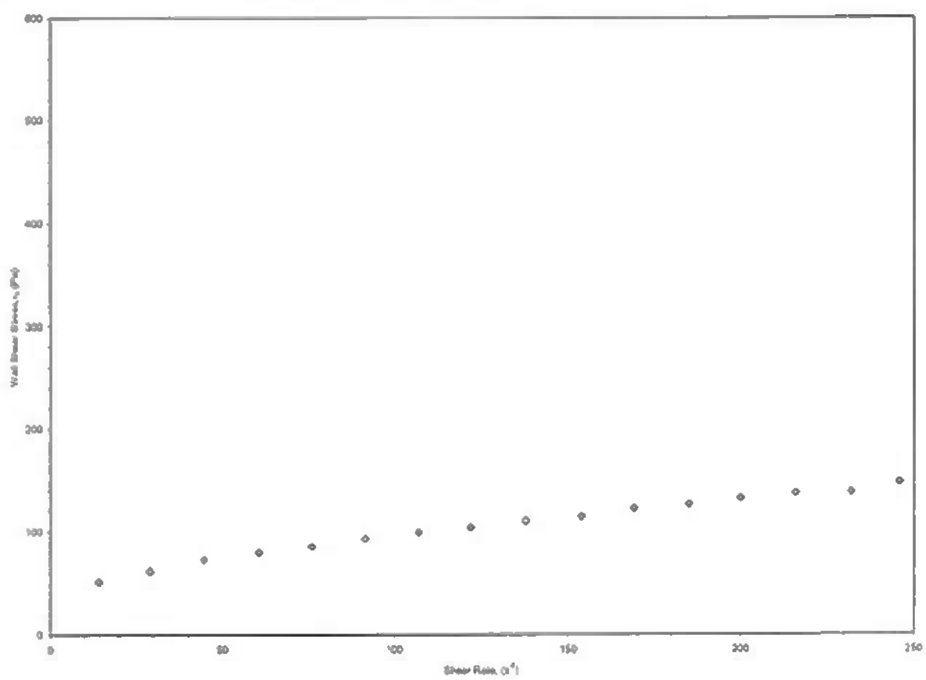
Data Series Information	
Name:	5034-005 1
Sample:	5
Operator:	HM
Remarks:	
Number of Intervals:	4
Application:	US200/32 V2.30 21001513-33024
Device:	MC1+ SN679534
Measurement Date:	2005/02/04
Measurement Time:	04:11 PM
Measuring Systems:	Z 2/3-DIN
Calculating Constants:	
- Css:	0.28396508
- Css:	21.5
- Start Delay Time [s]:	2.105
- Measurement Type:	2
Interval:	4
Number of Data Points:	20
Time Setting:	20 Meas. Pts. Meas. Pt. Duration 4 s
Measuring Profile:	
Shear Rate	d(gamma)/dt = 300 ... 5 1/s Lin, Continuous Ramp

Meas. Pts.	Shear Rate	Shear Stress	Viscosity	Mass Solids Concentration	Temperature
	[1/s]	[Pa]	[mPa·s]	[%w]	[°C]
1	247	187	760	73.2	25.5
2	231	178	769	73.2	25.5
3	216	174	808	73.2	25.6
4	200	168	842	73.2	25.5
5	185	160	867	73.2	25.5
6	169	156	921	73.2	25.6
7	153	146	953	73.2	25.5
8	138	142	1,030	73.2	25.5
9	122	132	1,080	73.2	25.5
10	107	126	1,180	73.2	25.5
11	91.4	118	1,290	73.2	25.6
12	75.9	109	1,430	73.2	25.5
13	59.9	101	1,680	73.2	25.5
14	44.2	91.5	2,070	73.2	25.5
15	29.4	78.1	2,650	73.2	25.5
16	14.1	66.9	4,750	73.2	25.6



Data Series Information	
Name:	5034-006 1
Sample:	6
Operator:	HM
Remarks:	
Number of Intervals:	4
Application:	US200/32 V2.30 21001513-33024
Device:	MC1+ SN679534
Measurement Date:	2005/02/04
Measurement Time:	04:53 PM
Measuring Systems:	Z 2/3-DIN
Calculating Constants:	
- Csr:	0.28396508
- Css:	21.5
- Start Delay Time [s]:	2.253
- Measurement Type:	2
Interval:	4
Number of Data Points:	20
Time Setting	20 Meas. Pts. Meas. Pt. Duration 4 s
Measuring Profile:	
Shear Rate	d(gamma)/dt = 300 ... 5 1/s Lin, Continuous Ramp

Meas. Pts.	Shear Rate	Shear Stress	Viscosity	Mass Solids Concentration	Temperature
	[1/s]	[Pa]	[mPa·s]	[%w]	[°C]
1	246	148	599	72.4	25.8
2	232	138	598	72.4	25.8
3	216	137	634	72.4	25.8
4	200	132	662	72.4	25.8
5	185	126	680	72.4	25.8
6	169	122	722	72.4	25.8
7	154	114	739	72.4	25.8
8	138	110	800	72.4	25.8
9	122	104	856	72.4	25.8
10	107	99.1	922	72.4	25.8
11	91.5	92.8	1,010	72.4	25.8
12	76	85.4	1,120	72.4	25.8
13	60.6	79.7	1,320	72.4	25.8
14	44.7	72.3	1,610	72.4	25.8
15	29.1	61.7	2,120	72.4	25.8
16	14.2	51.5	3,630	72.4	25.8



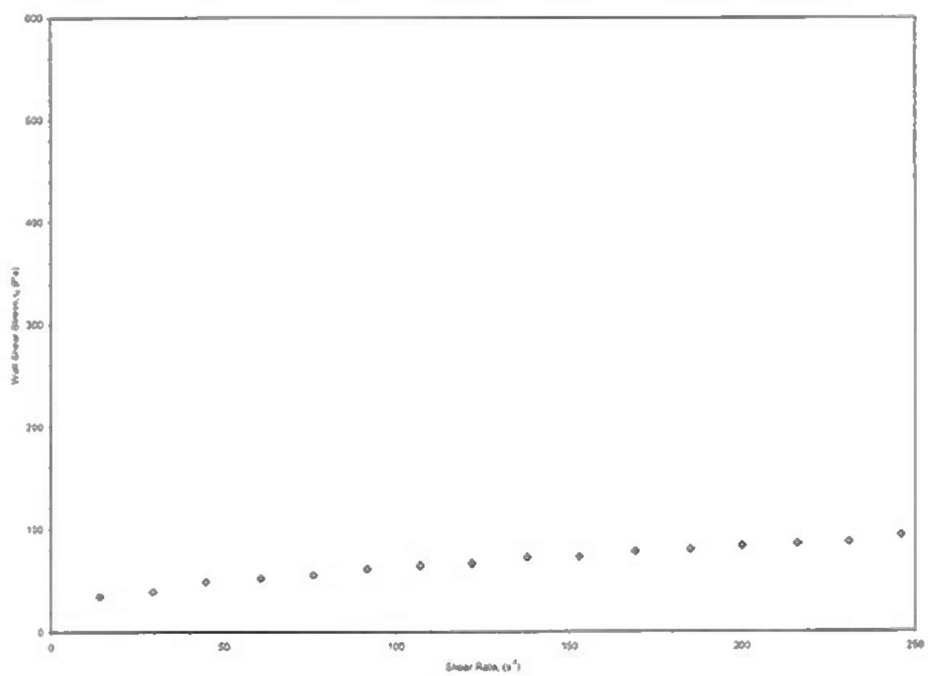
Data Series Information
Name: 5034-007 1
Sample: 7
Operator: HM
Remarks:
Number of Intervals: 4
Application: US200/32 V2.30 21001513-33024
Device: MC1+ SN679634
Measurement Date: 2005/02/04
Measurement Time: 05:17 PM
Measuring Systems: Z2/3-DIN

Calculating Constants:
- Csr: 0.28396508
- Css: 21.5
- Start Delay Time (s): 2.227
- Measurement Type: 2
Interval: 4
Number of Data Points: 20

Time Setting: 20 Meas. Pts.
Meas. Pt. Duration 4 s

Measuring Profile:
Shear Rate: d(gamma)/dt = 300 ... 5 1/s Lin. Continuous Ramp

Meas. Pts.	Shear Rate	Shear Stress	Viscosity	Mass Solids Concentration	Temperature
	[1/s]	[Pa]	[mPa s]	[%w]	[°C]
1	246	93.2	378	68.4	25.9
2	231	86.7	374	68.4	25.9
3	216	85	394	68.4	25.9
4	200	83	416	68.4	25.9
5	185	79.6	430	68.4	25.9
6	169	77.7	460	68.4	25.9
7	153	72.1	471	68.4	25.9
8	138	71.7	519	68.4	25.9
9	122	66.1	541	68.4	25.9
10	107	64.1	596	68.4	25.9
11	91.5	61.1	668	68.4	25.9
12	75.9	55.4	730	68.4	25.9
13	60.6	52.5	867	68.4	25.9
14	44.8	48.8	1,090	68.4	25.9
15	29.5	39.2	1,330	68.4	25.9
16	14.1	34.3	2,440	68.4	25.9



Data Series Information	
Name:	Hearne-001 1
Sample:	1
Operator:	HM
Remarks:	
Number of Intervals:	4
Application:	US200/32 V2.30 21001513-33024
Device:	MC1+ SN679534
Measurement Date:	2005/02/08
Measurement Time:	11:15 AM
Measuring Systems:	Z 2/3-DIN
Calculating Constants:	
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- Css:	21.5
- Start Delay Time [s]:	1.786
- Measurement Type:	2
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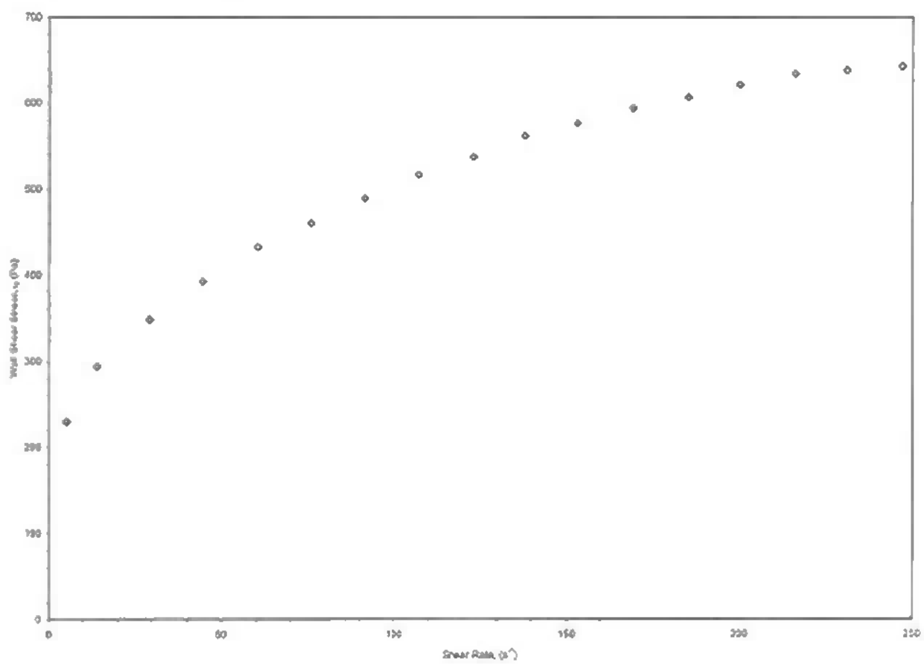
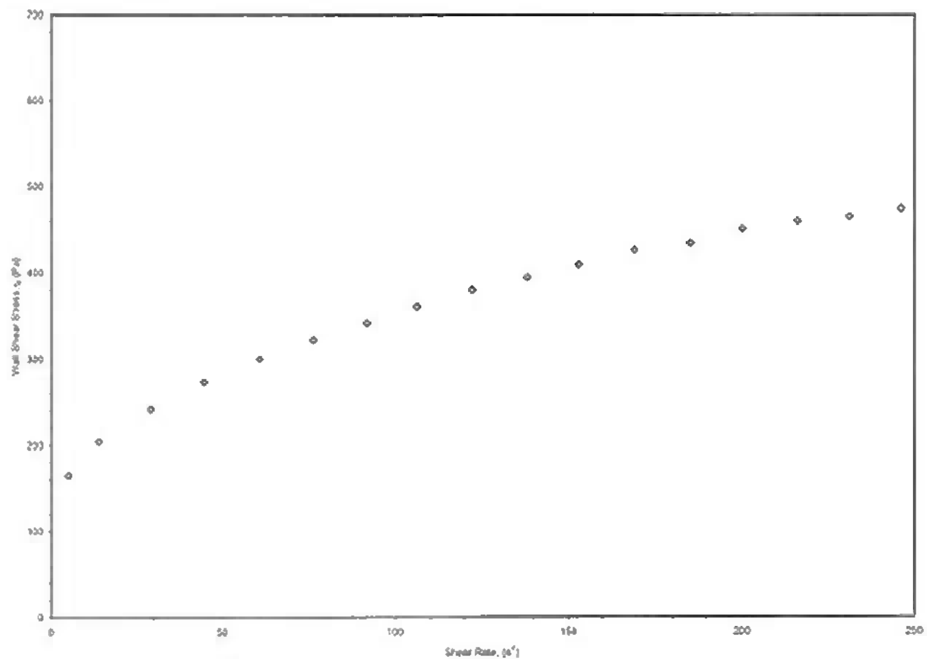
Time Setting:	20 Meas. Pts. Meas. Pt. Duration 4 s
Measuring Profile:	
Shear Rate	d(gamma)/dt = 300 ... 5 1/s Lin, Continuous Ramp

Meas. Pts.	Shear Rate	Shear Stress	Viscosity	Mass Solids Concentration	Temperature
	[1/s]	[Pa]	[mPa·s]	[%w]	[°C]
1	247	643	2,610	78.3	26
2	231	639	2,760	78.3	26
3	216	635	2,940	78.3	26
4	200	622	3,110	78.3	26
5	185	607	3,290	78.3	26
6	169	594	3,510	78.3	26
7	153	577	3,770	78.3	26
8	138	562	4,070	78.3	26
9	123	537	4,370	78.3	26
10	107	517	4,820	78.3	26
11	91.4	489	5,360	78.3	26
12	75.8	460	6,070	78.3	26
13	60.3	432	7,170	78.3	26
14	44.6	392	8,800	78.3	26
15	29.3	348	11,900	78.3	26
16	13.9	294	21,100	78.3	26
17	4.99	250	46,000	78.3	26



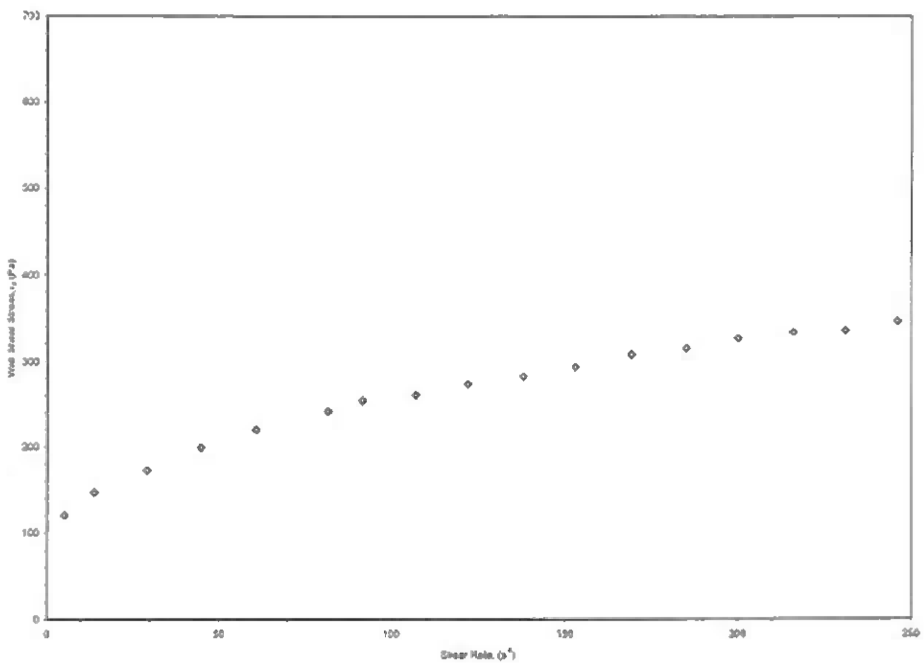
Data Series Information	
Name:	Hearne-002 1
Sample:	2
Operator:	HM
Remarks:	
Number of Intervals:	4
Application:	US200/32 V2.30 21001513-33024
Device:	MC1+ SN679534
Measurement Date:	2005/02/08
Measurement Time:	12:06 PM
Measuring Systems:	Z 2/3-DIN
Calculating Constants	
- Csr:	0.28396508
- Css:	21.5
- Start Delay Time [s]:	2.088
- Measurement Type:	2
Interval:	4
Number of Data Points:	20
Time Setting:	20 Meas. Pts. Meas. Pt. Duration 4 s
Measuring Profile:	
Shear Rate	d(gamma)/dt = 300 ... 5 1/s Lin, Continuous Ramp

Meas. Pts.	Shear Rate	Shear Stress	Viscosity	Mass Solids Concentration	Temperature
	[1/s]	[Pa]	[mPa·s]	[%w]	[°C]
1	246	473	1,920	77.8	26.5
2	231	464	2,010	77.8	26.4
3	216	459	2,120	77.8	26.4
4	200	450	2,250	77.8	26.4
5	185	433	2,340	77.8	26.4
6	169	425	2,510	77.8	26.4
7	153	409	2,670	77.8	26.4
8	138	394	2,860	77.8	26.4
9	122	379	3,100	77.8	26.4
10	106	360	3,380	77.8	26.4
11	91.6	341	3,720	77.8	26.4
12	76.1	321	4,220	77.8	26.4
13	60.7	300	4,940	77.8	26.4
14	44.7	273	6,110	77.8	26.4
15	29.1	242	8,300	77.8	26.4
16	14	204	14,600	77.8	26.4
17	4.98	166	33,200	77.8	26.4



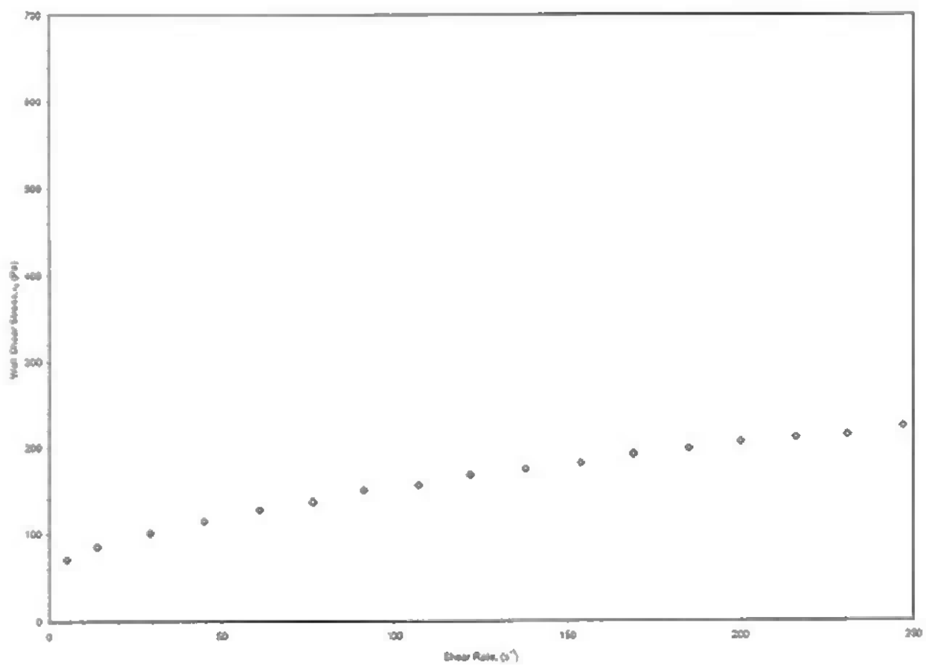
Data Series Information	
Name:	Hearne-003 1
Sample:	3
Operator:	HM
Remarks:	
Number of Intervals:	4
Application:	US200/32 V2.30 21001513-33024
Device:	MC1+ SN678534
Measurement Date:	2005/02/08
Measurement Time:	01:19 PM
Measuring Systems:	Z 2/3-DIN
Calculating Constants:	
- Csr:	0.28396508
- Css:	21.5
- Start Delay Time [s]:	1 668
- Measurement Type:	2
Interval:	4
Number of Data Points:	20
Time Setting:	20 Meas. Pts. Meas. Pt. Duration 4 s
Measuring Profile:	
Shear Rate	d(gamma)/dt = 300 ... 5 1/s Lin, Continuous Ramp

Meas. Pts.	Shear Rate	Shear Stress	Viscosity	Mass Solids Concentration	Temperature
	[1/s]	[Pa]	[mPa·s]	[%w]	[°C]
1	246	346	1,400	77.2	26.8
2	231	335	1,450	77.2	26.8
3	216	333	1,540	77.2	26.8
4	200	326	1,630	77.2	26.8
5	185	314	1,700	77.2	26.8
6	169	307	1,820	77.2	26.7
7	153	293	1,910	77.2	26.8
8	138	282	2,050	77.2	26.8
9	122	273	2,240	77.2	26.8
10	107	260	2,440	77.2	26.7
11	91.6	254	2,770	77.2	26.8
12	81.6	242	2,960	77.2	26.8
13	60.7	220	3,630	77.2	26.7
14	44.8	199	4,440	77.2	26.7
15	29.2	173	5,920	77.2	26.7
16	13.8	147	10,600	77.2	26.7
17	4.98	121	24,300	77.2	26.8



Data Series Information	
Name:	Hearne-004 1
Sample:	4
Operator:	HM
Remarks:	
Number of Intervals:	4
Application:	US200/32 V2.30 21001513-33024
Device:	MC1+ SN679534
Measurement Date:	2005/02/08
Measurement Time:	01:55 PM
Measuring Systems:	Z 2/3-DIN
Calculating Constants:	
- Csr:	0.28398508
- Css:	21.5
- Start Delay Time [s]:	1.719
- Measurement Type:	2
Interval:	4
Number of Data Points:	20
Time Setting:	20 Meas. Pts. Meas. Pt. Duration 4 s
Measuring Profile:	
Shear Rate	d(gamma)/dt = 300 ... 5 1/s Lin, Continuous Ramp

Meas. Pts.	Shear Rate	Shear Stress	Viscosity	Mass Solids Concentration	Temperature
	[1/s]	[Pa]	[mPa s]	[%w]	[°C]
1	247	224	909	76.1	26.9
2	231	214	923	76.1	26.9
3	216	211	979	76.1	26.9
4	200	206	1,030	76.1	26.9
5	185	198	1,070	76.1	26.9
6	169	192	1,140	76.1	26.9
7	154	182	1,180	76.1	26.9
8	138	175	1,270	76.1	26.9
9	122	168	1,370	76.1	26.9
10	107	156	1,460	76.1	26.9
11	91	150	1,640	76.1	26.9
12	76.2	137	1,800	76.1	26.9
13	60.7	128	2,110	76.1	26.9
14	44.8	115	2,530	76.1	26.9
15	29.3	101	3,430	76.1	26.9
16	13.9	85.2	6,150	76.1	26.9
17	5	71.2	14,200	76.1	26.9



Data Series Information
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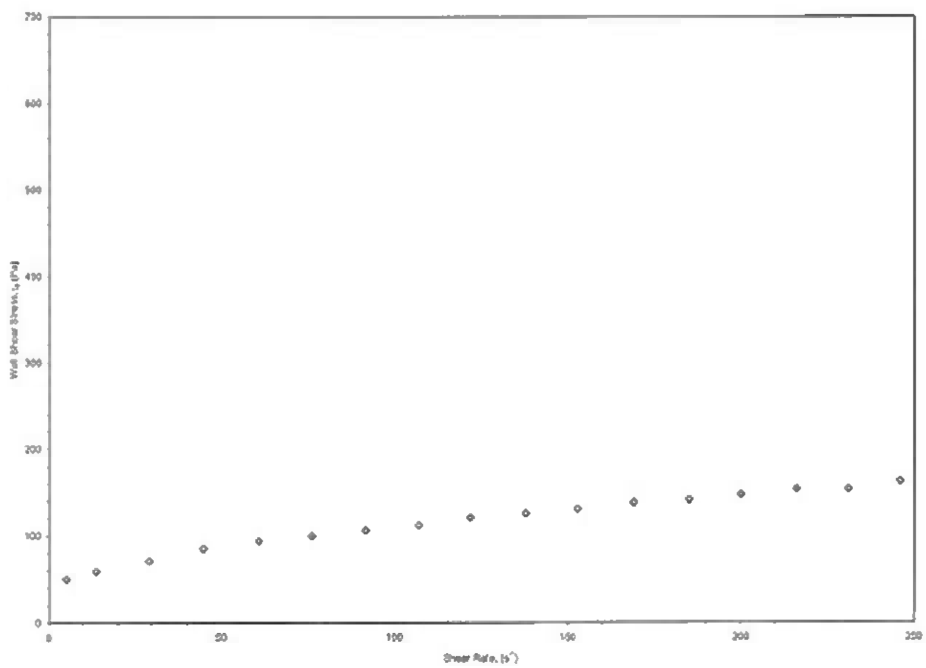
Sample: 5
Operator: HM
Remarks:
Number of Intervals: 4
Application: US200/32 V2.30 21001513-33024
Device: MC1+ SN679634
Measurement Date: 2005/02/08
Measurement Time: 02:34 PM
Measuring Systems: Z 2/3-DIN

Calculating Constants:
- Csr: 0.28396508
- Css: 21.5
- Start Delay Time [s]: 1.799
- Measurement Type: 2
Interval: 4
Number of Data Points: 20

Time Setting: 20 Meas. Pts.
Meas. Pt. Duration 4 s

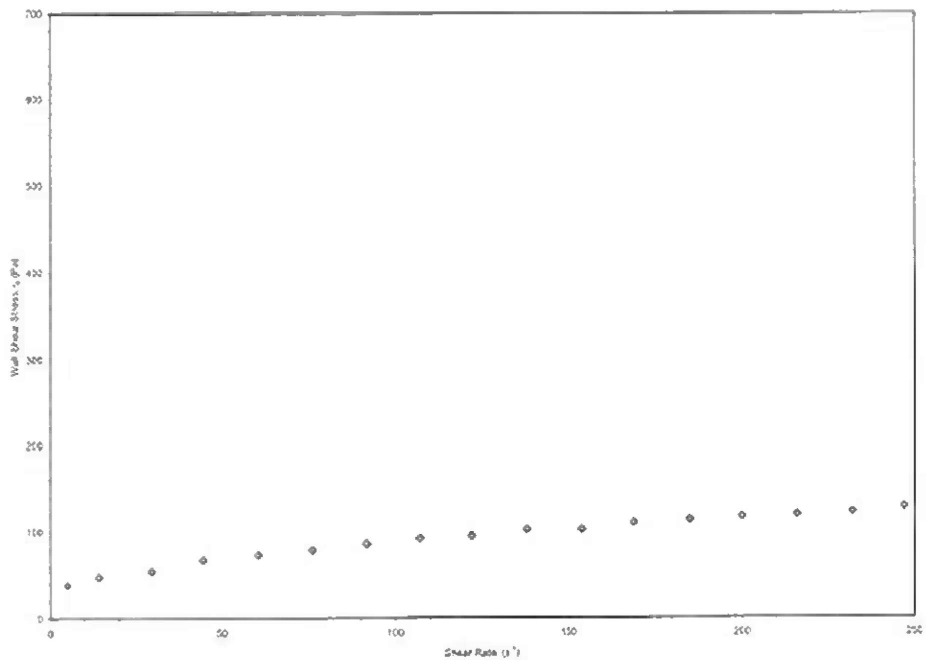
Measuring Profile:
Shear Rate: d(gamma)/dt = 300 ... 5 1/s Lin, Continuous Ramp

Meas. Pts.	Shear Rate	Shear Stress	Viscosity	Mass Solids Concentration	Temperature
	[1/s]	[Pa]	[mPa·s]	[%w]	[°C]
1	246	162	658	75.2	26.8
2	231	153	665	75.2	26.8
3	216	153	707	75.2	26.8
4	200	147	737	75.2	26.8
5	185	141	764	75.2	26.8
6	169	138	819	75.2	26.8
7	153	131	851	75.2	26.8
8	138	126	914	75.2	26.8
9	122	121	992	75.2	26.8
10	107	112	1,050	75.2	26.8
11	91.6	106	1,160	75.2	26.8
12	76	99.6	1,310	75.2	26.8
13	60.7	93.7	1,540	75.2	26.8
14	44.9	85.4	1,900	75.2	26.8
15	29.2	71.5	2,450	75.2	26.8
16	13.8	59.3	4,310	75.2	26.8
17	4.99	49.9	10,000	75.2	26.8



Data Series Information	
Name:	Hearne-005 1
Sample:	6
Operator	HM
Remarks:	
Number of Intervals:	4
Application	US200/32 V2 30 21001513-33024
Device:	MC1+ SN679534
Measurement Date:	2005/02/08
Measurement Time:	02:56 PM
Measuring Systems:	Z 2/3-DIN
Calculating Constants	
- Csr:	0.28396503
- Css:	21.6
- Start Delay Time [s]:	1.835
- Measurement Type:	2
Interval:	4
Number of Data Points:	20
Time Setting:	20 Meas. Pts. Meas. Pt. Duration 4 s
Measuring Profile:	
Shear Rate	d(gamma)/dt = 300 ... 5 1/s Lin. Continuous Ramp

Meas. Pts.	Shear Rate	Shear Stress	Viscosity	Mass Solids Concentration	Temperature
	[1/s]	[Pa]	[mPa·s]	[%w]	[°C]
1	247	128	517	73.3	26.8
2	232	122	525	73.3	26.8
3	216	119	552	73.3	26.8
4	200	117	586	73.3	26.8
5	185	113	613	73.3	26.7
6	169	110	651	73.3	26.7
7	154	102	661	73.3	26.7
8	138	102	738	73.3	26.7
9	122	94.4	771	73.3	26.7
10	107	91.5	852	73.3	26.7
11	91.6	85.8	937	73.3	26.7
12	76	79	1,040	73.3	26.7
13	60.6	73.3	1,210	73.3	26.6
14	44.7	67.6	1,510	73.3	26.7
15	29.6	54.3	1,840	73.3	26.7
16	14.2	47.6	3,350	73.3	26.7
17	6	38.1	7,630	73.3	26.7



APPENDIX E – CLAY BEHAVIOURAL ANALYSIS

Paterson & Cooke Consulting Engineers (Pty) Ltd

Clay Behavioural Analysis of Gacho Kue Ore Samples

Report Number: DCA-GAK-8004.R01 Rev 01

11 March 2005

PATERSON & COOKE
CONSULTING SCIENTISTS

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SUMMARY

This report details the results of the Clay Behavioural Analysis of both the Hearne and 5034 ore bodies for the proposed Gacho Kue mine in Canada.

Both Gacho Kue ore bodies contain significant amounts of Smectite clay. The clay (-2μm) size fraction in particular, consists of mainly Smectite clay. The natural state of the Smectite clays, however appears to be highly calcium exchanged in the dry *in situ* state before contact with the process water. After contact with calcium rich simulated process waters, the clays became slightly more calcium exchanged. It is expected that colloidally unstable (settling) slurries would be generated from these ore-water combinations at the natural pH condition, through restriction of the swelling and dispersion of the Smectite clays.

Colloidal analysis of the simulated slurries confirmed that the natural state of the Gacho Kue materials fall within a favourable colloidally unstable (settling) condition extending across the entire pH range. Good slurry flocculation and settling characteristics are expected.

TERMS OF REFERENCE

This work has been conducted by Paterson & Cooke Consulting Scientists (Pty) Ltd for Paterson & Cooke Consulting Engineers (Pty) Ltd under PCCE project DGK-571. The proposal for this work was presented in PCCS Proposal DCA-GAK-8004.P01 dated 27/01/2005.

CONTENTS

DOCUMENT DISTRIBUTION AND REVISION HISTORY

Rev	Date	Distribution / Revisions	Prepared	Reviewed	Client Approval
1	11/03/2005	Issued to Mr. Angus Paterson of PCCE	FD	AJV	-

1. INTRODUCTION

De Beers Canada is currently conducting an ore dressing studies campaign on the Gacho Kue ore bodies as part of a pre-feasibility study of the proposed new Gacho Kue mine in Canada.

As part of the ore dressing studies campaign, Paterson & Cooke Consulting Scientists (Pty) Ltd conducted a Clay Behavioural Analysis of the Gacho Kue ore bodies, in order to provide the client with important additional information to develop a full understanding of future process behaviour.

The Clay Behavioural Analysis consists of the following two test work packages, aimed at determining the behavioural state of the clay minerals before and after contact with the process water for the prediction of future process behaviour:

- Dry *in situ* Ore Characteristics
- Wet Process Ore Characteristics

2. MATERIALS

The following samples were received:

- 1 kg of dry crushed drill core from the Hearne ore body
- 1 kg of dry crushed drill core from the 5034 ore body
- 1 litre of de-ionised water in contact with the Hearne ore

The Clay Behavioural Analysis was conducted on the crushed drill core material (-1.5 mm) from both the Hearne and 5034 ore bodies before and after contact with a simulated process water.

Since no actual raw or process water were available, a simulated process water was generated for each ore type using tap water from the Rand Water Board, according to the procedure in Appendix A.

A simulated slurry sample was generated for each ore type out of the dry ore and simulated process water samples, according to the procedure in Appendix A.

3. TEST WORK

3.1 Dry *in situ* Ore Characteristics

The Dry *in situ* Ore Characteristics Work Package consists of the following suite of tests designed to determine the total and clay (-2 μm) mineral fractions within the ore and the cation exchanged nature of the clays in the dry *in situ* state before contact with the process water:

- Total mineral analysis
- Clay mineral analysis
- Exchangeable cation analysis
- Cation exchange capacity (CEC)
- pH of saturated paste extract

The total and clay mineral analyses can be described as semi-quantitative XRD mineralogical analyses on respectively the -1.5 mm + 2 µm fraction and the -2 µm fraction of the ore samples, and determines the relative proportions of clay and other minerals in the ore body.

The exchangeable cation analysis determines the ion exchanged nature of the clay, which in turn indicates its colloidal characteristics when in contact with the process water. The respective concentrations of the major exchangeable cations (i.e. Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) are determined through an ammonium acetate wash of the clay particles. The CEC is defined as the total concentration of exchangeable cations on the clay surface. A high CEC indicates an increased ability of the clay to change its ion exchanged nature upon contact with the process water.

The pH of the saturated paste extract can be described as the pH of the solids when just saturated with distilled water.

3.2 Wet Process Ore Characteristics

The Wet Process Ore Characteristics Work Package consists of the following suite of tests designed to determine the process water quality, if and how the cation exchanged nature of the clays are altered after contact with the process water and the colloidal characteristics of the subsequent slurry:

- Process water analysis
- Exchangeable cation analysis
- Cation exchange capacity (CEC)
- Slurry colloidal analysis
- Particle size distribution analysis

The process water analysis can be described as a chemical analysis of the major cations and anions in solution and other associated properties such as pH and conductivity in order to determine the quality of the process water. The quality of the process water could significantly affect the colloidal characteristics of clay particles in suspension through its impact on the ion exchanged nature of the clay.

The slurry colloidal analysis provides an indication of the colloidal characteristics of the slurry across a range of pH values. The slurry colloidal analysis enables the identification of optimum clay behavioural zones for specific process applications.

The particle size distribution is determined in a Malvern Particle Size Analyzer and indicates the size of the fines fraction (-20 µm) primarily responsible for absorbing most of the flocculant.

4. RESULTS

4.1 Dry *in situ* Ore Characteristics

4.1.1 Mineral analysis

Figure 1 and Figure 2 respectively presents the results of the total mineral analysis and clay (-2μm) mineral analysis of both the Hearne and 5034 ore bodies.

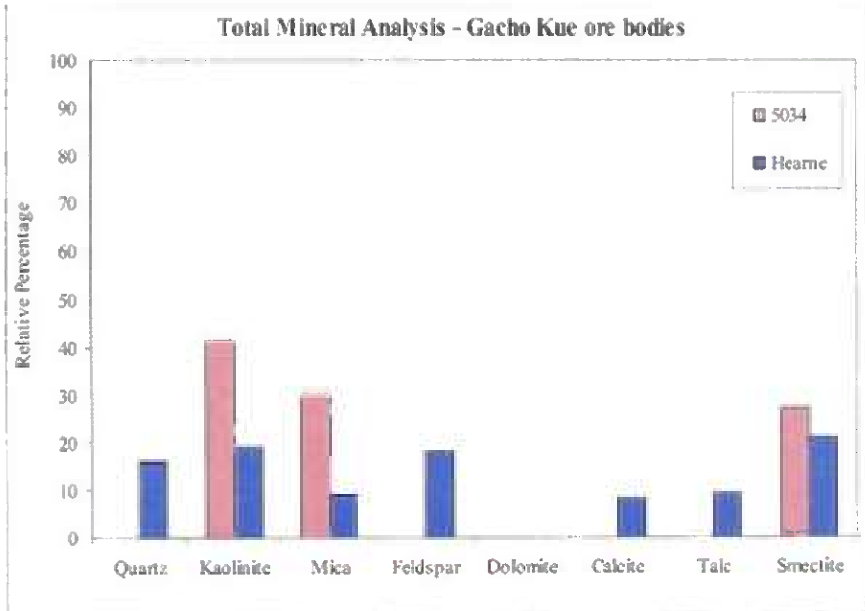

Figure 1 : Total Mineral Analysis

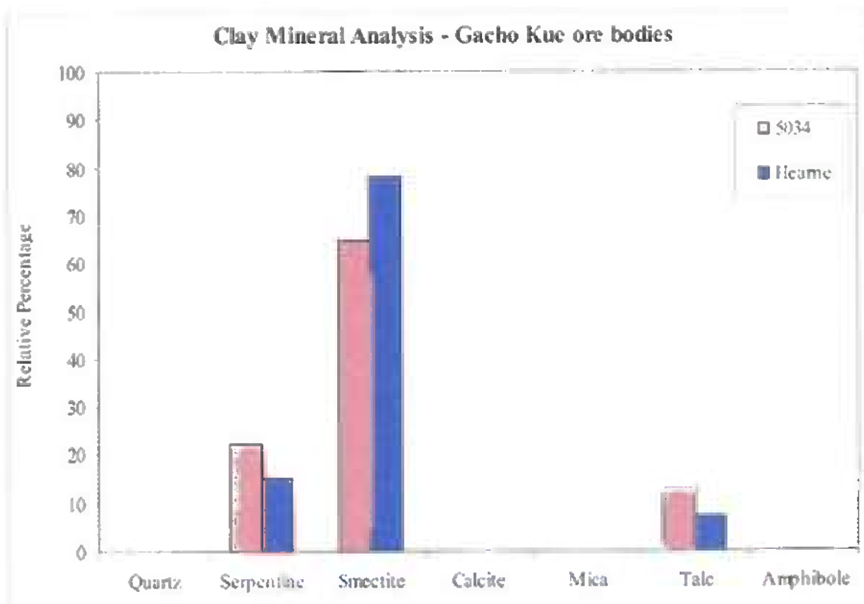

Figure 2 : Clay Mineral Analysis

4.1.2 *Exchangeable cation analysis*

Figure 3 and Table I present the results of the exchangeable cation analysis of both the Hearne and 5034 ore bodies in the dry *in situ* state before contact with the simulated process water.

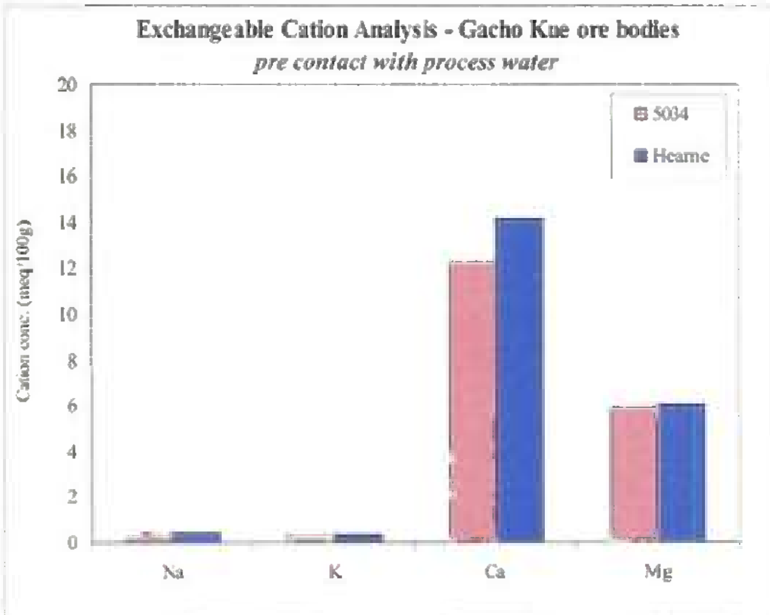

Figure 3 : Exchangeable Cation Analysis

The cation exchanged capacity (CEC) and exchangeable sodium percentage (ESP) are calculated according to Equation 1 and Equation 2.

Table I : CEC and ESP Values

Parameters	***Pre contact with process water***	
	Hearne	***5034***
CEC (meg/100g)	14.8	10.8
ESP (%)	2.8	3.7
pH of saturated paste	7.0	7.5

Equation 1 : Cation Exchange Capacity (CEC)

$$CEC = [Ca^{2+}] + [Mg^{2+}] + [Na^{+}] + [K^{+}]$$

Equation 2 : Exchangeable Sodium Percentage (ESP)

$$ESP = \frac{[Na^+]}{CEC}$$

where the concentrations of the cations are expressed in meq/100g.

4.2 Wet Process Ore Characteristics

4.2.1 Process water quality

Table II presents a summary of the quality of the simulated process waters associated with each of the Hearne and 5034 ore bodies. A full range of simulated process water quality data is provided in Appendix B.

Table II : Summary of Simulated Process Water Quality Data

Parameters	***Simulated process water***	
	Hearne	***5034***
pH	7.82	8.03
Conductivity (mS/cm)	0.29	0.26
SAR	0.95	1.00

The SAR values in Table II refer to the Sodium Adsorption Ratio, which is the ratio of the monovalent to the divalent cations in the process water, calculated by Equation 3.

Equation 3 : Sodium Adsorption Ratio

$$SAR = \frac{[Na^+]}{\sqrt{([Ca^{2+}]+[Mg^{2+}])/2}}$$

where the concentrations of the cations are expressed in meq/100g.

Process waters with SAR values in excess of 15 are expected to generate sodium exchanged clays and therefore colloidally stable slurries.

4.2.2 Exchangeable cation analysis

Figure 4 and Table III present the results of the exchangeable cation analysis of both the Hearne and 5034 ore bodies in the wet state after contact with the simulated process water.

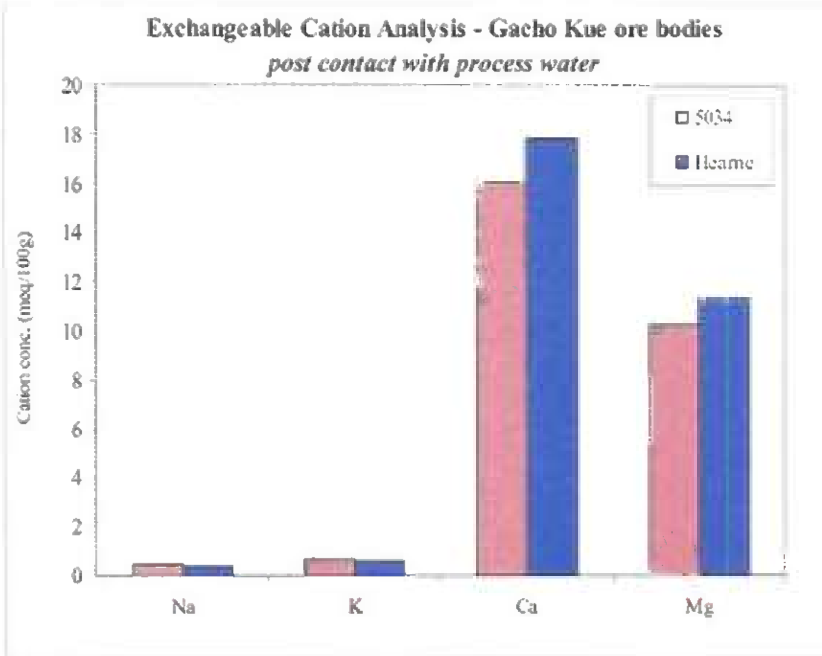

Figure 4 : Cation Exchange Analysis

Table III : CEC and ESP Value

Parameters	***Post contact with process water***	
	Hearne	***5034***
CEC (meg/100g)	17.0	11.8
ESP (%)	1.9	3.6
pH of saturated paste	6.8	7.3

4.2.3 Slurry colloidal analysis

Figure 5 presents the colloidal characteristics of the simulated slurries associated with each of the Hearne and 5034 ore bodies after a settling period of 10 minutes, over a range of pH values (i.e. pH 4, 6, 8, 10, 11.5).

Table IV presents the natural pH, conductivity and key particle size distribution parameters of the simulated slurries associated with each of the Hearne and 5034 ore bodies.

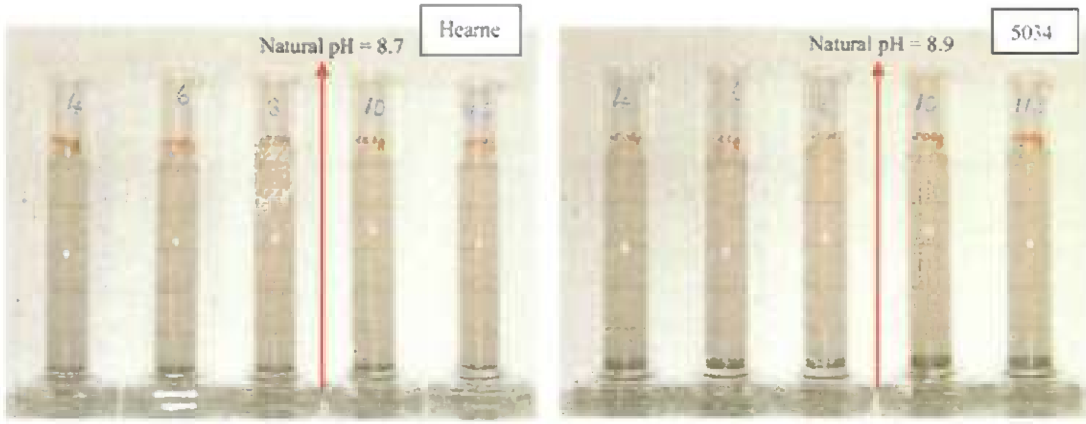

Figure 5 : Colloidal Characteristics of Simulated Slurries

Table IV : Simulated Slurry Characteristics

Parameters	***Simulated slurry***	
	Hearne	***5034***
Natural pH	8.70	8.93
Conductivity (mS/cm)	0.33	0.35
D_{50} (µm)	265	377
D_{90} (µm)	936	1009
Vol. % passing 20 µm	17	13

Figure 6 presents the particle size distributions of both the Hearne and 5034 ore bodies.

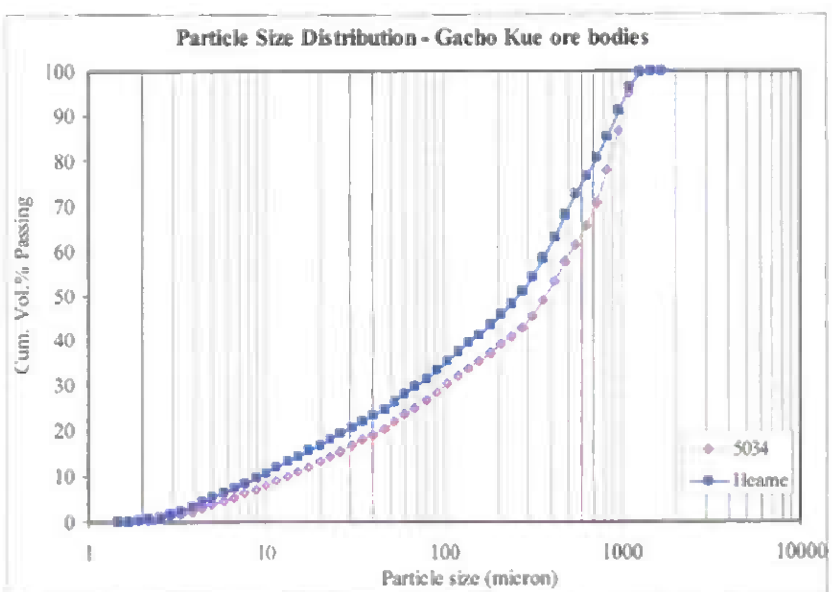

Figure 6 : Particle Size Distribution

5. DISCUSSION OF RESULTS

The mineral analyses show that both Gacho Kue ore bodies contain significant amounts of Smectite clay. The clay (-2µm) size fraction in particular, consists of mainly Smectite clay. Smectite clays are often referred to as swelling clays as a result of their ability to adsorb water molecules between the clay platelets, which therefore lead to swelling of the clay structure and may result in colloidally dispersive behaviour. The swelling and dispersive characteristics of Smectite clays are determined by the cation exchanged nature of the clay and the quality of the process water. Sodium exchanged clays or sodium rich water induces swelling and dispersion, while calcium exchanged clays or calcium rich water restricts swelling and induce coagulation.

The low SAR values (< 15) of the respective simulated process waters indicate calcium rich waters, expected to generate colloidally unstable (settling) slurries.

The exchangeable cation analyses of the Gacho Kue ore bodies show that the Smectite clays associated with each of the Hearne and 5034 ores appear to be highly calcium exchanged in the dry *in situ* state before contact with the simulated process waters, as indicated by the low ESP values. After contact with the calcium rich simulated process waters, the concentrations of exchangeable calcium and magnesium increased slightly, which reflects the low SAR conditions of the simulated process waters. As a result the ESP values of the ores in the wet state, after contact with the simulated process waters, decreased slightly.

Figure 7 presents the predicted clay behavioural nature of the Gacho Kue ore bodies before and after contact with the simulated process water on a plot of the saturated paste pH vs. ESP. Typically, Smectite clays exhibit non-interactive (dispersive) properties in a zone between about pH 8 to 11 and at ESP values greater than about 15-20%. Outside of this non-interactive zone, clays normally occur in a coagulated state as a result of significant particle to particle interaction taking place. This occurs under low ionic concentrations (low conductivity).

The combination of the calcium exchanged clays of the Gacho Kue ore bodies and calcium rich process waters is expected to restrict swelling and dispersion of the Smectite clays and therefore generate colloidally settling slurries.

The results of the slurry colloidal analysis presented in Figure 5 confirmed that the natural state of the Gacho Kue slurries fall within a colloidally unstable (coagulated) zone extending across the entire pH range, which supports the behaviour predicted in Figure 7.

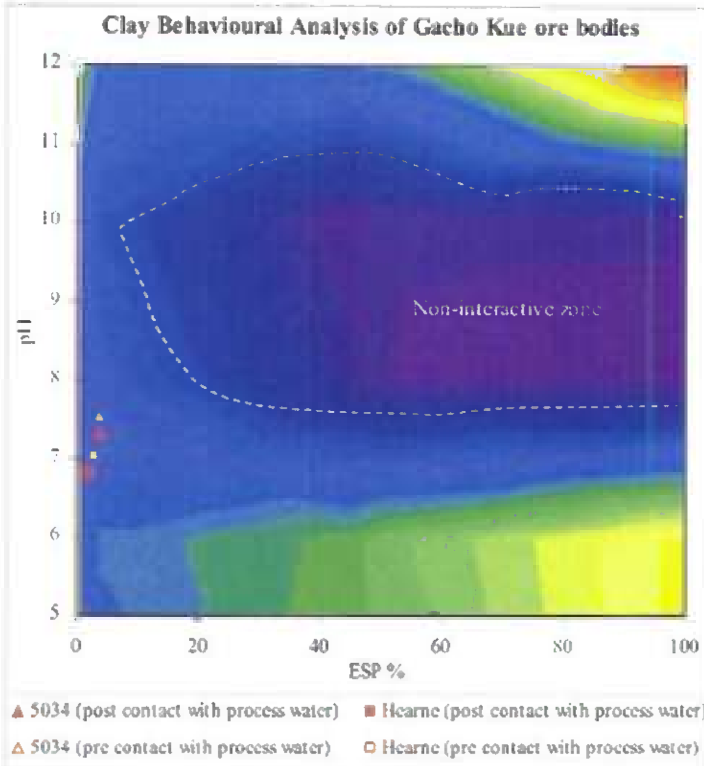

Figure 7 : Clay Behavioural Analysis

6. CONLCUSIONS AND RECOMMENDATIONS

It is concluded that both the Hearne and 5034 ore bodies from Gacho Kue are highly calcium exchanged and exhibits interactive (coagulated) behaviour at their natural pH condition. The simulated process waters appear to be calcium rich. It is expected that colloidally unstable (settling) slurries would be generated from these ore-water combinations.

It was confirmed that the natural state of the Gacho Kue slurries fall within a favourable colloidally unstable condition, based on the results of the slurry colloidal analysis. It is therefore expected that the Gacho Kue slurries would exhibit good flocculation and settling characteristics.

It is recommended to evaluate the identified raw water source for the proposed Gacho Kue mine in order to determine its potential impact on the colloidal behaviour of the slurries.

F Dunn
Project Engineer
11 March 2005

AJ Vietti
Project Scientist

APPENDIX A – PROCEDURES FOR GENERATION OF SIMULATED PROCESS WATER AND SLURRY

Simulated Process Water :

- Make up close to a 20% by mass slurry out of the dry crushed drill core sample and tap water from Rand Water Board.
- Stir the slurry for a few minutes and allow to settle.
- Pour off the supernatant water and use as simulated process water.

Simulated Slurry :

- Make up close to a 1-2% by mass slurry using the dry crushed drill core sample and the simulated process water.
- Stir the slurry for a few minutes.
- Use as simulated slurry.

APPENDIX B – SIMULATED PROCESS WATER QUALITY DATA

Table B1 : Simulated Process Water Quality Data

Determinants	PCCS Number			
	5034		*Hearne*	
pH	8.03		7.82	
pHs (saturated with $CaCO_3$)	8.43		8.40	
SAR	1.00		0.95	
Conductivity mS/m at 25°C	26.00		29.00	
mS/cm at 25°C	0.26		0.29	
Cations	*mg/l*	*meq/l*	*mg/l*	*meq/l*
Sodium as Na	18.05	0.79	19.12	0.83
Potassium as K	10.78	0.28	8.18	0.21
Calcium as Ca	14.95	0.75	18.63	0.93
Magnesium as Mg	5.75	0.47	7.31	0.60
Boron	0.83	0.23	0.57	0.16
Subtotal	**50.36**	**2.51**	**53.81**	**2.73**
Anions	*mg/l*	*meq/l*	*mg/l*	*meq/l*
Fluoride as F	0.19	0.01	0.28	0.01
Nitrite	0.00	0.00	0.00	0.00
Nitrate as NO_3	3.33	0.05	3.17	0.05
Chloride as Cl	38.07	1.07	55.00	1.55
Sulphate as SO_4	9.04	0.19	10.56	0.22
Phosphate as P	0.14	0.00	0.21	0.00
Carbonate as CO_3	0.00	0.00	0.00	0.00
Bicarbonate as HCO_3	76.25	1.25	67.10	1.10
Subtotal	**127.02**	**2.57**	**136.32**	**2.93**
TOTAL	**177.38**	**5.08**	**190.13**	**5.66**
Alkalinity	62.50	1.25	55.00	1.10

APPENDIX D

GAHCHO KUÉ TUZO SLIMES DEWATERING TEST REPORTS (2008)

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NOTE FOR THE RECORD

GAHCHO KUE TUZO SLIMES DEWATERING TESTS REPORT

19 May 2008

Compiled by

Phakamele Tomo

Document Number: 2240-R00219-PSS-00001-5624

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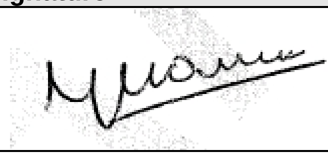
G Dellas Manager – Metallurgical Services		19th May 2008

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1 INTRODUCTION

Clay analysis and slimes characterisation were conducted on fifteen (15) drill core samples from Gahcho Kue Tuzo as part of ore dressing studies. DebTech's involvement aims to characterise the samples to establish the treatability of the slimes.

2 METHODOLOGY

2.1 Chemical Analysis

No raw water samples were submitted from Canada and thus distilled water from Consolidated Water Conditioning SA (Pty) Ltd was used for preparing slurry samples. One litre each of "typical" process water samples were dispatched to AARL for full chemical analysis.

The stability of a clay suspension is influenced by the type of ions dissolved in the water, which in turn influences the types of ions adsorbed onto the clay surfaces, thus the need to perform the chemical analysis.

2.2 Mineralogical Analysis

A sample was dispatched to Agricultural Research Council for mineralogical analysis. The analysis included the following characterisation:

- Total analysis
- Clay mineral analysis
- Exchangeable cations and cation exchange capacity
- Particle size distribution

2.3 Slimes Characterisation

Slimes characterisation was conducted on Gahcho Kue Tuzo ore samples as per test procedure highlighted in the Group Mining & Exploration Slimes Characterisation Work Instruction Manual, Document No. 5624-B00P01-PSS-00001-5624.

2.4 Sample Description

Gahcho Kue Tuzo Mine sampling programme supplied ore material in the form of drill core as presented in Table 1 below.

Table 1: Tuzo sample descriptions

Description	Position	LR No	Number of Trays
MPV-07-280C	Bottom	LR-070925-001	8
	Middle	LR-070925-002	6
	Top	LR-070925-003	10
MPV-07-294C	Bottom	LR-070925-004	8
	Middle	LR-070925-005	6
	Top	LR-070925-006	7
MPV-07-297C	Bottom	LR-070925-007	6
	Middle	LR-070925-008	6
	Top	LR-070925-009	6
MPV-07-298C	Bottom	LR-070925-010	7
	Middle	LR-070925-011	7
	Top	LR-070925-012	7
MPV-07-299C	Bottom	LR-070925-013	7
	Middle	LR-070925-014	6
	Top	LR-070925-015	8

3 WATER ANALYSIS RESULTS

3.1 Chemical Analysis and Sodium Adsorption Ratio

Summarised chemical analysis results of the raw and 'typical' process water samples for Gahcho Kue area are presented in Table 2 and a complete analysis is presented in Appendix A. An analysis of the water in which kimberlitic clay is suspended provides information as to the colloidal nature of the suspension. The stability of a clay suspension is influenced by the type of ions dissolved in the water, which in turn influences the types of ions adsorbed onto the clay surfaces.

If calcium is adsorbed on the clay surface it provides a divalent link to adjacent clay layers, meaning that although the clay swells in the presence of water, the layers are bound together by the calcium ion preventing complete dissociation. Sodium is a monovalent ion and therefore cannot provide a link between clay layers. When sodium-exchanged clay comes into contact with water it completely dissociates, resulting in a stable colloidal suspension.

The raw and 'typical' water had a very low conductivity of less than 0.2 mS/cm. This water when in contact with any ore material whose clays are sodium-exchanged will potentially generate slurry suspension described as colloidally stable (partial to non-settling slurry). However, most of the Gahcho Kue material clays are not sodium-exchanged, thus the low water conductivity will be of little concern.

Table 2: Summarised water analysis results of Gahcho Kue raw & "typical" process water

SAMPLE I.D.	Tuzo ODS		Phase II ODS (2004)			
	Tuzo Proc H_2O 008	Tuzo Proc H_2O 013	Raw H_2O	Hearne Proc H_2O	5034 Proc H_2O	Supernatant
pH at 25 ^{0}C	8.4	9.4	6.7	6.4	7.1	6.7
Alkalinity as $CaCO_3$	67	97	7	50	58	38.3
Conductivity mS/m at 25 ^{0}C	20	21	2	20	20	14.0
TDS at 180 ^{0}C	156	190	<20	92	98	95.0
Fluoride as F	0.49	0.21	<0.04	0.41	0.31	0.4
Chloride as Cl	2	10	1	26	23	16.7
Sulphate as SO_4	31	12	1	8	5	4.7
Calcium as Ca	20	< 2	2	11	11	8.0
Sodium as Na	31	47	0.6	13	9	7.5
Potassium as K	4	3	0.7	7	10	5.9
Magnesium as Mg	4	< 2	0.6	5	4	3.2
SAR (meq/l)			0.1	0.8	0.6	
Ionic Strength			0.0003	0.0024	0.0024	

4 MINERALOGICAL ANALYSIS RESULTS

4.1 Exchangeable cations and ESP

The results of exchangeable sodium percentage (ESP) are presented graphically in Figure 1. The ESP is a measure of the sodium adsorbed on the clay surface and thus together with SAR provides information as to the colloidal nature of the suspension. When sodium-exchanged clay comes into contact with water, it completely dissociates, resulting in a stable colloidal suspension. The ESP is defined as the amount of exchangeable sodium expressed as a percentage of the cation exchange capacity (i.e. the total amount of all positively charged ions adsorbed on the clay surface).

Major problem caused by excessive salts in soils, is due to the dispersive effect sodium has on soil clays. Dispersion is the reverse process to aggregation, (Ca, Mg and other di- or trivalent cations promote aggregation). Unless the soil salinity is high, dispersion will occur in soils having excess sodium and relatively low calcium and magnesium. **As a general rule, within the slurry pH range of 9.0 to 11, dispersion can be expected to occur when ESP is greater than 15 percent and electrical conductivity is less than 3 mS/cm.**

Most of the Tuzo samples recorded relatively low ESP values. Only two samples, LR070925-001 and 007 recorded higher ESP values and thus would be expected to generate collodially stable slurry suspension when in contact with Gahcho Kue raw water.

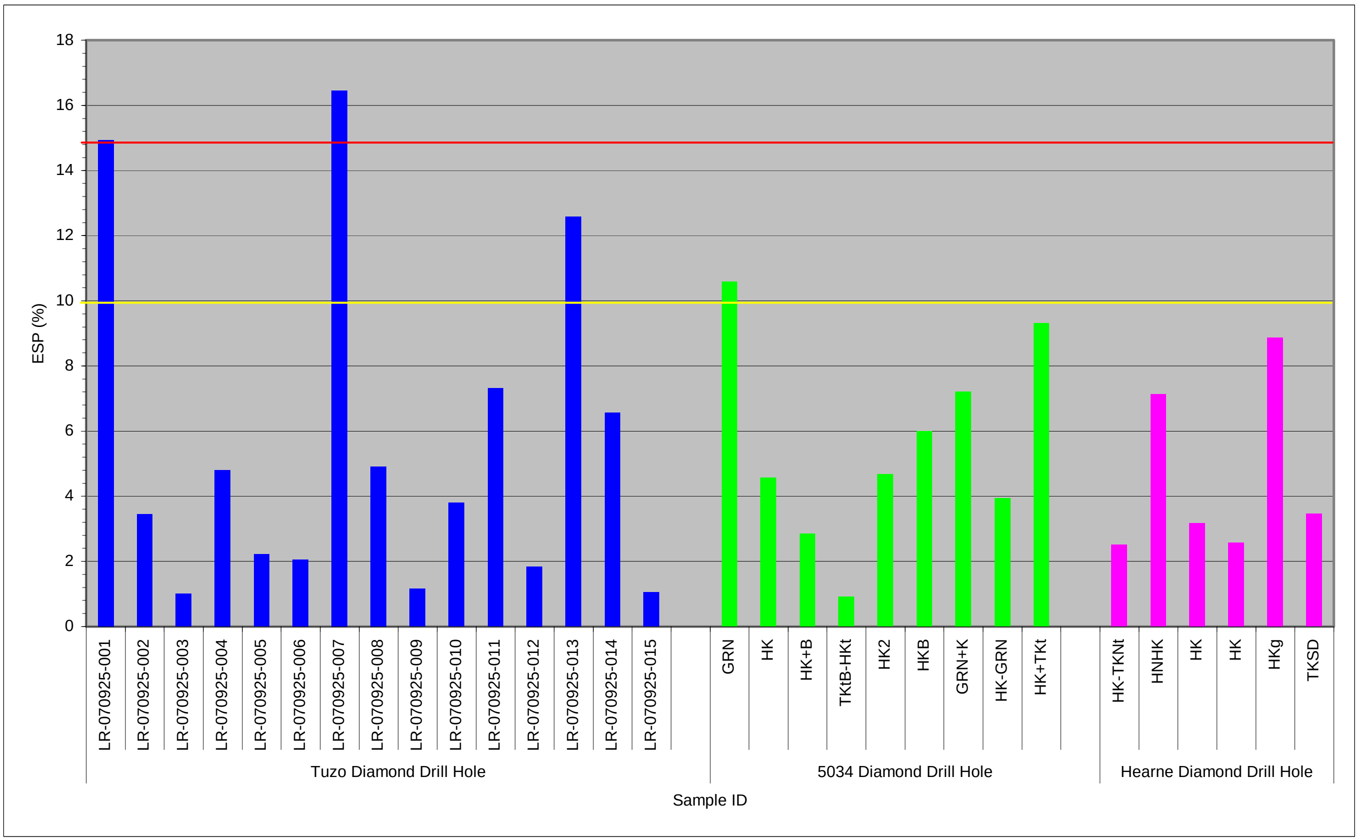

Figure 1: Comparison of the Tuzo ESP with that of the Hearne & 5034 material

4.2 Total and Clay Mineral Analysis

The total and clay mineralogical analyses of the Gahcho Kue samples are presented in Figure 2 and 3 respectively, with detailed data appended in Appendix C and D. Total and clay mineral analysis indicates minerals present in the **–2 mm + 2 μm** and **-2 μm** size fraction of the sample.

The results of total mineral analysis indicated that the Gahcho Kue ore is composed of a wide range of minerals which includes serpentine, smectite, talc, calcite, amphibole, kaolinite, dolomite, feldspar, mica, quartz, pyrophyllite and gibbsite.

The known problematic swelling mineral, smectite, was found in a varying proportion in all Tuzo pipe samples. Smectite has ability to absorb water molecules between the crystal layers, which cause the clay structure to expand and could lead to the dissociation of clay platelets and ultimately dispersion in slurry suspension. The average content of smectite in the Total Mineral Analysis (**–2 mm + 2 μm)** for Tuzo material was 37 percent with a range of 1 to 66 percent.

In general, the mineralogical characteristic of the Tuzo pipe indicate some potential of generating difficult slurry suspension due to swelling smectite content. However, most of the Tuzo material is expected to behave similar to the Hearne and 5034 pipe material when in slurry suspension.

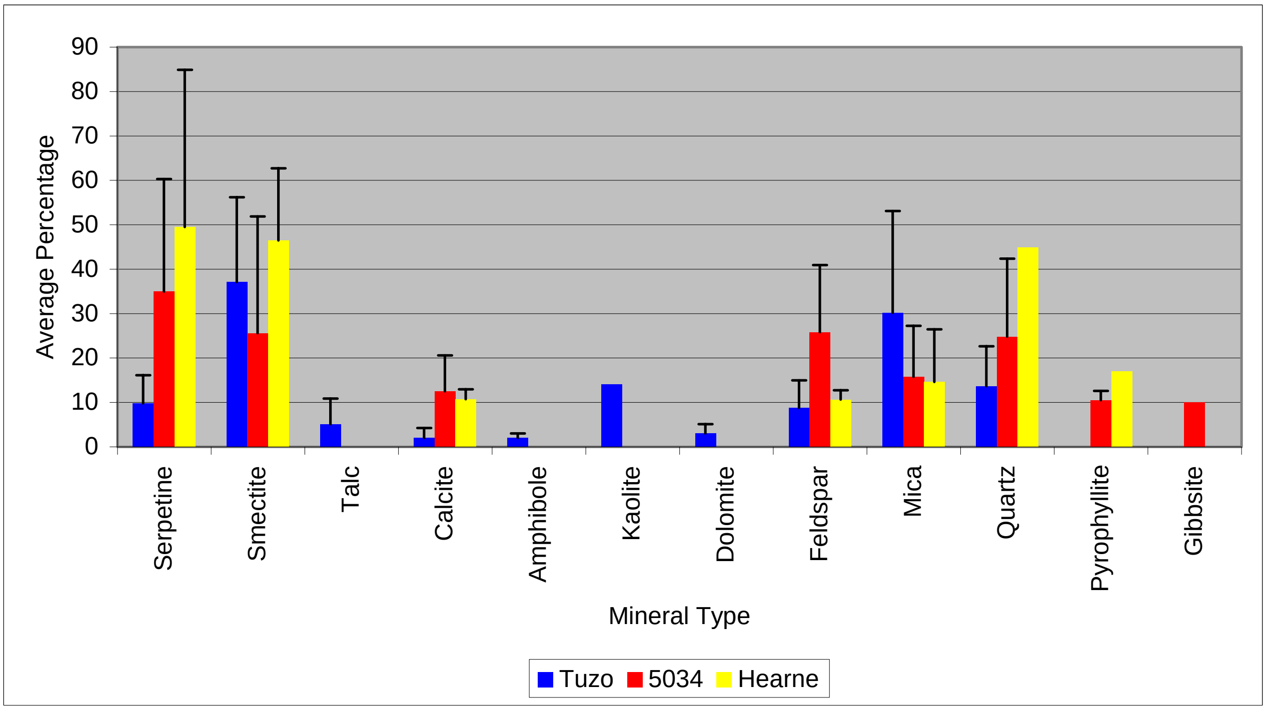

Figure 2: Total Mineral Analysis for Gahcho Kue material

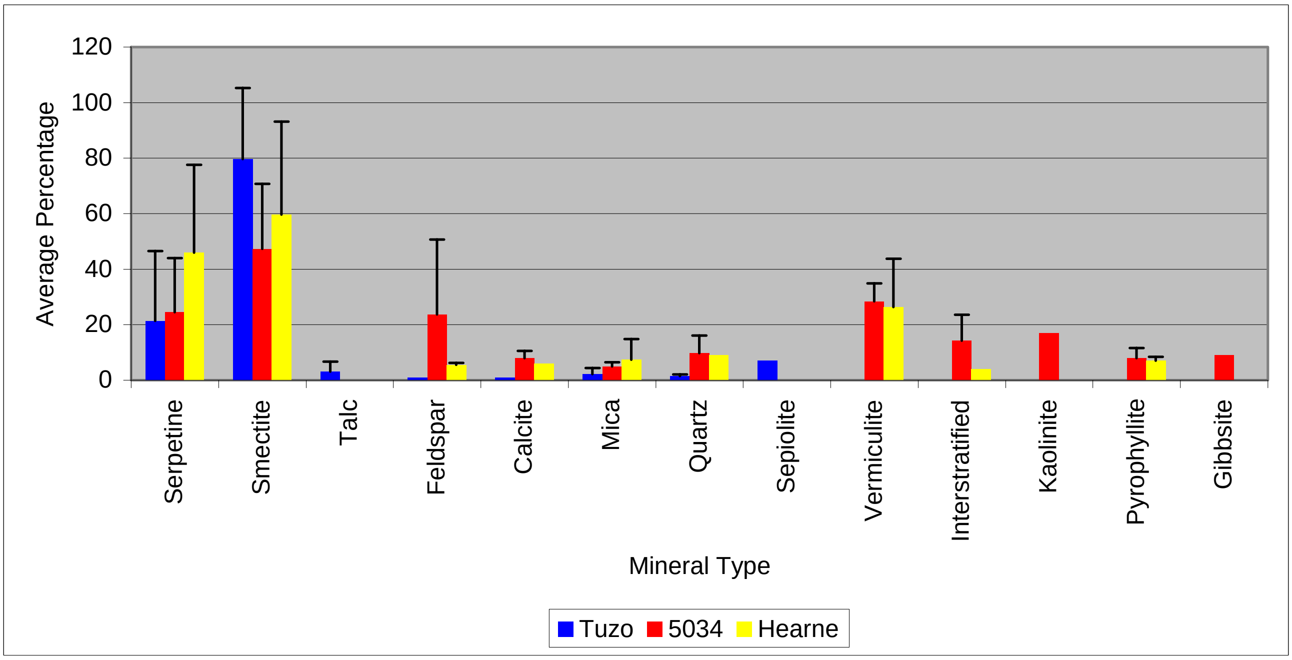

Figure 3: Clay Mineral Analysis for Gahcho Kue material

4.3 Particle Size Distribution (*in situ*)

Figure 4 presents the averaged PSD of the Gahcho Kue material in dry form. The results indicated a low ultra-fine content (-20 µm size fraction) which ranges between 7 and 25 percent. However, it should be noted that when the samples are wetted, they will swell and weather, thereby generating additional ultra-fines. Thus, in a slurry form, an elevated ultra-fine content will be noticed.

Tuzo material indicated a much finer PSD compared to Hearne and 5034 material. A high ultra-fine content in excess of 40 percent increases the surface area of suspension when in contact with water and thus its colloidal stability increases.

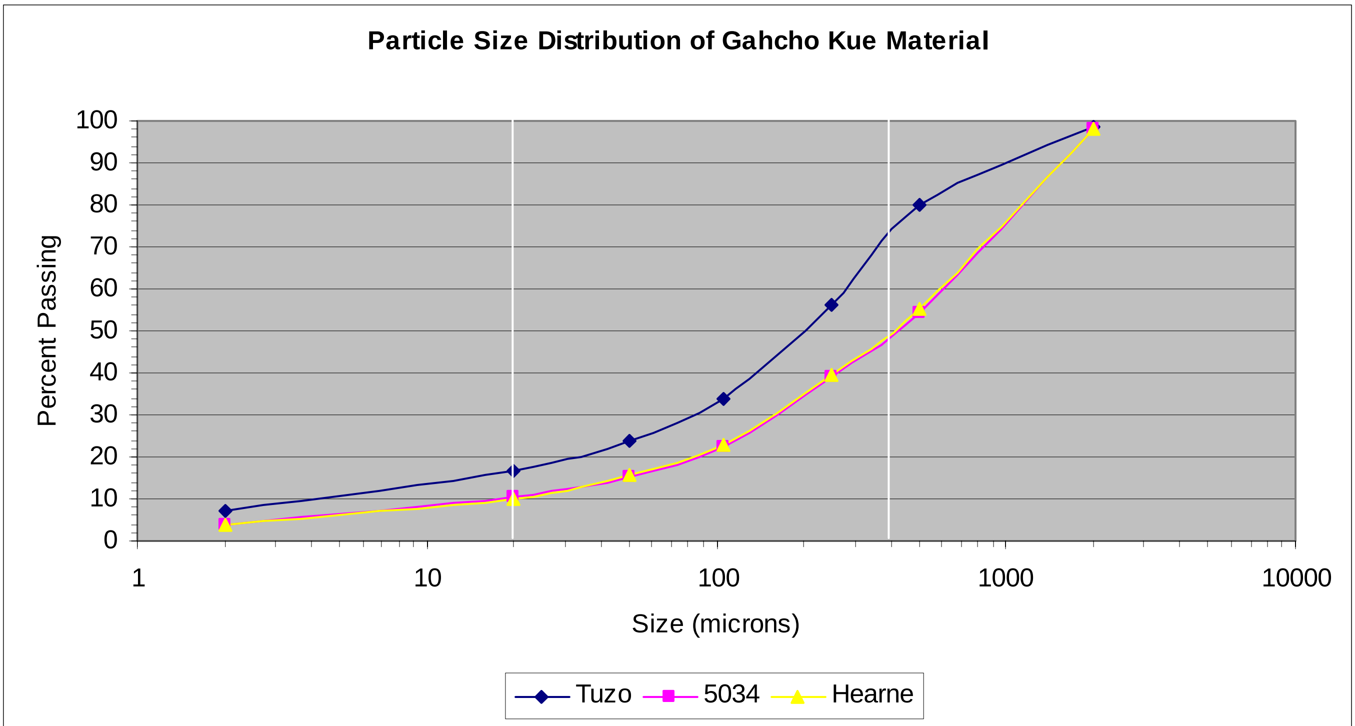

Figure 4: Particle size distribution of Gahcho Kue material (*in-situ*)

5 SLIMES CHARACTERISATION RESULTS

5.1 Feed Solids Optimisation

The process plant typically produces a thickener feed slurry at variable solids concentration based on the water usage at the various metallurgical unit processes. The internal dilution features of the thickening units are then used to adjust the thickener feed solids concentration to the optimum required for flocculation as determined through the static dewatering test work. Most modern thickeners have variable internal dilution features that are capable of adjusting the dilution ratio as the feed characteristics change.

The results indicated that the optimum settling rate and settling flux were achieved at about 7.5 percent solids concentration for the majority of Tuzo slurry samples. Characterisation of the Hearne and 5034 material was only conducted on the 5 and 10 percent slurry solids concentration.

5.2 Slimes Settling Data

The summarised settling data of Tuzo Pipe slurry are presented in Table 3 according to the geological description. Detailed results are presented in Appendix E.

The unflocculated slimes characteristics indicated the slurry pH range of 8.8 – 9.6 and conductivity of 0.65 – 2.62 mS/cm. *Experience has shown that slurry samples with conductivity, in excess of 3.0 mS/cm tends to settle easily and in most cases would not require coagulation or salt/pH modification.*

The optimised flocculant dosage rate for the majority of Tuzo slimes material indicated relatively low consumption rates which are similar to the previous Gahcho Kue study for the Hearne and 5034 ore materials. Flocculant consumption for the Tuzo slurry samples (excluding outliers) was ranging between 2.4 – 60.4 g/t.

An outlier in the MPV-07-280C and 297C was recorded for the bottom samples which resulted in coagulant consumption of 304 g/t and a flocculant consumption of about 200 g/t. The reasons for this elevated reagent consumption can be attributed to relatively high ESP in excess of 15% and pH value of 9.6 which is in the colloidally stable pH range.

The optimised settling rate envelope for Tuzo slurries ranges from 7.2 to 18 m/h, which are relatively lower than those achieved for 5034 and Hearne slurry samples (about 10 – 35 m/h). For high rate and paste thickeners, when sizing is based on the internal rise rate, a typical rise rate in the order of 6 m/h is generally applied. The smaller difference between the optimised settling rate of the Tuzo material and the rise rate of the clarified fluid inside the thickener, would not allow for additional thickening capacity.

The slurry generated underflow slurry with moderately high solids concentration slurry ranging from 37 to 63 percent solids. These underflow slurries were generated under static gravity consolidation conditions (unraked). When a rake was employed, an improvement in the compaction and the underflow solids concentration was noticed.

Table 3: Summarised settling characteristics of Tuzo samples

Sample Description		pH	Conductivity (mS/cm)	Coag.	Floc.	Settling Rate	Clarity	% Underflow Slurry	
				g/t	g/t	m/h	NTU	Unraked	Raked
MPV-07-280C	Bottom	9.6	1.24	304	199	11.5	1794	37.2	41.3
	Middle	9.0	0.66		10	16.2	735	52.9	53.4
	Top	8.8	1.10		9.8	16.3	292	49.5	50.4
MPV-07-294C	Bottom	9.2	1.87		2.6	16.5	208	52.5	55.9
	Middle	9.1	2.08		2.5	17.9	178	61.4	63.1
	Top	8.9	0.93		7.8	18.0	1055	52.4	52.5
MPV-07-297C	Bottom	9.6	1.40	305	201	7.2	2000	39.8	40.4
	Middle	9.2	1.24		15.1	14.7	976	45.2	46.0
	Top	8.8	1.31		2.6	13.4	256	52.9	53.5
MPV-07-298C	Bottom	8.8	2.62		2.4	17.7	67	56.5	57.0
	Middle	9.4	1.13		2.6	17.3	45	63.3	64.6
	Top	9.0	1.09		2.5	16.8	42	59.7	60.6
MPV-07-299C	Bottom	9.6	1.45		60	15.2	979	43.5	47.1
	Middle	9.5	0.87		60	14.2	794	40.2	41.3
	Top	9.0	0.65		10.2	16.0	306	50.8	51.2

6 GENERAL COMPARISON OF TUZO WITH PREVIOUS DATA

This section compares the findings of the previous Gahcho Kue ore dressing study with the current data. The high level comparison is as follows:

- Typical process water for the Tuzo ore body exhibited similar conductivity values with that of the Hearne and 5034 ore bodies. Conductivity values of Gahcho Kue process water are regarded as low at 0.2 mS/cm.
- Most of the Tuzo ore samples had low ESP values similar to that exhibited by the Hearne and 5034 ore samples. The outlier was only two Tuzo samples, *MPV-07-280C Bottom* and *MPV-07-297C Bottom*, which had relatively high ESP values in excess of 15 percent. Based purely on the interpretation of the ESP, these two samples are expected to generate partial or non-settling slurry suspension.
- Tuzo material showed finer slurry PSD compared to Hearne and 5034.
- Similar flocculants dosages were recorded for the Tuzo, Hearne and 5034 ore bodies, except for the two outlier samples found in Tuzo ore body.
- Tuzo ore samples had relatively lower settling rates ranging between 7.2 – 18 m/h compared to Hearne and 5034 samples with settling rates of 10 – 35 m/h.

7 CONCLUSIONS AND RECOMMENDATIONS

Clay Behavioural Analysis

Analysis of the dry in-situ ore characterisation with respect to ESP and cation exchange capacity indicate that two out of fifteen Tuzo samples had a potential to generate partially to non-settling slurry suspensions.

Static Settling Tests

The static slimes characterisation result for the fifteen (15) Tuzo samples can be summarised as follows:

- Optimum slurry feed solids concentration is 7.5 percent solids,
- Optimum flocculant dose range is 2.5 to 60 g/t for most of slurry samples while the outlier two samples required coagulant at a rate of 304 g/t and flocculant dose of 200 g/t,
- Settling rate envelope is 7 to 18 m/h,
- Achievable underflow solids concentration under static un-raked consolidation range from 37 to 63 percent.

Most of the Tuzo ore samples can be treated efficiently on the water reticulation circuit designed based on the Hearne and 5034 samples data.

8 REFERENCES AND APPLICABLE DOCUMENTS

Tomo P, "*Note for the Record – Gahcho Kue Phase II ODS Slimes Characterisation*", MPS Internal Report, Document No. 2240-900559-PSS-00001-5624, October 2004.

Tomo P, "*Note for the Record – Gahcho Kue Slimes Characterisation*", MPS Internal Report, Document No. T05-4000130-855, October 2002.

Patterson RA, "*Explaining the mysteries of salinity, sodicity, SAR and ESP in On-site practice in Proceedings of On-Site '01 Conference: Advancing On-site Wastewater Systems* by RA Patterson & MJ Jones (Eds), published by Lafax Laboratories, Armidale, 2001.

APPENDIX A: DETAILED WATER ANALYSIS RESULTS

SAMPLE NUMBER	Tuzo ODS		Phase II ODS (2004)			
SAMPLE I.D.	**Tuzo Proc H_2O 008**	**Tuzo Proc H_2O 013**	**Raw Water**	**Hearne Proc Water**	**5034 Proc Water**	**Supernatant**
pH at 25 degrees C	8.4	9.4	6.7	6.4	7.1	6.7
Alkalinity as $CaCO_3$	< 2	15				
Alkalinity as $CaCO_3$	67	97	7	50	58	38.3
Conductivity mS/m at 25 ^{0}C	20	21	2	20	20	14.0
Total Dissolved Solids at 180 ^{0}C	156	190	<20	92	98	95.0
Total Suspended Solids at 105 ^{0}C	4755	9231	<10	644	441	542.5
Fluoride as F	0.49	0.21	<0.04	0.41	0.31	0.4
Chloride as Cl	2	10	1	26	23	16.7
Nitrite as NO_2	< 0.5	< 0.5	<0.5	<0.5	<0.5	<0.5
Nitrate as NO_3	< 0.5	< 0.5	<0.5	2	<0.5	2.0
Nitrate as N	< 0.5	< 0.5	<0.5	0.50	<0.5	0.5
Phosphate as PO_4	< 0.5	< 0.5	<0.5	<0.5	<0.5	<0.5
Sulphate as SO_4	31	12	1	8	5	4.7
AA Calcium as Ca	20	< 2	2	11	11	8.0
AA Sodium as Na	31	47	0.6	13	9	7.5
AA Potassium as K	4	3	0.7	7	10	5.9
AA Magnesium as Mg	4	< 2	0.6	5	4	3.2
Silica as Si			<0.5	4	5	4.5
Calcium Hardness as $CaCO_3$	49	3	5	27	21	17.7
Magnesium Hardness as $CaCO_3$	15	7	2	21	48	23.7
Total Hardness as $CaCO_3$	64	10	7	48	69	41.4
Cation / Anion Balance - % Diff.			1.1	**-9.8**	**-15.6**	-8.1

APPENDIX B: CATIONS & CATION EXCHANGE CAPACITY

Pipe	Description	Depth	Sample #	Na	K	Ca	Mg	S Value	CEC (T Value)	ESP
Tuzo Diamond Drill Hole	MPV-07-280C	Bottom	LR-070925-001	5.27	0.54	29.34	11.14	46.29	35.29	**14.9**
		Middle	LR-070925-002	0.99	0.51	24.61	10.41	36.52	28.7	3.4
		Top	LR-070925-003	0.34	0.38	28.55	12.19	41.46	33.71	1.0
	MPV-07-294C	Bottom	LR-070925-004	0.57	0.44	17	2.95	20.97	11.85	4.8
		Middle	LR-070925-005	0.08	0.33	9.33	5.29	15.03	3.61	2.2
		Top	LR-070925-006	0.56	0.31	21.83	10.63	33.33	27.16	2.1
	MPV-07-297C	Bottom	LR-070925-007	5.17	0.54	29.3	13.28	48.25	31.42	**16.5**
		Middle	LR-070925-008	1.78	0.51	28.82	13.02	44.13	36.22	4.9
		Top	LR-070925-009	0.37	0.44	27.48	12.31	40.59	31.97	1.2
	MPV-07-298C	Bottom	LR-070925-010	0.26	0.26	14.83	7.88	23.22	6.85	3.8
		Middle	LR-070925-011	0.34	0.63	12.19	3.85	17.01	4.65	7.3
		Top	LR-070925-012	0.28	0.46	16.55	8.1	25.39	15.17	1.8
	MPV-07-299C	Bottom	LR-070925-013	3.9	0.47	25.58	10.09	40.04	31	12.6
		Middle	LR-070925-014	2.5	0.46	32.49	12.56	48	38.07	6.6
		Top	LR-070925-015	0.36	0.41	29.85	11.61	42.23	34.23	1.1
5034 Diamond Drill Hole	MPV-02-076C	236	GRN	0.42	0.34	8.17	1.18	10.10	3.96	10.6
	MPV-02-079C	47	HK	0.15	0.17	12.32	5.22	17.86	3.19	4.6
	MPV-02-082C	105	HK+B	0.51	0.68	12.78	8.15	22.11	17.88	2.9
	MPV-02-087C	153	TKtB-HKt	0.42	0.21	35.26	14.25	50.13	45.70	0.9
	MPV-02-076C	284	HK2	0.08	0.13	13.63	3.04	16.87	1.67	4.7
	MPV-02-079C	112	HKB	0.43	0.40	16.00	2.29	19.12	7.15	6.0
	MPV-02-082C	189	GRN+K	0.31	0.19	16.00	1.18	17.67	4.31	7.2
	MPV-02-079C	160	HK-GRN	0.40	0.31	14.08	4.39	19.17	10.12	3.9
	MPV-02-082C	243	HK+TKt	2.07	0.17	26.68	5.81	34.72	22.23	9.3

Pipe	Description	Depth	Sample #	Na	K	Ca	Mg	S Value	CEC (T Value)	ESP
Hearne Diamond Drill Hole	MPV-02-080C	100	HK-TKNt	0.88	0.26	23.53	11.88	36.55	35.07	2.5
	MPV-02-080C	231	HNHK	0.17	0.08	9.22	10.91	20.38	2.38	7.1
	MPV-02-084C	86	HK	0.12	0.20	13.33	4.35	17.99	3.74	3.2
	MPV-02-085C	60	HK	0.07	0.12	7.65	15.10	22.95	2.67	2.6
	MPV-02-085C	142	HKg	0.12	0.18	10.67	3.56	14.52	1.35	8.9
	MPV-02-085C	237	TKSD	1.33	0.21	23.89	9.12	34.55	38.40	3.5

APPENDIX C: TOTAL MINERAL ANALYSIS

Pipe	Description	Depth	Serpetine	Smectite	Talc	Calcite	Amphibole	Kaolite	Dolomite	Feldspar	Mica	Quartz	Pyrophyllite	Gibbsite
Tuzo Diamond Drill Hole	MPV-07-280C	Bottom	2	66	3					8	9	12		
		Middle	9	27		2			1	15	11	35		
		Top	8	50			2		4	4	16	16		
	MPV-07-294C	Bottom	10	19	3					11	32	25		
		Middle	9			1				3	82	5		
		Top		54	18		3				18	7		
	MPV-07-297C	Bottom	1	51	2	1				23	18	4		
		Middle	6	38		1			1	8	31	15		
		Top	8	42						5	20	25		
	MPV-07-298C	Bottom	21	19		7				1	48	4		
		Middle	14	1	1	1					77	6		
		Top	23	11	9	1			6		36	14		
	MPV-07-299C	Bottom	8	45	3					5	30	9		
		Middle	8	57	2					14	8	11		
		Top		40			1	14	3	8	17	17		
5034 Diamond Drill Hole	MPV-02-076C	236								50	19	31		
	MPV-02-079C	47	59			9				9	23			
	MPV-02-082C	105	29	15		21					13		12	10
	MPV-02-087C	153		70						13	5	12		
	MPV-02-076C	284	77			10					13			
	MPV-02-079C	112	38							20	42			
	MPV-02-082C	189	5	3		4				29	6	53		
	MPV-02-079C	160	19	13		7				34	14	13		
	MPV-02-082C	243	18	27		24					7	15	9	

Pipe	Description	Depth	Serpetine	Smectite	Talc	Calcite	Amphibole	Kaolite	Dolomite	Feldspar	Mica	Quartz	Pyrophyllite	Gibbsite
Hearne Diamond Drill Hole	**MPV-02-080C**	**100**	11	58							14		17	
	MPV-02-080C	**231**	79			10					11			
	MPV-02-084C	**86**	66			14				13	7			
	MPV-02-085C	**60**	90			10								
	MPV-02-085C	**142**	46			9				10	35			
	MPV-02-085C	**237**	5	35						9	6	45		

APPENDIX D: CLAY MINERAL ANALYSIS

Pipe	Description	Depth	Serpentine	Smectite	Talc	Feldspar	Calcite	Mica	Quartz	Sepiolite	Vermiculite	Interstratified	Kaolinite	Pyrophyllite	Gibbsite
Tuzo Diamond Drill Hole	**MPV-07-280C**	**Bottom**	2	97	1										
		Middle		98	1			1							
		Top		98	1			1							
	MPV-07-294C	**Bottom**	4	89	2			3	2						
		Middle	57	42			1								
		Top	13	81	6										
	MPV-07-297C	**Bottom**	2	97	1										
		Middle	1	98	1										
		Top	2	88	1			1	1	7					
	MPV-07-298C	**Bottom**	49	49					2						
		Middle	45	37	11			7							
		Top	59	32	9										
	MPV-07-299C	**Bottom**		97	2			1							
		Middle	2	96	1										
		Top		97		1		1	1						
5034 Diamond Drill Hole	**MPV-02-076C**	**236**	13	39		26		5				17			
	MPV-02-079C	**47**	52				10	6	8		24				
	MPV-02-082C	**105**	39	34					7					11	9
	MPV-02-087C	**153**	6	87				3						4	
	MPV-02-076C	**284**	56				5		6		33				
	MPV-02-079C	**112**	8	14		61							17		
	MPV-02-082C	**189**	9	39		4		5	21			22			
	MPV-02-079C	**160**	22	56		4		7	7			4			
	MPV-02-082C	**243**	16	62			9	4						9	

Pipe	Description	Depth	Serpetine	Smectite	Talc	Feldspar	Calcite	Mica	Quartz	Sepiolite	Vermiculite	Interstratified	Kaolinite	Pyrophyllite	Gibbsite
Hearne Diamond Drill Hole	**MPV-02-080C**	**100**	15	71				2				4		8	
	MPV-02-080C	**231**	69	22					9						
	MPV-02-084C	**86**	53			6					41				
	MPV-02-085C	**60**	87				6				7				
	MPV-02-085C	**142**	48			5		16			31				
	MPV-02-085C	**237**	4	86				4						6	

APPENDIX E: SETTLING DATA SUMMARY

Sample Description			pH	Feed Slurry		Conductivity (mS/cm)	Coag.	Floc.	Settling Rate	Clarity		Unraked Underflow Slurry		Raked Underflow Slurry	
				t/m^3	%		g/t	g/t	m/h	NTU	Wedge	%	t/m^3	%	t/m^3
Tuzo Drill Hole	MPV-07-280C	Bottom	9.6	1.049	7.5	1.24	304	199	11.5	1794	11	37.2	1.302	41.3	1.346
		Middle	9.0	1.050	7.6	0.66		10	16.2	735	22	52.9	1.492	53.4	1.498
		Top	8.8	1.049	7.5	1.10		9.8	16.3	292	46	49.5	1.446	50.4	1.457
	MPV-07-294C	Bottom	9.2	1.048	7.4	1.87		2.6	16.5	208	46	52.5	1.486	55.9	1.534
		Middle	9.1	1.051	7.8	2.08		2.5	17.9	178	46	61.4	1.619	63.1	1.647
		Top	8.9	1.032	5.0	0.93		7.8	18.0	1055	32	52.4	1.485	52.5	1.486
	MPV-07-297C	Bottom	9.6	1.051	7.8	1.40	305	201	7.2	2000	12	39.8	1.330	40.4	1.336
		Middle	9.2	1.048	7.4	1.24		15.1	14.7	976	20	45.2	1.392	46.0	1.401
		Top	8.8	1.049	7.5	1.31		2.6	13.4	256	46	52.9	1.490	53.5	1.500
	MPV-07-298C	Bottom	8.8	1.051	7.8	2.62		2.4	17.7	67	46	56.5	1.543	57.0	1.550
		Middle	9.4	1.048	7.4	1.13		2.6	17.3	45	46	63.3	1.650	64.6	1.672
		Top	9.0	1.050	7.6	1.09		2.5	16.8	42	46	59.7	1.591	60.6	1.606
	MPV-07-299C	Bottom	9.6	1.049	7.5	1.45		60	15.2	979	13	43.5	1.371	47.1	1.414
		Middle	9.5	1.048	7.4	0.87		60	14.2	794	22	40.2	1.333	41.3	1.346
		Top	9.0	1.049	7.4	0.65		10.2	16.0	306	46	50.8	1.463	51.2	1.468

Sample Description			pH	Feed Slurry		Conductivity (mS/cm)	Coag.	Floc.	Settling Rate	Clarity		Unraked Underflow Slurry		Raked Underflow Slurry	
				t/m^3	%		g/t	g/t	m/h	NTU	Wedge	%	t/m^3	%	t/m^3
5034 Diamond Drill Hole	MPV-02-076C	GRN	8.0	1.033	5.1	1.61		4.7	32.5			30.1	1.231		
			8.4	1.066	9.9	1.80		5.9	23.6			42.3	1.357		
		HK2	8.5	1.033	5.1	2.09		4.7	31.2			30.0	1.230		
			8.8	1.067	10.1	2.14		5.8	23.0			44.4	1.382		
	MPV-02-079C	HK	8.5	1.034	5.3	1.78		4.6	31.9			32.2	1.251		
			8.7	1.066	9.9	1.92		5.9	21.6			40.7	1.339		
		HKB	8.3	1.034	5.3	1.18		4.6	31.6			43.0	1.365		
			8.7	1.067	10.1	1.70		8.1	18.6			50.3	1.457		
		HK-GRN	8.3	1.033	5.1	1.54		4.7	34.0			32.8	1.256		
			8.7	1.066	9.9	1.88		5.9	22.5			53.0	1.492		
	MPV-02-082C	HK+B	8.1	1.033	5.1	1.29		9.4	20.5			40.2	1.333		
			8.4	1.066	9.9	1.81		10.6	16.7			54.6	1.515		
		GRN+K	8.2	1.034	5.3	2.09		11.4	33.5			39.0	1.320		
			8.9	1.066	9.9	2.38		11.8	18.0			51.1	1.467		
		HK+TKt	8.2	1.033	5.1	1.07		11.8	28.1			40.3	1.335		
			8.6	1.066	9.9	1.39		11.8	13.3			59.0	1.580		
	M PV	TKtB-HKt	8.2	1.034	5.3	1.38		9.2	23.2			30.9	1.238		
			8.7	1.066	9.9	2.08		11.8	10.0			52.8	1.490		
Hearne Diamond Drill Hole	MPV-02-080C	HK-TKNt	8.3	1.035	5.4	1.05		8.9	19.7			30.8	1.237		
			8.6	1.067	10.1	1.98		10.5	10.4			46.0	1.401		
		HNHK	8.3	1.034	5.3	1.19		6.9	34.6			43.9	1.376		
			8.7	1.066	9.9	2.08		7.1	19.7			50.7	1.461		
	M PV	HK	8.2	1.034	5.3	1.16		6.9	32.4			40.2	1.334		
			8.4	1.066	9.9	1.94		9.4	23.4			52.1	1.481		
	MPV-02-085C	HK	8.2	1.034	5.3	1.13		13.7	32.8			46.2	1.403		
			8.7	1.066	9.9	1.71		11.8	16.8			59.1	1.582		
		HKg	8.1	1.033	5.1	1.11		7.1	35.8			30.8	1.237		
			8.6	1.066	9.9	1.68		10.6	24.8			54.7	1.516		
		TKSD	8.2	1.033	5.1	1.65		9.4	22.7			31.1	1.240		
			8.8	1.066	9.9	1.98		11.8	12.2			52.2	1.481		

APPENDIX E

TECHNICAL MEMORANDUM DCN-033 GAHCHO KUÉ EIS POST SUBMISSION/INTEGRATED EVALUATION OF POST CLOSURE ALTERNATIVES, PHASE 2030: TASK 20: MATERIAL CHARACTERIZATION (2011)

DCN-033

TECHNICAL MEMORANDUM

DATE October 14, 2011 **PROJECT No.** 11-1365-0001

TO Andrew Williams
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FROM Rashid Bashir **EMAIL** Rashid_Bashir@golder.com

GAHCHO KUE EIS POST-SUBMISSION\INTEGRATED EVALUATION OF POST-CLOSURE ALTERNATIVES. PHASE 2030: TASK 20: MATERIAL CHARACTERIZATION

1.0 INTRODUCTION

Golder Associates Ltd. (Golder) was retained by De Beers Canada Inc. (De Beers) to identify modifications to the closure options for the Processed Kimberlite Facility (PKC) and mine rock stockpiles at the Gahcho Kué Project that could result in improvements to post-closure water quality. The scope of work requires close integration between several tasks, including soil atmospheric analysis; hydrogeological modelling; geochemical characterization, and iterative updates of the water quality model for the Project.

Saturated-unsaturated soil properties of potential cover materials are key inputs required for soil-atmospheric analysis and hydrogeological modeling. The current cover scenario assumes a 2m thick cover comprising of 1m thick coarse PK layer overlain by 1m of waste rock. The geotechnical and hydraulic properties of these materials, and the underlying fine PK are of great importance in carrying out the soil atmospheric analysis and hydrogeological modeling.

Geotechnical/hydrogeological testing was completed on the samples of the fine and coarse PK to estimate the relevant parameters to be used in the modeling exercise. Waste rock samples were not available for testing. The testing program consisted of the following tests:

- grain size analyses;
- specific gravity;
- standard Proctor compaction;
- soil-water characteristic curve (SWCC); and
- saturated hydraulic conductivity.

In addition to the hydrogeological parameters, coupled soil atmospheric analysis also requires thermal properties of the cover materials. Thermal conductivity and volumetric heat capacity of the fine and coarse PK were also measured in the lab. The following sections provide a summary of the testing results. Detailed results of the tests are presented in Appendix A.

2.0 LABORATORY TESTING

The following section outlines the testing that was undertaken to characterize the geotechnical, hydraulic, and thermal properties of the fine and coarse PK materials.

2.1 Grain Size Distribution

Representative samples of the fine and coarse PK were not available owing to the limited material availability from the pilot plant run by De Beers. Target grain size distributions were provided and are shown in Figure 1 as target fine and coarse PK.

A crushing, sorting and mixing effort was initiated at the Golder unsaturated soils laboratory in Saskatoon, to produce fine and coarse PK materials with grain size distributions as close as possible to the target grain size distributions. Grain size tests were conducted on all the PK material provided to Golder. Following the measurement of grain size distributions, the material was sorted out in various sizes. The sorting effort revealed that there were various size fractions missing that were necessary to generate a material close to the target grain size distributions.

Crushing was initiated to generate the various size fractions necessary. Various sizes were mixed in estimated proportions to generate grain size distributions that will be representative of the target grain size distributions. The generated grain size distributions are also shown in Figure 1.

A closer look at Figure 1 indicates that for the coarse PK, the target and generated grain size distributions are in close proximity to each other. Some of the variation between the target and generated sizes is due to the sample variance.

For the fine PK there is some discrepancy between the generated and target grain size distribution, especially at the smaller grain sizes. A part of this discrepancy is due to the sample variance. The discrepancy at the finer grain sizes can be explained as follows. The target grain size distribution was estimated by simple averaging of discrete grain size measurements from two different tailings streams. A hydrometer analysis would have provided a more representative distribution of grain sizes, especially for the finer sizes. Figure 1 also shows the sieve sizes for the #200 and #400 sieves. An observation can be made when these sieve sizes are compared to the target and generated material. The target and generated materials are in close proximity to each other for the sieve sizes up to the #400 sieve. As the #400 sieve is the finest sieve available, it is difficult to control the grain sizes below this size.

2.2 Specific Gravity

Specific gravity tests were conducted on the fine and coarse PK samples based on the procedures provided in ASTM designation D854. Specific gravity test results were used to determine void ratio and porosity used in the SWCC tests. The specific gravity of the fine and coarse PK were measured to be 2.71 and 2.79, respectively. The measured specific gravity values are similar to those reported in JDS (2010).

2.3 Standard Proctor Compaction Tests

Standard Proctor compaction tests were conducted on the fine and coarse PK samples based on the procedures provided in ASTM designation D698 Method A. The intent of this testing was to obtain values of maximum dry density and optimum water content, for use in sample preparation for hydraulic conductivity and SWCC measurements. The results of these tests are shown in Figure 2 and Figure 3. For the fine PK material, the maximum dry density was 1,763 kg/m^3 with an optimum moisture content of 18.5%. For the coarse PK material, the maximum dry density was 1,950 kg/m^3 with an optimum moisture content of 14.0%.

2.4 Saturated Hydraulic Conductivity Measurements

For the coarse PK sample, the Proctor test yielded a maximum dry density of 1,950 kg/m^3 (1.95 t/m^3) with an optimum water content of 14%. In the Gahcho Kué Project Feasibility Study Report (JDS, 2010) , it is stated that the dry density of coarse PK placed above water and compacted will be 2,000 kg/m^3 (2.0 t/m^3), and the dewatered coarse PK moisture content to be around 18%. The values are similar to the values measured in the Proctor test. It is mentioned in JDS (2010) that compaction in the deposition area will be limited to routing of hauling and spreading equipment. Therefore, it was decided to proceed with 95% of the maximum dry density value of 1,950 kg/m^3 (1.95 t/m^3) for the saturated hydraulic conductivity measurement. This value of density could possibly be achieved for the deposition area as compaction limited to routing of hauling and spreading equipment. The saturated hydraulic conductivity measurement was carried out in a fixed wall permeameter employing the constant head method. The hydraulic conductivity was measured to be 1.1E-05 m/sec and the test results are shown in Figure 4.

The Proctor test for the fine PK yielded a maximum dry density of 1,763 kg/m^3 (1.763 t/m^3) with an optimum moisture content of 18.5%. According to JDS (2010), the dry density of the settled fine PK (no excess ice) is reported as a calculated value of 1,000 kg/m^3 (1.0 t/m^3). This value is substantially less than values of densities measured from the Proctor test in the laboratory.

A decision was made to slurry out a sample of fine PK in to a cell and then to consolidate it with a relatively low stress of 30 kPa. The initial dry density of the slurried sample was 1,180 kg/m^3 with an initial water content of 47.5%. The sample was then consolidated at 30 kPa stress prior to the hydraulic conductivity testing. The density and water content of the consolidated sample, after testing were 1,396 kg/m^3 and 35.2%, respectively. The hydraulic conductivity was measured using the fixed wall permeameter employing the falling head method. The hydraulic conductivity was measured to be 1.4E-09 m/sec and the test results are shown in Figure 5. The test was repeated by preparing another sample using the same procedure as described above. The test results are also shown in Figure 5 and the results from the two tests correlate well.

2.5 Soil-water Characteristic Curves

A SWCC test measures the relationship between the amount of water in the pores of the soil and the negative pore water pressure (or soil suction). This test is necessary in this analysis to assess the water retention and storage capacity of the soil samples. SWCC's were measured using a combined Tempe cell and desiccators with saturated salt solutions, following the selected procedures provided in ASTM designation D6836. A cross-section of a Tempe cell is shown in Figure 6.

For low suctions (up to about 10 kPa), a hanging water column was used with the Tempe cells. For suctions from 10 kPa to 400 kPa, the axis translation method was used, with the Tempe cell pressurized with air. For suctions from 4,100 kPa to 300,000 kPa, controlled relative humidity cells were prepared using various salt solutions. The relative humidity environment can be converted to an equivalent suction value through the use of the Lord Kelvin equation.

Soil-water characteristic curves were measured for the fine and coarse PK according to the procedure described above. Samples were packed to similar densities according to the procedure as described above for the saturated hydraulic conductivity testing. The measured SWCCs for fine and coarse PK are shown in Figure 7 and Figure 8. The Fredlund and Xing (1994) fit to the measured data is also shown in these figures.

2.6 Thermal Properties

Thermal conductivity and specific heat capacity were measured for the fine and coarse PK materials using a KD2 Pro Thermal Properties Analyzer manufactured by Decagon Devices, Inc. The device uses a probe that measures the thermal conductivity according to the procedure ASTM designation D5334 – 08.

Thermal conductivity characterizes the ability of a soil medium to transmit heat by conduction, and is defined as the quantity of heat that will flow through a unit area of a soil medium of unit thickness in unit time under a unit temperature gradient. The thermal conductivity of a soil medium is a function of material type, saturation, and density.

Thermal conductivity measurements were initially made on samples during the Proctor testing and results are shown in Figure 9. The measured thermal conductivity values are plotted as a function of water content with dry density for each sample and also reported on the figure. It should be noted that the results presented in Figure 9 correlate well with the expected effects of material type, density and water content.

Additional measurements of thermal conductivity were made on the fine and coarse samples with densities representative of their state in PK facility. The sample preparation procedure was consistent with the sample procedure adopted for hydraulic conductivity and SWCC measurements. These measurements were made on completely dry and fully saturated samples. The results of these measurements are shown in Table 1.

Table 1: Thermal Conductivity for Coarse and Fine PK in dry and saturated conditions

	Coarse PK, saturated		**Fine PK, saturated**	
	Thermal Conductivity $W\ m^{-1}\ K^{-1}$	Temperature ^{o}C	Thermal Conductivity $W\ m^{-1}\ K^{-1}$	Temperature ^{o}C
1)	1.136	20.51	1.198	19.12
2)	1.261	20.41	1.252	19.08
3)	1.216	20.50	1.243	19.01
	Coarse PK, dry		Fine PK, dry	
1)	0.374	24.49	0.331	24.42
2)	0.371	24.23	0.326	24.34
3)	0.376	24.82	0.431	23.71

The heat capacity of a material is defined as the quantity of heat required to raise the temperature of the material by a unit degree. Expressed on a unit weight basis, it is referred as specific heat capacity and on volume basis as volumetric heat capacity.

Heat capacity of a soil medium is dependent on the heat capacities of its different constituents, namely, soil particles, water, ice (if present), and air. The volumetric heat capacity of the fine and coarse PK were measured using the dual needle probe of KD2 Pro. Measurements were made on the fine and coarse samples with densities representative of their state in PK facility. The results of the measurements are shown in Table 2.

Table 2: Volumetric Specific Heat capacities of Fine and Coarse PK at dry and saturated conditions

	Coarse PK, saturated		**Fine PK, saturated**	
	Volumetric Specific Heat MJ m^{-3} K^{-1}	Temperature °C	Volumetric Specific Heat MJ m^{-3} K^{-1}	Temperature °C
1)	2.387	20.51	2.730	19.12
2)	2.542	20.41	3.085	19.08
3)	2.758	20.50	2.997	19.01
	Coarse PK, dry		Fine PK, dry	
1)	N/A	24.49	2.036	24.42
2)	1.786	24.23	2.103	24.34
3)	1.282	24.82	2.045	23.71

3.0 CLOSURE

We trust that this memo meets your requirements at the present time. Please contact the undersigned if you have any questions regarding this report.

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Greg Misfeldt, M.Sc., P. Eng.
Principal, Senior Geotechnical Engineer

RB/GAM/pls

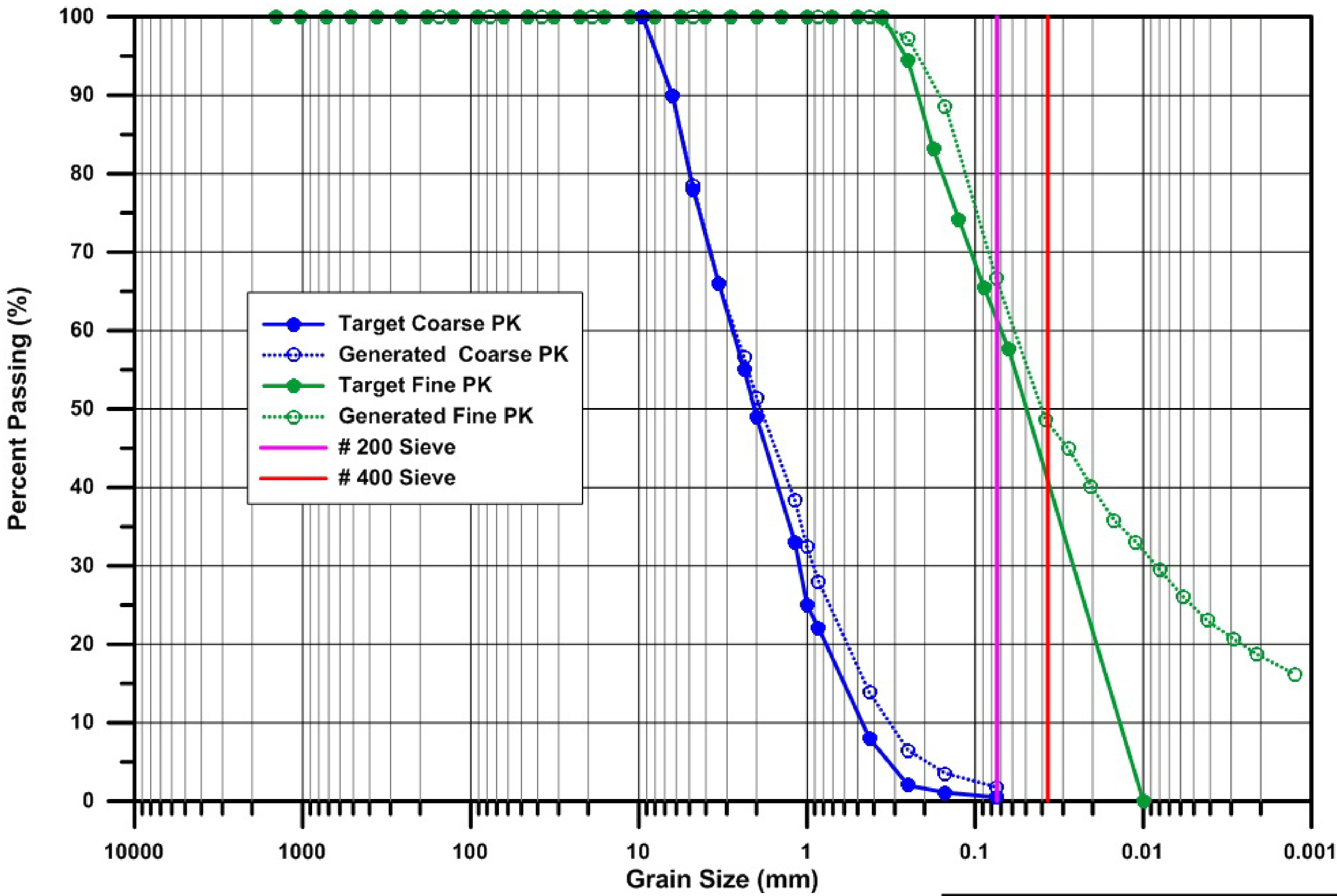
n:\active\2011\1365\11-1365-0001 gahcho kue eis post-submission\integrated evaluation of post-closure alternatives\material characterization\report\11-1365-0001 gahcho kue eis post-submission geotechnical testing _reviewed (5june12).docx

4.0 REFERENCES

Fredlund D G, Xing A. 1994. Equations for the soil-water characteristic curve. Can. Geotech. J 31: 521-532

JDS. 2010. Gahcho Kué Project Feasibility Study Report

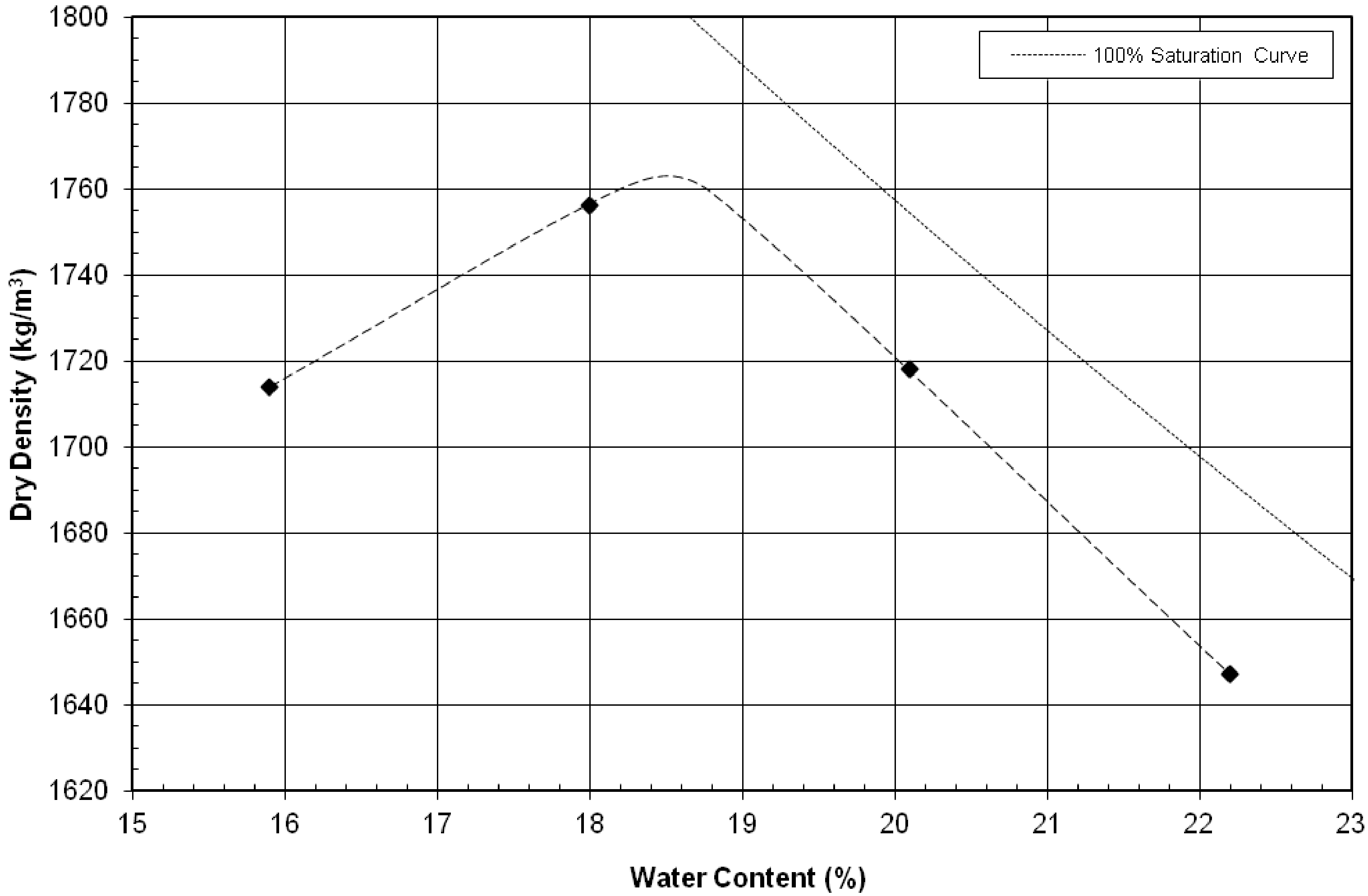
FIGURES



PROJECT	GAHCHO KUE EIS POST-SUBMISSION/ SOIL-ATMOSPHERIC ANALYSIS
TITLE	**Grain Size Distribution Curves**

PROJECT	11-1365-0001		FILE No.
DESIGN	RB		SCALE N/A · REV.
CADD			**FIGURE: 1**
CHECK	JJS	11/10/11	
REVIEW			

Golder Associates
Saskatoon, Saskatchewan



PROJECT

DE BEERS CANADA

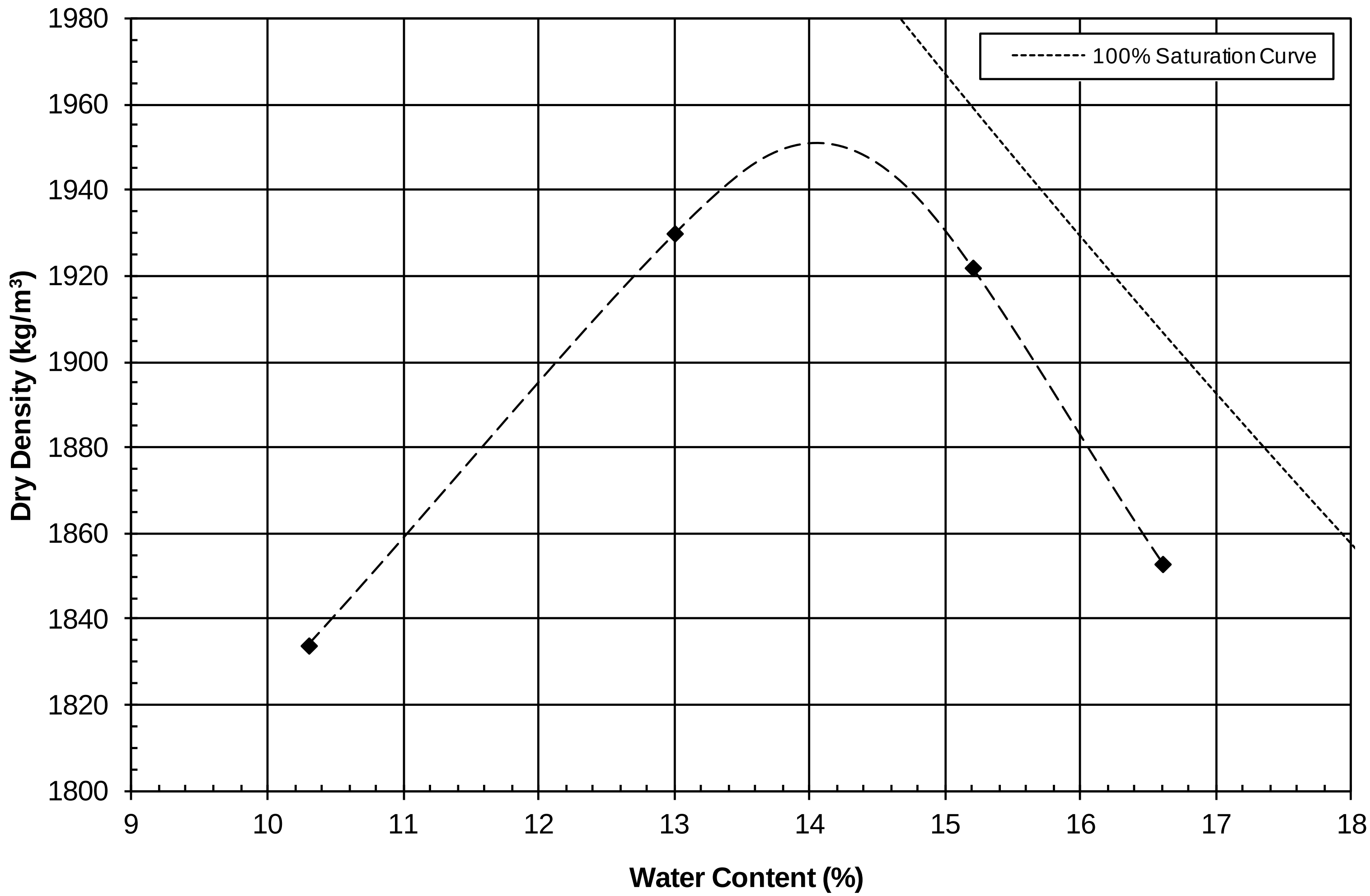
GAHCHO KUE EIS POST-SUBMISSION/
SOIL-ATMOSPHERIC ANALYSIS

TITLE

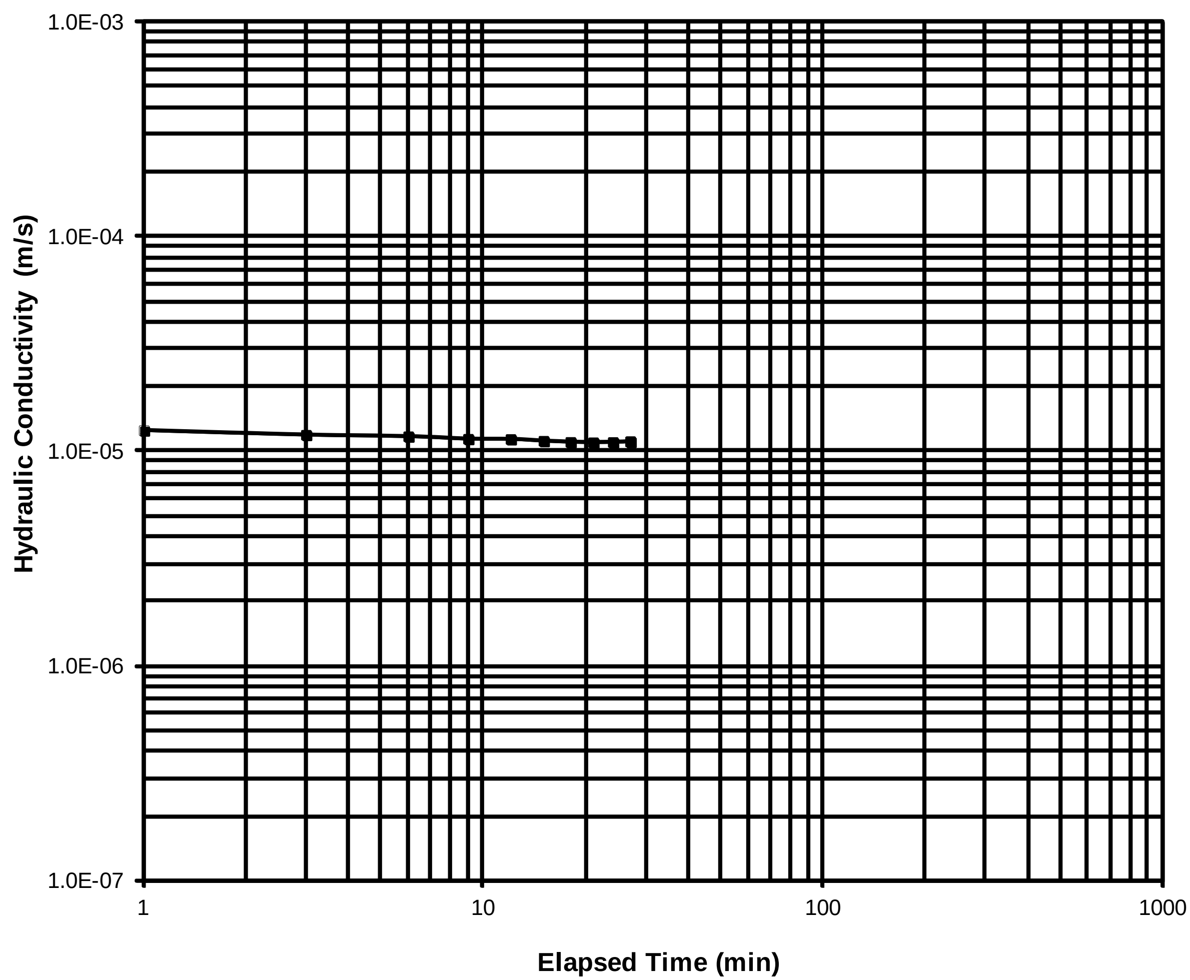
Standard Proctor Curve for the Fine PK

Golder Associates
Saskatoon, Saskatchewan

PROJECT	11-1365-0001		FILE No.	
DESIGN	RB		SCALE N/A	REV.
CADD			**FIGURE: 2**	
CHECK	JJS	11/10/11		
REVIEW				



PROJECT	DE BEERS CANADA	GAHCHO KUE EIS POST-SUBMISSION/ SOIL-ATMOSPHERIC ANALYSIS		
TITLE	**Standard Proctor Curve for the Coarse PK**			
Golder Associates Saskatoon, Saskatchewan	PROJECT	11-1365-0001		FILE No.
	DESIGN	RB		SCALE N/A / REV.
	CADD			**FIGURE: 3**
	CHECK	JJS	11/10/11	
	REVIEW			



PROJECT

DE BEERS CANADA

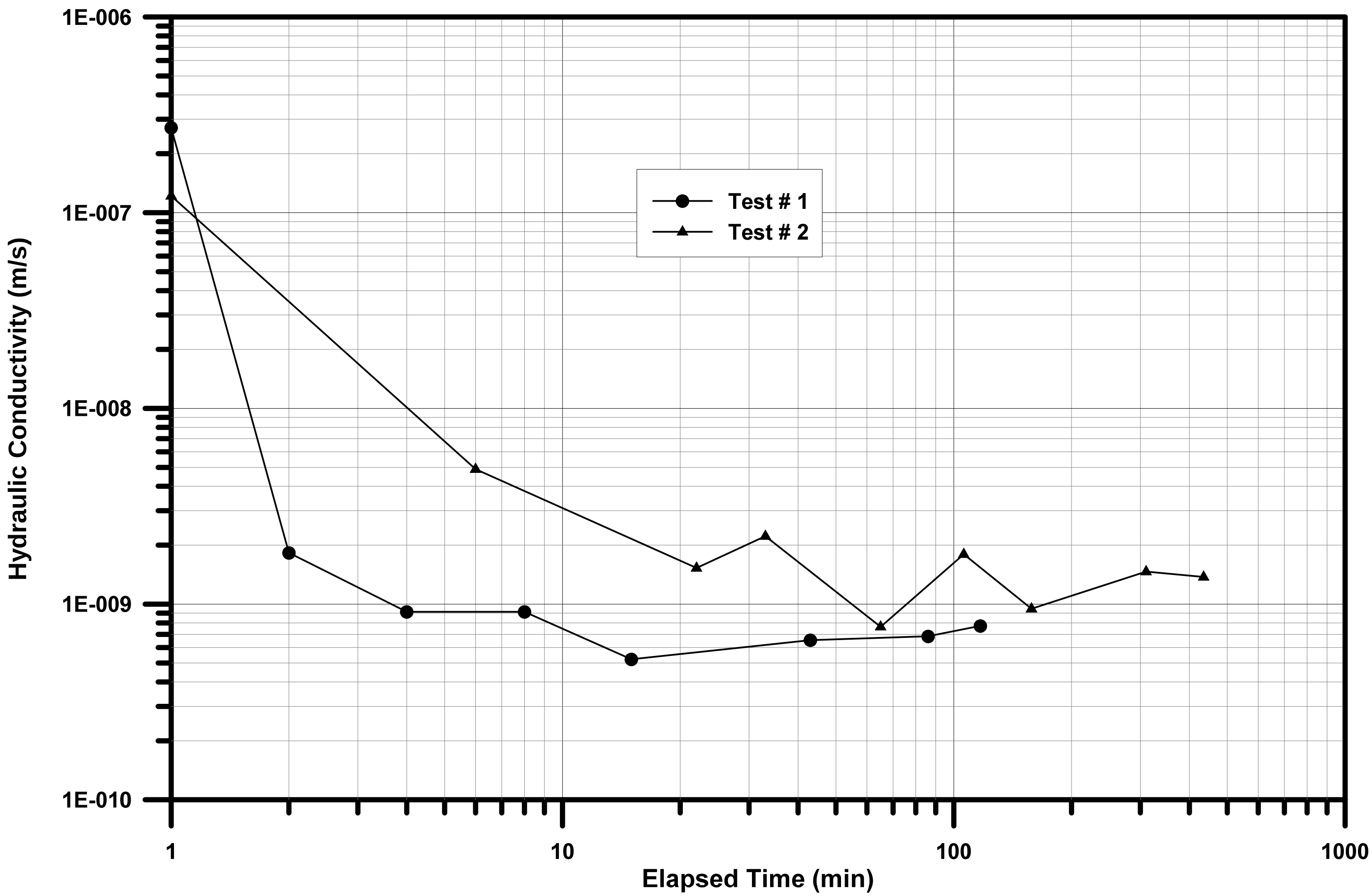
GAHCHO KUE EIS POST-SUBMISSION/
SOIL-ATMOSPHERIC ANALYSIS

TITLE

Saturated Hydraulic Conductivity for the Coarse PK

Golder Associates
Saskatoon, Saskatchewan

PROJECT	11-1365-0001		FILE No.	
DESIGN	RB		SCALE N/A	REV.
CADD			**FIGURE: 4**	
CHECK	JJS	11/10/11		
REVIEW				



PROJECT

DE BEERS CANADA

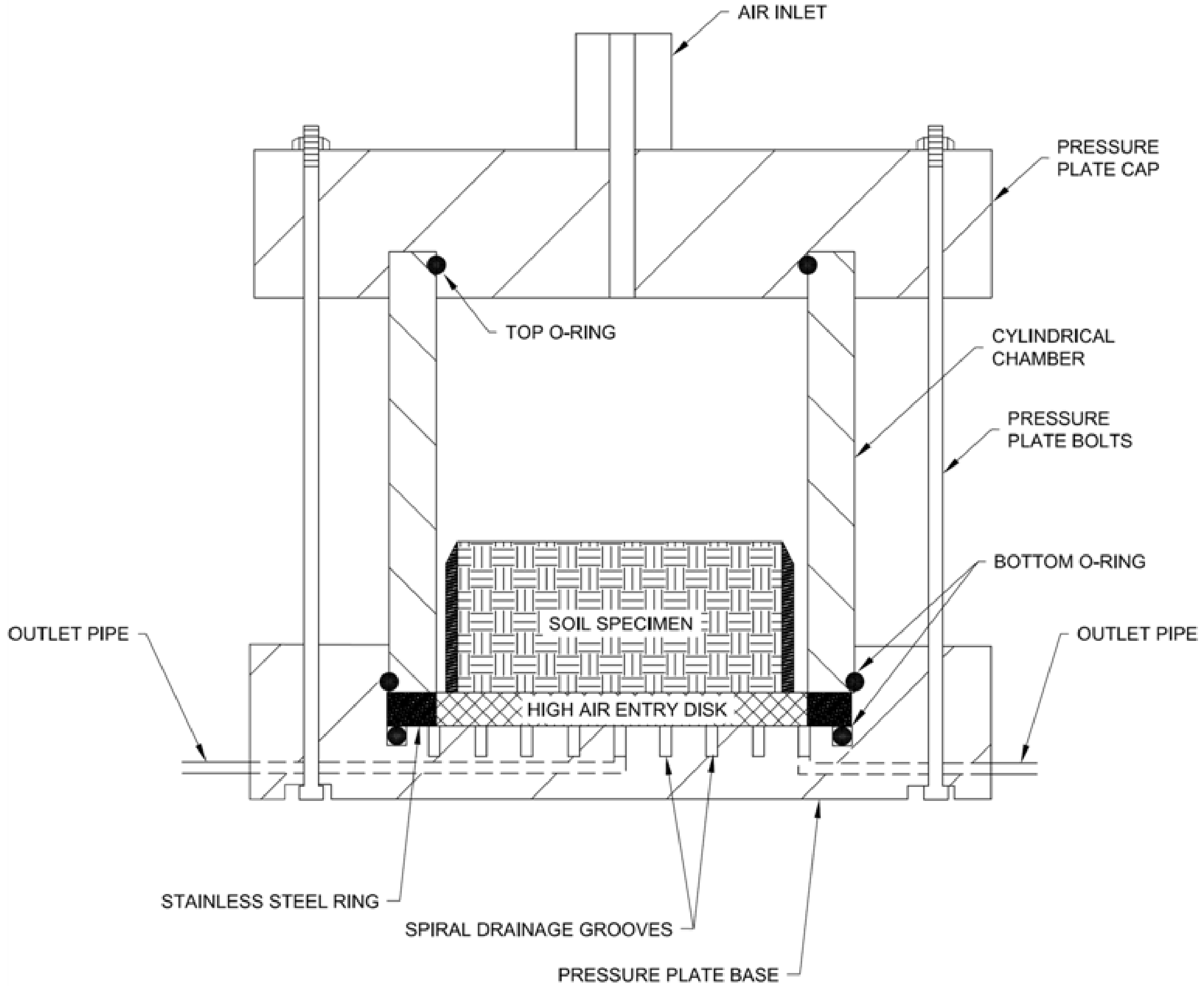
GAHCHO KUE EIS POST-SUBMISSION/
SOIL-ATMOSPHERIC ANALYSIS

TITLE

Saturated Hydraulic Conductivity for the Fine PK

Golder Associates
Saskatoon, Saskatchewan

PROJECT	11-1365-0001		FILE No.	
DESIGN	RB		SCALE N/A	REV.
CADD			**FIGURE: 5**	
CHECK	JJS	11/10/11		
REVIEW				



PROJECT

De Beers Canada

GAHCHO KUE EIS POST-SUBMISSION/
SOIL-ATMOSPHERIC ANALYSIS

TITLE

Cross-section of a Tempe Cell

Golder Associates
Saskatoon, Saskatchewan

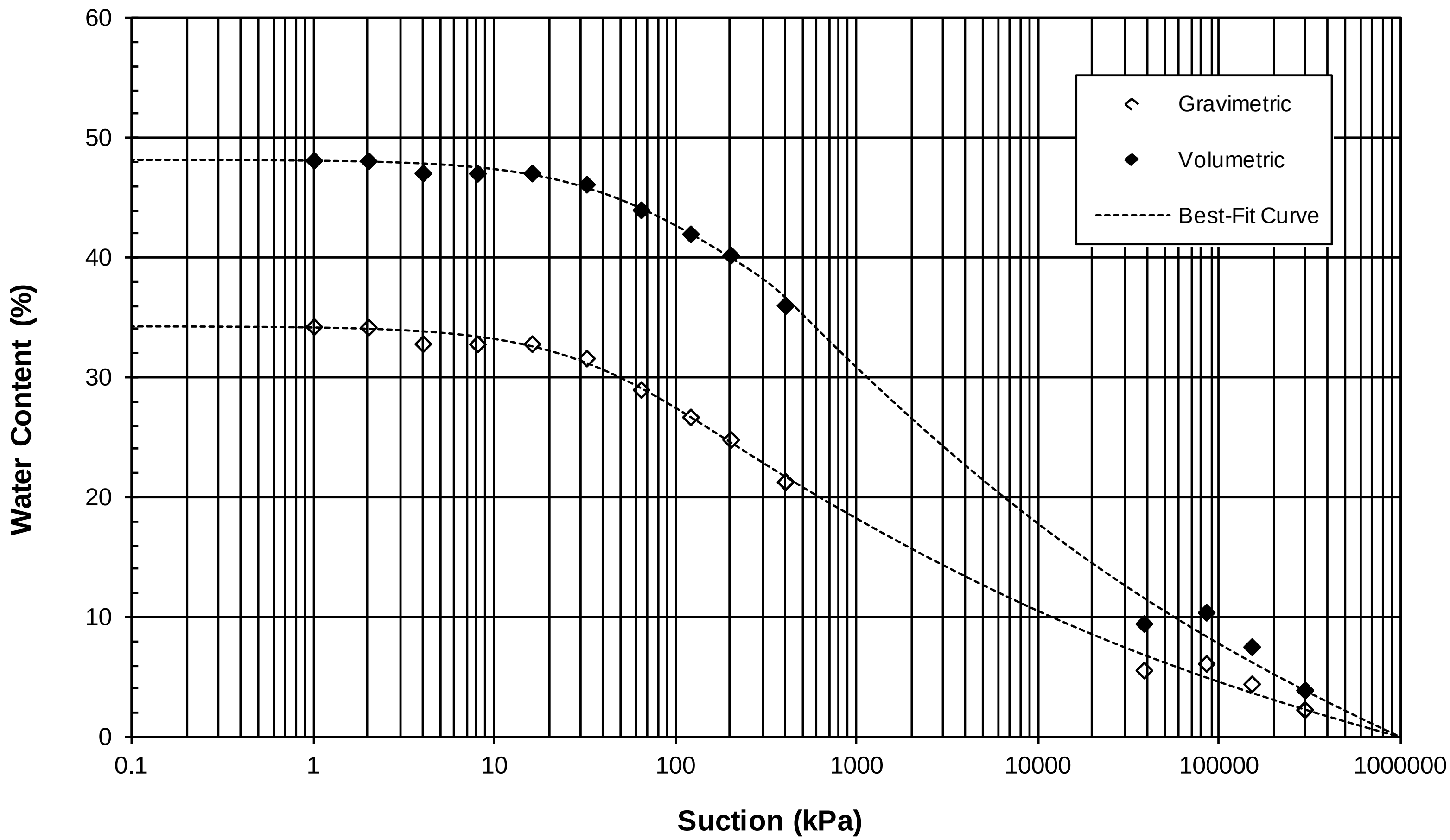
PROJECT	11-1365-0001	
DESIGN	RB	
CADD		
CHECK	JJS	11/10/11
REVIEW		

FILE No.

SCALE N/A

REV.

FIGURE: 6



PROJECT

DE BEERS CANADA

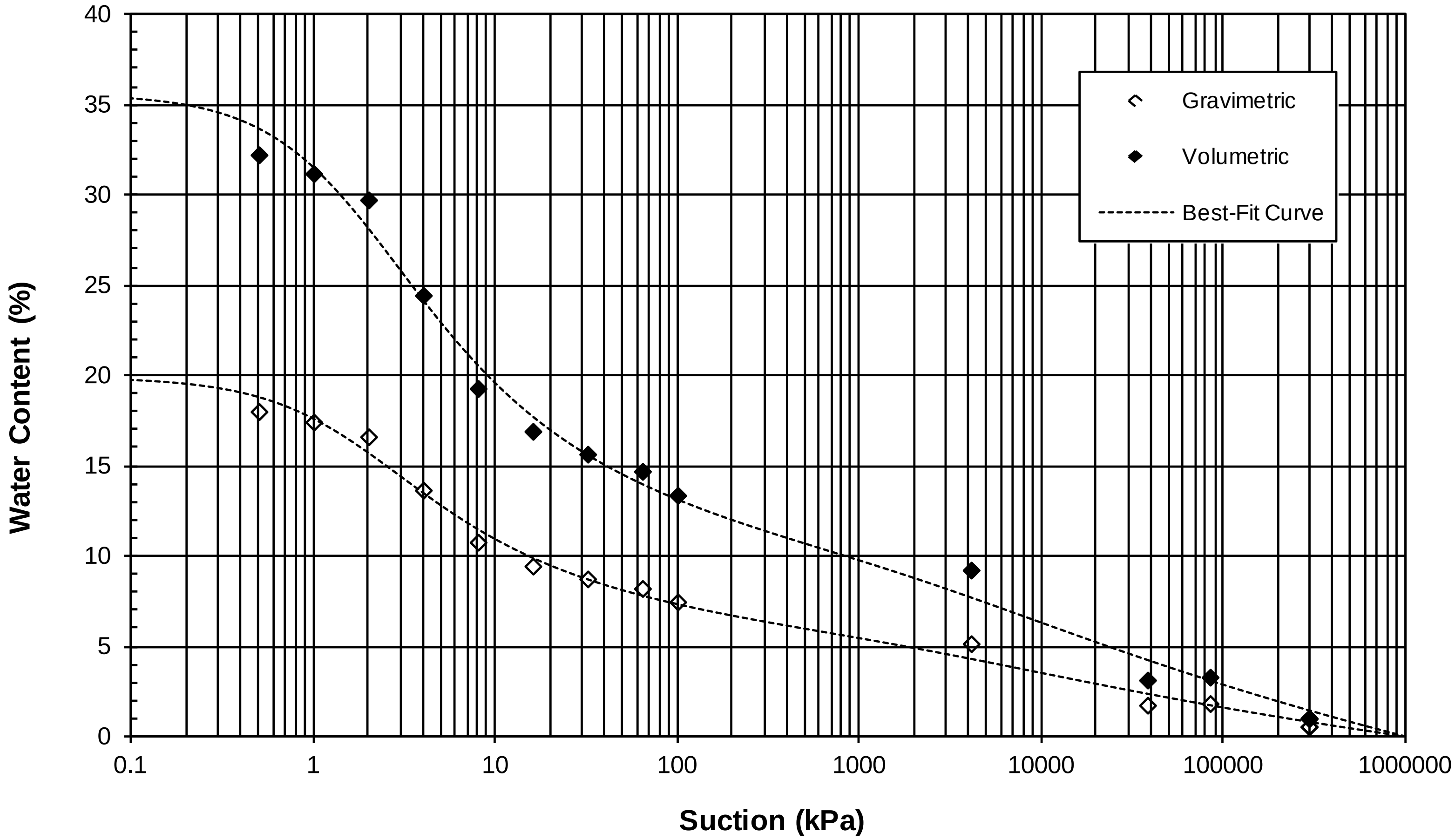
GAHCHO KUE EIS POST-SUBMISSION/
SOIL-ATMOSPHERIC ANALYSIS

TITLE

SWCC for the Fine PK material

Golder Associates
Saskatoon, Saskatchewan

PROJECT	11-1365-0001		FILE No.	
DESIGN	RB		SCALE N/A	REV.
CADD			**FIGURE: 7**	
CHECK	JJS	11/10/11		
REVIEW				



PROJECT

DE BEERS CANADA

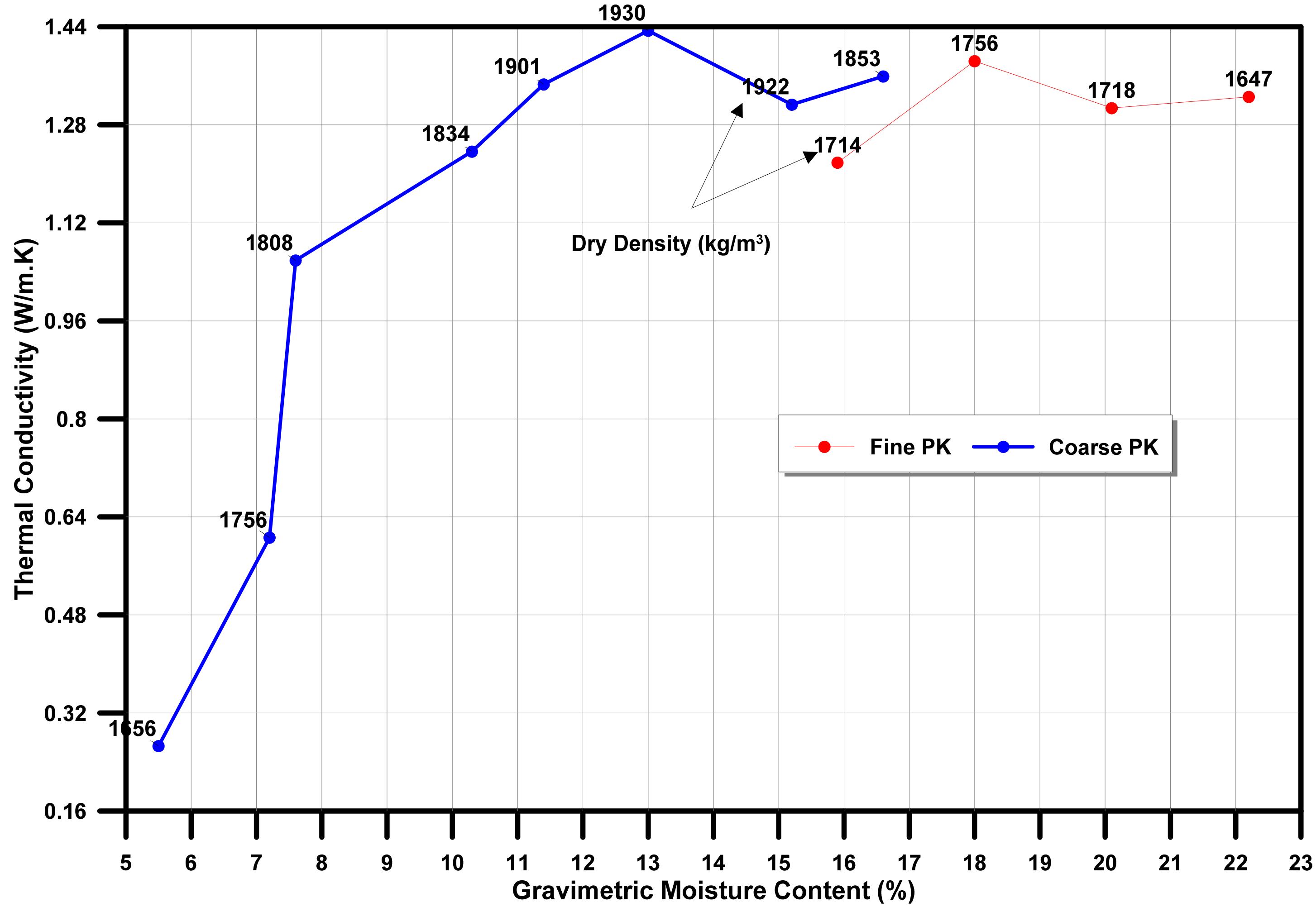
GAHCHO KUE EIS POST-SUBMISSION/
SOIL-ATMOSPHERIC ANALYSIS

TITLE

SWCC for the Coarse PK material

Golder Associates
Saskatoon, Saskatchewan

PROJECT	11-1365-0001		FILE No.	
DESIGN	RB		SCALE N/A	REV.
CADD			**FIGURE: 8**	
CHECK	JJS	11/10/11		
REVIEW				



PROJECT

DE BEERS CANADA

GAHCHO KUE EIS POST-SUBMISSION/
SOIL-ATMOSPHERIC ANALYSIS

TITLE

Thermal Conductivity Measurements for Fine and Coarse PK

Golder Associates
Saskatoon, Saskatchewan

PROJECT	11-1365-0001		FILE No.	
DESIGN	RR		SCALE N/A	REV.
CADD			**FIGURE: 9**	
CHECK	JJS	11/10/11		
REVIEW				

APPENDIX A

Golder Associates

STANDARD PROCTOR - ASTM D698

Project #:	11-1365-0001	Phase:	2030 / 20
Short Title:	DeBeers / Post EIS Submission / GK		
Tested by:	R.S.	Date:	July 5, 2011

Sample#: Fine PK
Source:
Visual Description of Sample:
Date Sample Received:

Compaction Test Results:

water content (%)	dry density (kg/m^3)
15.9	1714
18.0	1756
20.1	1718
22.2	1647

Maximum dry density: ***1763*** ***kg/m^3***
Corrected for oversize material: ***N/A*** ***kg/m^3***

Optimum water content: ***18.5*** ***%***
Corrected for oversize material: ***N/A*** ***%***

Test Summary:
Method used: A
Material used passing: 4.75 mm sieve
Preparation method: dry
Rammer type: manual

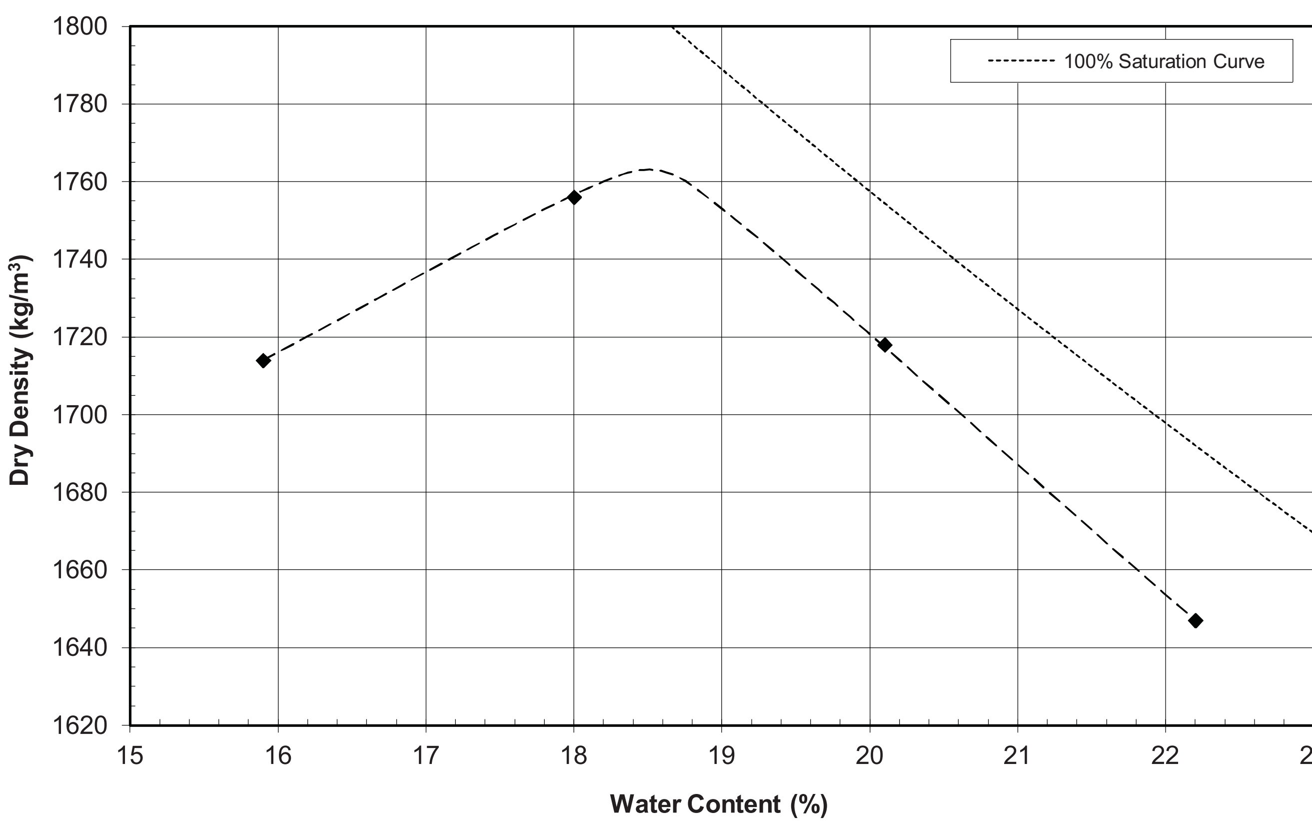
Oversize Correction Data (if applicable):
Oversize fraction: N/A
Bulk Specific Gravity N/A
Water content N/A

100% Saturation Curve Data:
Specific Gravity: 2.71 value: calculated

Comments:

Water content of sample as received in lab:

Graphical Analysis



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Reviewed by:

Golder Associates

STANDARD PROCTOR - ASTM D698

Project #: 11-1365-0001 Phase: 2030 / 20
Short Title: DeBeers / Post EIS Submission / GK
Tested by: R.S. Date: June 21, 2011

Sample#: Coarse PK
Source:
Visual Description of Sample:
Date Sample Received:

Compaction Test Results:

water content (%)	dry density (kg/m^3)
10.3	1834
13.0	1930
15.2	1922
16.6	1853

Maximum dry density: ***1950*** ***kg/m^3***
Corrected for oversize material: ***N/A*** ***kg/m^3***

Optimum water content: ***14.0*** ***%***
Corrected for oversize material: ***N/A*** ***%***

Test Summary:
Method used: C
Material used passing: 19.0 mm sieve
Preparation method: dry
Rammer type: manual

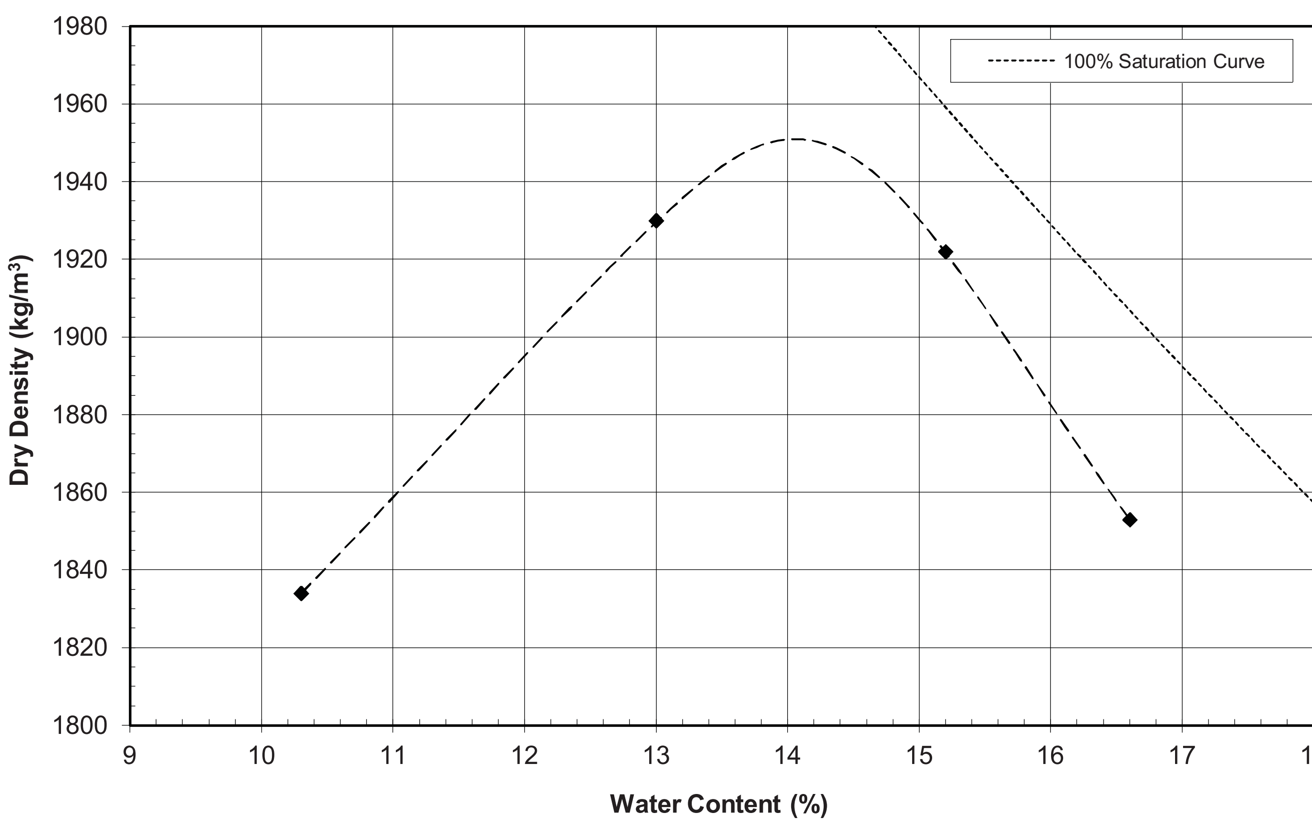
Oversize Correction Data (if applicable):
Oversize fraction: N/A
Bulk Specific Gravity N/A
Water content N/A

100% Saturation Curve Data:
Specific Gravity: 2.79 value: calculated

Comments:

Water content of sample as received in lab:

Graphical Analysis



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Reviewed by: [signature]

CONSTANT HEAD FIXED WALL HYDRAULIC CONDUCTIVITY TEST

Golder Associates

Project #:	11-1365-0001	Phase:	2030 / 20
Short Title:	DeBeers / Post EIS Submission / GK		
Tested By:	D.B.	Date:	August 25, 2011
Sample:	Coarse PK		

Hydraulic Conductivity:

k = 1.1E-05 m/s

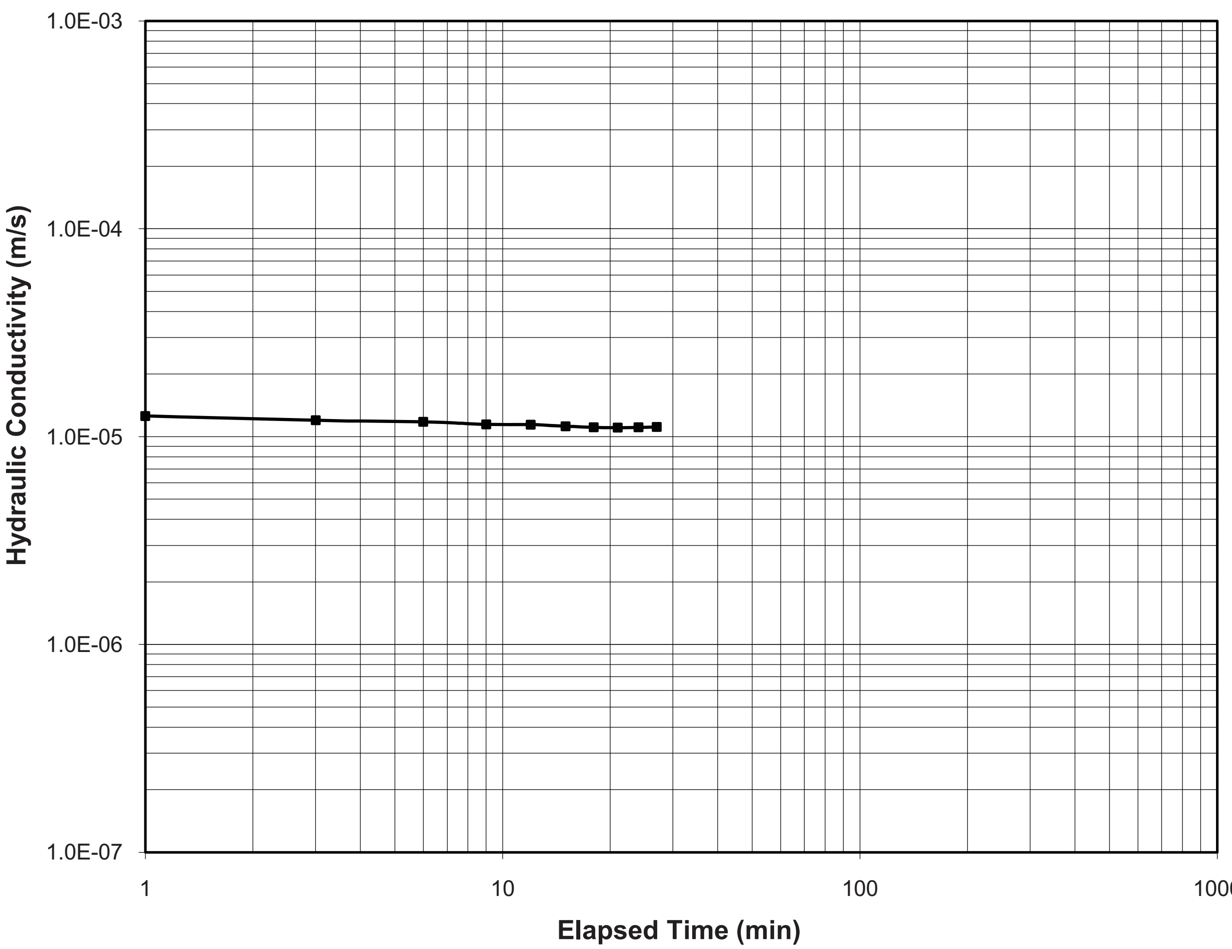
Test Summary:

Initial Dry Density:	1838	kg/m^3
Initial Water Content:	13.9	%
Final Dry Density:	1838	kg/m^3
Sample Diameter:	101.5	mm
Sample Height:	119.6	mm
Material used passing:	9.5	mm sieve

Comments:

Permeant Liquid: tap water

Graph of Hydraulic Conductivity versus Time



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Reviewed by:

FIXED WALL FALLING HEAD HYDRAULIC CONDUCTIVITY TEST

Project #:	11-1365-0001	Phase:	2030 / 20
Short Title:	Debeers / Post EIS Submission / GK		
Tested By:	D.B.	Date:	September 7, 2011
Sample:	Fine PK		

Final Hydraulic Conductivity:

k = 1.4E-09 m/s

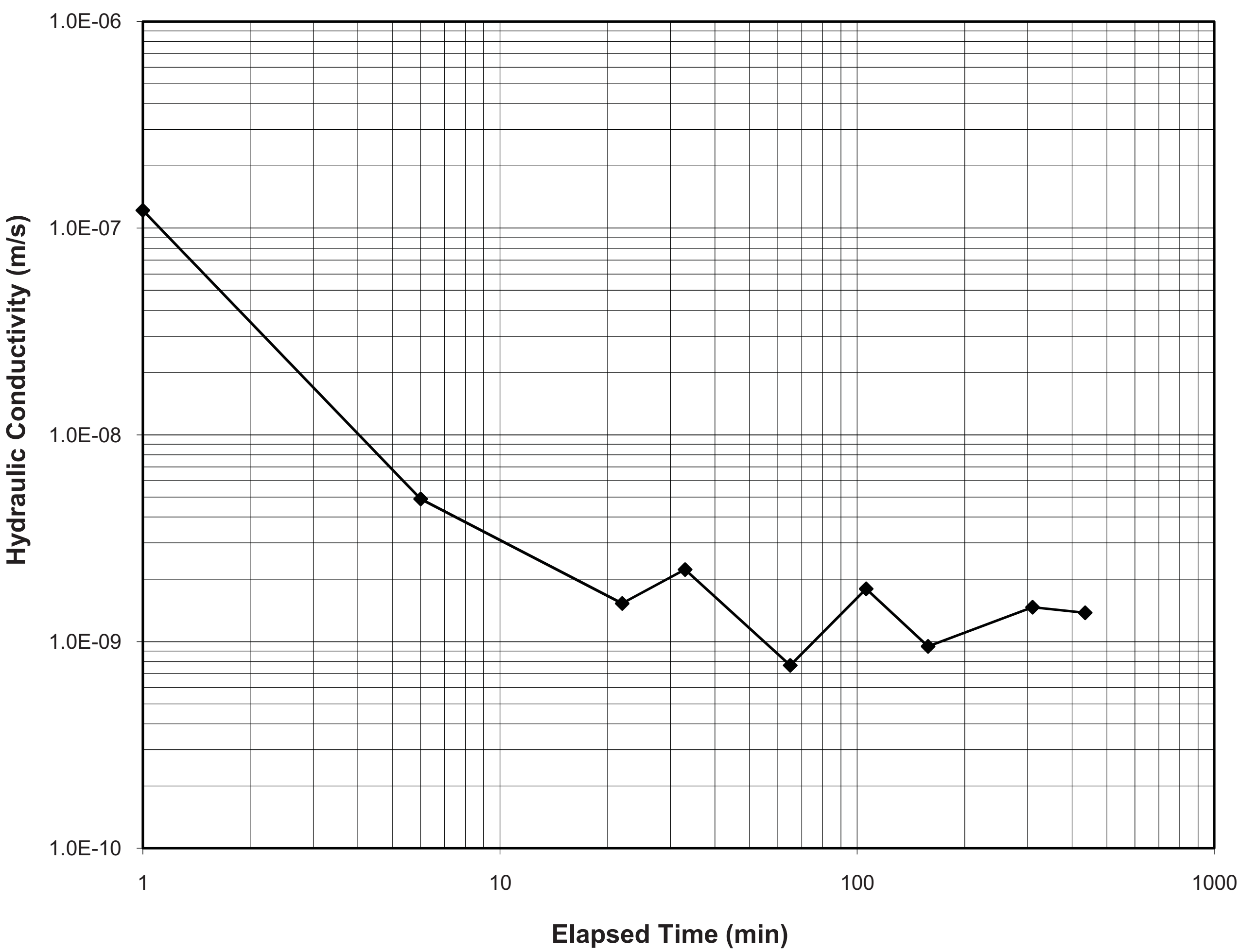
Test Summary:

Initial Water Content:	47.5	%
Initial Dry Density:	1180	kg/m^3
Final Water Content:	35.2	%
Final Dry Density:	1396	kg/m^3
Sample Diameter:	114.34	mm
Final Sample Height:	87.27	mm

Comments:

Specimen consolidated at 30 kPa stress prior to testing. Initial water content and dry density are prior to loading.

Graph of Hydraulic Conductivity versus Time



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Reviewed by:

FIXED WALL FALLING HEAD HYDRAULIC CONDUCTIVITY TEST

Golder Associates

Project #:	11-1365-0001	Phase:	2030 / 20
Short Title:	Debeers / Post EIS Submission / GK		
Tested By:	D.B.	Date:	October 13, 2011
Sample:	Fine PK		

Final Hydraulic Conductivity:

k = 7.0E-10 m/s

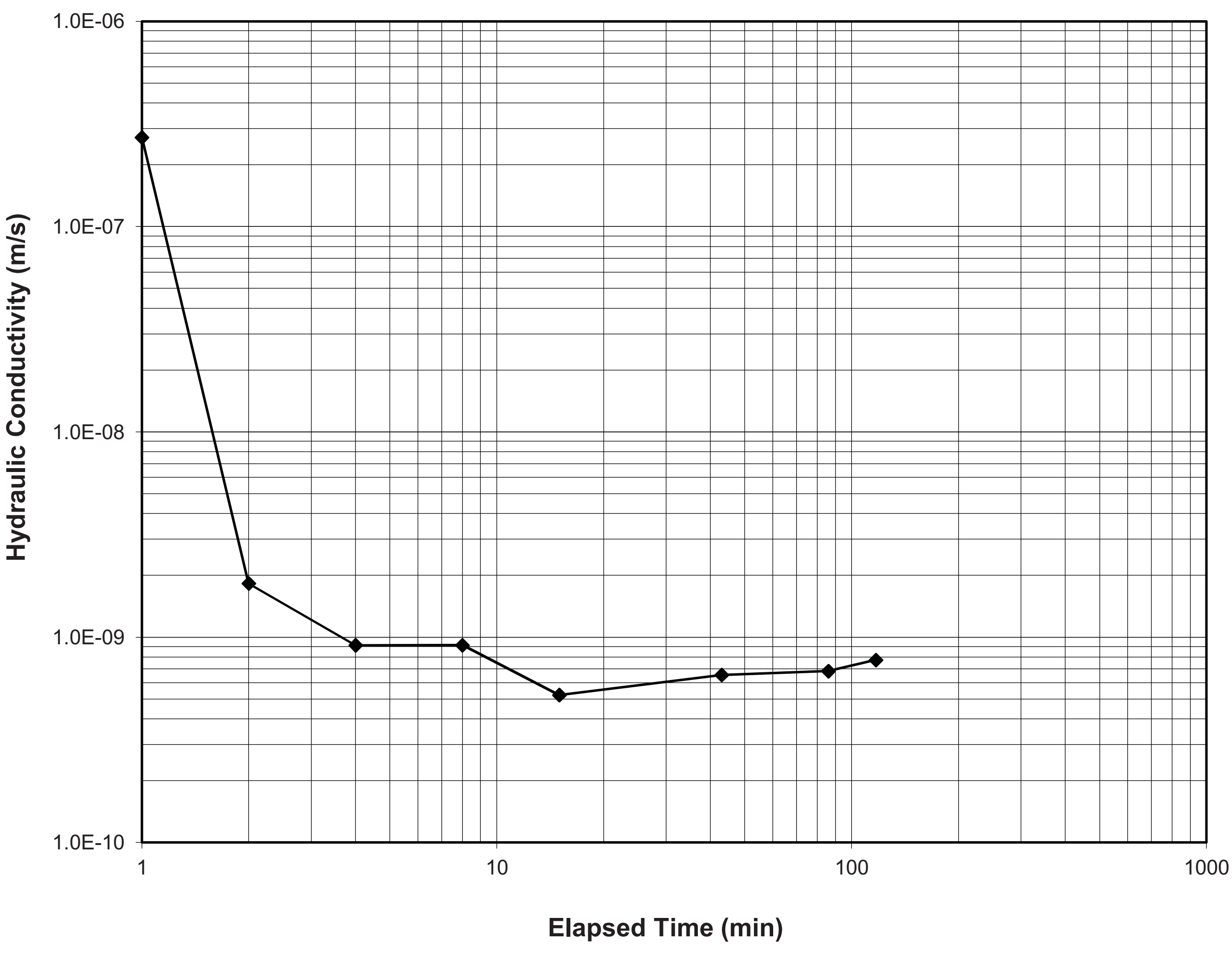
Test Summary:

Initial Water Content:	43.2	%
Initial Dry Density:	1249	kg/m^3
Final Water Content:	33.5	%
Final Dry Density:	1427	kg/m^3
Sample Diameter:	114.24	mm
Final Sample Height:	57.56	mm

Comments:

Specimen consolidated at 30 kPa stress prior to testing. Initial water content and dry density are prior to loading.

Graph of Hydraulic Conductivity versus Time



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Reviewed by:

Golder Associates

SOIL-WATER CHARACTERISTIC CURVE

Project #:	11-1365-0001	Phase:	2030 / 20
Short Title:	DeBeers / Post EIS Submission / GK		
Tested By:	D.B./C.H.Z.	Date:	September 11, 2011
Sample:	Fine PK		

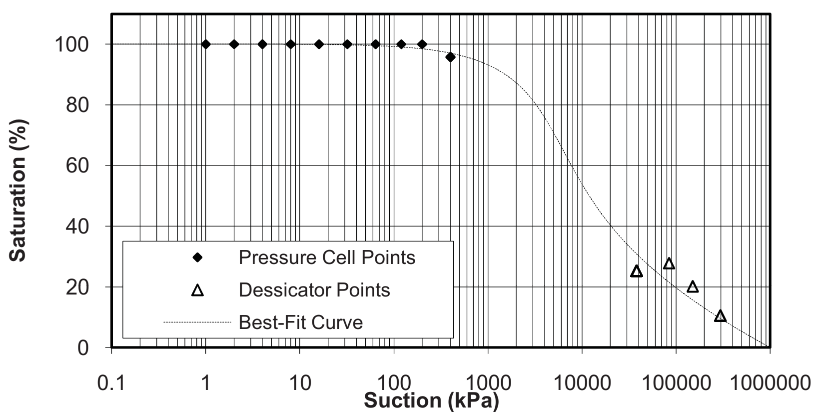
Test Results:

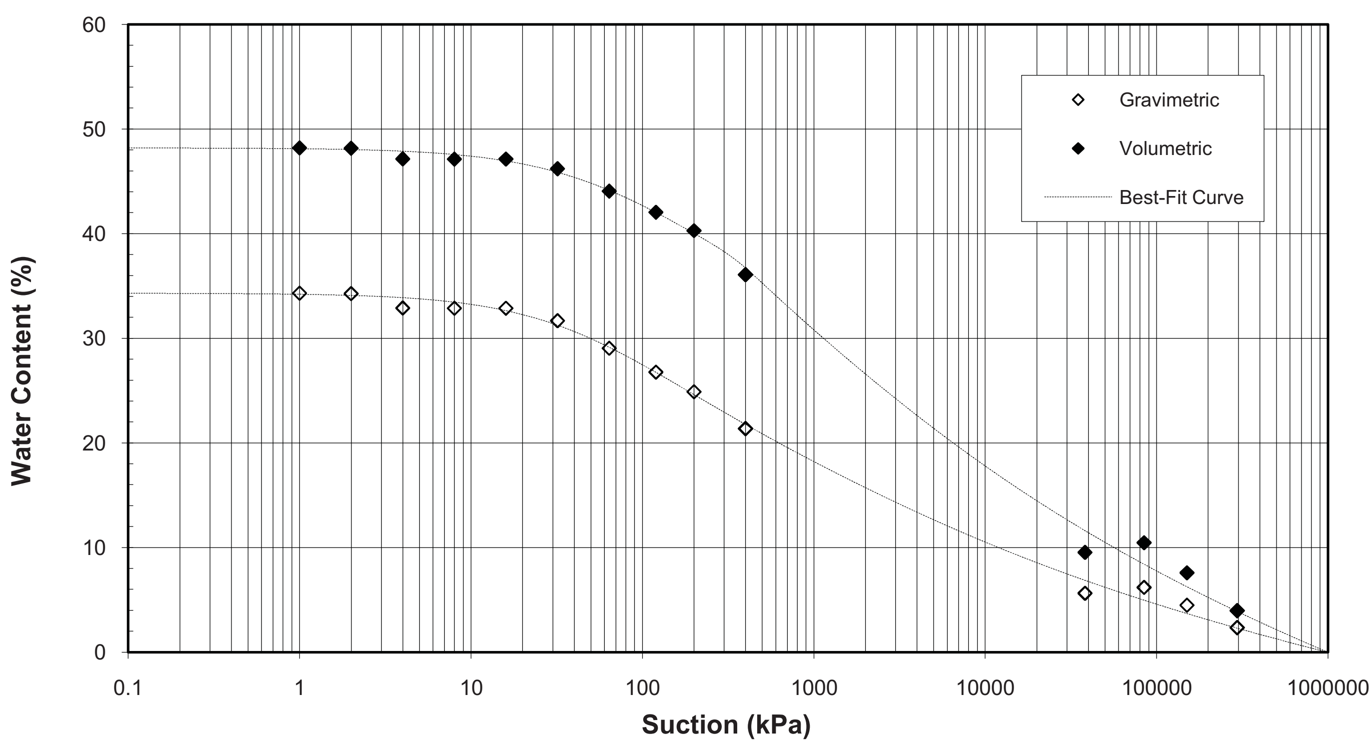
Suction (kPa)	Water Content (%) Gravimetric	Volumetric
1.0	34.3	48.2
2.0	34.3	48.1
4.0	32.9	47.1
8.0	32.9	47.1
16	32.9	47.1
32	31.7	46.2
64	29.1	44.0
120	26.8	42.0
200	24.9	40.3
400	21.4	36.1
38200	5.6	9.5
84350	6.2	10.5
150300	4.5	7.6
295000	2.3	4.0

Sample Data:

Diameter:	63.57	mm (initial)
Height:	32.23	mm (initial)
Initial Water Content:	34.7	% (gravimetric)
Dry Density:	1387	kg/m^3 (initial)
Material used passing:	4.75	mm sieve

Comments:
SWCC specimen taken from material slurried, then consolidated at 30 kPa stress.





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Reviewed by:

SOIL-WATER CHARACTERISTIC CURVE

Project #: 11-1365-0001 Phase: 2030 / 20
Short Title: DeBeers / Post Eis Submission / GK
Tested By: D.B. Date: September 23, 2011
Sample: Coarse PK

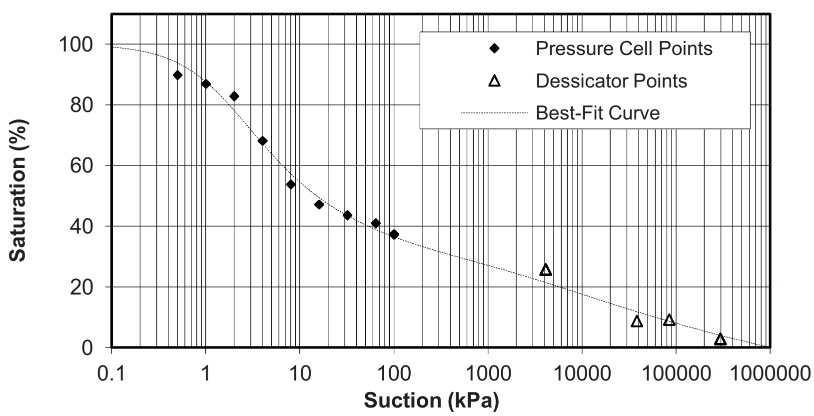
Test Results:

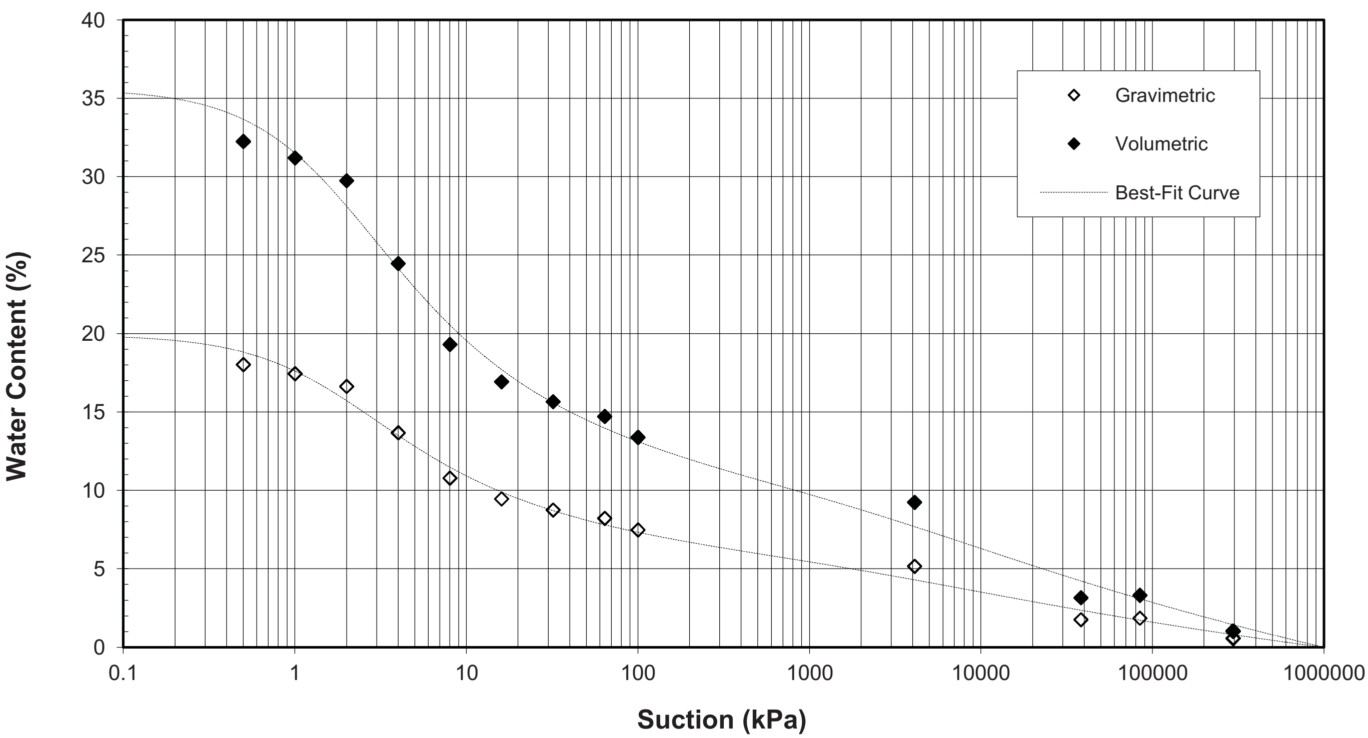
Suction (kPa)	Water Content (%) Gravimetric	Volumetric
0.5	18.0	32.3
1	17.4	31.2
2	16.6	29.8
4	13.7	24.5
8	10.8	19.3
16	9.5	16.9
32	8.8	15.7
64	8.2	14.7
100	7.5	13.4
4100	5.2	9.2
38200	1.8	3.2
84350	1.9	3.3
295000	0.6	1.0

Sample Data:

Diameter:	322.75	mm (initial)
Height:	38.62	mm (initial)
Initial Water Content:	17.4	% (gravimetric)
Dry Density:	1789	kg/m^3 (initial)
Material used passing:	4.75	mm sieve

Comments:





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Reviewed by:

THERMAL CONDUCTIVITY / SPECIFIC HEAT TEST

Project #: 11-1365-0001 Phase: 2030 / 20
Short Title: Debeers / Post EIS Submission / GK
Tested By: DB Date: October 13, 2011

Measurements were made using a KD2 Pro Thermal Properties Analyzer (Decagon Devices)

Sample: Fine PK, saturated

	Thermal Conductivity $W\ m^{-1}\ K^{-1}$	Volumetric Specific Heat $MJ\ m^{-3}\ K^{-1}$	Temperature ^{o}C
1)	1.198	2.730	19.12
2)	1.252	3.085	19.08
3)	1.243	2.997	19.01

Measurements made on material initially slurried, then consolidated at 30 kPa stress in consolidation apparatus

Sample: Fine PK, dry

	Thermal Conductivity $W\ m^{-1}\ K^{-1}$	Volumetric Specific Heat $MJ\ m^{-3}\ K^{-1}$	Temperature ^{o}C
1)	0.331	2.036	24.42
2)	0.326	2.103	24.34
3)	0.431	2.045	23.71

Measurements made on specimen from above, after drying at 110^{o}C and allowing to cool

Comments:

1721 8th Street E.,
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Reviewed by:

THERMAL CONDUCTIVITY / SPECIFIC HEAT TEST

Project #: 11-1365-0001 Phase: 2030 / 20
Short Title: Debeers / Post EIS Submission / GK
Tested By: DB Date: October 13, 2011

Measurements were made using a KD2 Pro Thermal Properties Analyzer (Decagon Devices)

Sample: Coarse PK, saturated

	Thermal Conductivity $W\ m^{-1}\ K^{-1}$	Volumetric Specific Heat $MJ\ m^{-3}\ K^{-1}$	Temperature ^{o}C
1)	1.136	2.387	20.51
2)	1.261	2.542	20.41
3)	1.216	2.758	20.50

Measurements made on material initially compacted in Proctor mould at water content = 14.6% and dry density = 1853 kg/m^3, then saturated

Sample: Coarse PK, dry

	Thermal Conductivity $W\ m^{-1}\ K^{-1}$	Volumetric Specific Heat $MJ\ m^{-3}\ K^{-1}$	Temperature ^{o}C
1)	0.374	N/A	24.49
2)	0.371	1.786	24.23
3)	0.376	1.282	24.82

Measurements made on specimen from above, after drying at 110^{o}C and allowing to cool

Comments:

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Reviewed by:

THERMAL CONDUCTIVITY TEST

Project #: 11-1365-0001 Phase: 2030 / 20
Short Title: Debeers / Post EIS Submission / GK
Tested By: DB Date: July 5, 2011

Measurements were made using a KD2 Pro Thermal Properties Analyzer (Decagon Devices)

Sample: Fine PK

	Thermal Conductivity $W\ m^{-1}\ K^{-1}$	Temperature ^{o}C	Water Content %	Dry Density kg/m^3
1)	1.218	21.48	15.9	1714
2)	1.384	21.54	18.0	1756
3)	1.307	21.58	20.1	1718
4)	1.326	21.36	22.2	1647

Measurements conducted on compacted specimens from standard Proctor compaction test

Comments:

1721 8th Street E.,
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Reviewed by:

THERMAL CONDUCTIVITY TEST

Project #: 11-1365-0001 Phase: 2030 / 20
Short Title: Debeers / Post EIS Submission / GK
Tested By: DB Date: June 21, 2011

Measurements were made using a KD2 Pro Thermal Properties Analyzer (Decagon Devices)

Sample: Coarse PK

	Thermal Conductivity $W\ m^{-1}\ K^{-1}$	Temperature ^{o}C	Water Content %	Dry Density kg/m^3
1)	0.280	23.21	5.5	1656
2)	0.606	22.84	7.2	1756
3)	1.059	22.09	7.6	1808
4)	1.236	21.56	10.3	1834
5)	1.346	21.26	11.4	1901
6)	1.434	21.03	13.0	1930
7)	1.313	20.89	15.2	1922
8)	1.359	20.89	16.6	1853

Measurements conducted on compacted specimens from standard Proctor compaction test (not all points shown in Proctor test results)

Comments:

1721 8th Street E.,
Saskatoon, Saskatchewan, S7H 0T4

Reviewed by: