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RE-EXAMINATION OF THE RELATIONSHIP BETWEEN DAVIS TUBE DATA ON DRILL CORE AND ACTUAL PLANT OPERATION

By

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RE-EXAMINATION OF THE RELATIONSHIP BETWEEN DAVIS TUBE DATA ON DRILL CORE AND ACTUAL PLANT OPERATION

COLERAINE MINERALS RESEARCH LABORATORY

March 27, 2006

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Re-Examination of the Relationship
Between Davis Tube Data on Drill Core and Actual Plant Operation

Summary

In general, mine blending at the taconite plants involves the use of liberation grinds and Davis tube testing of drill core. It has generally been assumed that the liberation data is additive, i.e., mixing an ore with a 7 percent silica concentrate at grind with an ore with a 3 percent silica concentrate in equal portions would produce a blend with a 5 percent silica concentrate at grind. While this method usually provides a good estimate of how the plant will process that ore, there are times that the plant performance is significantly different from that predicted by the mine. The purpose of this program is to determine if the liberation data is truly additive. Samples of five different ores were obtained. Standard liberation grinds and Davis tubes were run on each sample, and the Davis tube silica at grind was determined for each ore. Three blends of the ores were made and the Davis tube silica at grind was calculated for each, based on the weight of each ore in the blend. Liberation grinds and Davis tubes were run on the blends, and the Davis tube silicas at grind were calculated for processing the blends. There was significant difference in the silica from processing the blends, as compared to the silicas calculated from the mathematical combination of the individual ores.

Laboratory plant simulation was conducted on the three blends. The blends were crushed to minus 6-mesh and were concentrated by magnetic separation. Liberation grinds and Davis tube tests on the resultant magnetic concentrates indicated improved liberation. The magnetic concentrates were ground to typical plant grind and run through two stages of magnetic separation followed by elutriation of the magnetic concentrate. Davis tube tests on the two stage magnetic concentrate indicated improved liberation. The final product was close to typical plant grind, weight recovery and silica grade.

To confirm the tests with the initial three blends, four more ore samples were obtained. The liberation characteristics of the individual ores were determined. An additional three blends were made from the four ores. The blends were made to produce a 4.93 percent silica Davis tube concentrate at grind from each blend. The liberation characteristics of the blends were determined and, as with the first three blends, the liberation characteristics of the blends were different from what was calculated from the individual constituents of the blends. Unpublished data from testing binary blends of another seven different ores indicated the same non-additive properties.

While the test work indicated that the additive assumption for the drill core liberation data is not valid and may be why there are differences between mine predicted and plant performance, it is obvious that the drill core data is going to continue to be used. Further development of the laboratory procedure used in this program may

provide a tool for determining if differences between mine predicted silica and actual plant silica are ore or plant related.

Introduction

The standard method for predicting how a given ore blend will perform in the concentrating plant is to use the liberation grind-Davis tube data from drill core. From the drill core liberation data, a silica content at plant grind is calculated for each drill core. The silicas at plant grind values are added in proportion to the percentage of the ore blend. A plant factor or factors are usually applied to account for the difference between the Davis tube efficiency and plant efficiency. This method works fairly well over the long term, but there are significant times when the mine predicted silica is vastly different from what the plant actually produces, sometimes higher and sometimes lower. The purpose of this program is to re-examine the idea that liberation data are additive, i.e., that a blend made up of 50 percent ore with a 3.0 percent silica at plant grind and 50 percent ore with a 7.0 percent silica will produce a 5.0 percent silica at plant grind when processed as a mixture. Also stage grinding with magnetic separation between stages may alter the liberation characteristics of the blend. The Permanent University Trust Fund funded this program.

Test Program and Results

Samples of five different ores that would be typical in an ore blend were obtained from a taconite plant. The liberation characteristics of the individual samples were determined, as given in Table 1 and plotted on Figure 1. The individual ore samples were combined to make three blends as given in Table 2. Based on the liberation characteristics, the Davis tube concentrate silica at a grind of 85 percent passing 270-mesh should have been 4.80 percent for Blend 1, 4.46 percent for Blend 2, and 4.36 percent for Blend 3. Liberation grinds and Davis tube tests on the blends produced different liberation characteristics from the one calculated from the individual ore samples. The liberation results for the blends are given in Table 3 and are plotted in Figure 2. The Davis tube concentrate silicas at 85 percent passing 270-mesh were 4.15 percent for Blend 1 compared to a predicted 4.80 percent; 3.87 percent for Blend 2 compared to a predicted 4.46 percent and 3.95 percent for Blend 3 compared to a predicted 4.36 percent.

To simulate how the blends would perform in the concentrating plant, a portion of each sample was crushed to nominal minus 6-mesh and was run through a laboratory magnetic separator to simulate the first stage of plant magnetic separation. The results of the magnetic separation tests are given in Table 4. The liberation characteristics of the resultant magnetic concentrate were also determined, Table 4, and were plotted with the liberation tests on the blends, Figure 3. The magnetic separation stage improved the liberation characteristics for all blends. The minus 6-mesh magnetic concentrates were ground to about 87 percent passing 270-mesh and passed through two stages of magnetic separation with de-magnetizing between stages. The size distributions of the minus 6-mesh magnetic concentrate for each blend are given in Table 6. As can be seen from Table 6, the size distributions for the blends are fairly uniform. The results of the two stage magnetic separator tests are given in Table 7. Weight recoveries were similar for all blends and ranged between 51.7 and 52.8 percent. Davis tube tests were run on the magnetic concentrates, Table 7, and resultant concentrate silicas were lower than the liberation grinds on the minus 6-mesh magnetic concentrate. The size distributions for the final magnetic concentrates for each blend are given in Table 8, which indicates very similar distributions. Since the Davis tube tests on the magnetic concentrates rejected so much silica, elutriation tests (simulate hydroseparator) were run on the final magnetic concentrates from each blend. Elutriation test results are given in Table 9. The resultant elutriation underflows had silica contents close to typical plant values. Davis tube tests were run on the elutriation underflows, Table 9, and the resultant concentrate silicas were essentially the same as the Davis tube results on the elutriation feed, Table 7. Interestingly, the silica content on the elutriation underflows for each blend was consistent with the values calculated for each blend from the individual ore samples, Table 2. For Blend 1, the calculated silica at 85 percent passing 270-mesh was 4.80 percent, and the final lab product was 4.90 percent. Likewise for Blend 2, the predicted was 4.46 compared with 4.65, and for Blend 3 the predicted was 4.36 compared with 4.55.

To confirm the differences in liberation characteristics between mathematically combining liberation data from individual and running the tests on the combined material, four additional ore samples were obtained. One sample was from the Lower Slate (LS) horizon, two samples were from the Lower Cherty 3 and 4 (LC 34) units and the fourth sample was Interbedded Chert (IBC). Standard liberation grinds and Davis tubes were run on each of the four samples, Table 10. The liberation curves for each ore sample are shown on Figure 4. Based on the individual liberation characteristics, three more blends (designated 4, 5, and 6) were produced by combining the individual samples as shown in Table 11. With these combinations, each blend should have produced at concentrate silica at 85 percent passing 270-mesh of about 4.93 percent. Liberation grinds and Davis tube tests were run on the blends, with the results being given in Table 12 and plotted on Figure 5. Again, the Davis tube concentrate silicas at a grind of 85 percent passing 270-mesh produced from processing the blends were significantly different than the values predicted from mathematically combining the results from the individual ores. For Blend 4, the predicted value was 4.93 percent compared to the actual of 3.99 percent; for Blend 5 the predicted value was 4.91 percent compared to the actual of 5.00 percent; and for Blend 6 the predicted value was 4.94 percent compared to the actual of 4.35 percent.

In looking into previous work on the additive properties of liberation grinds, some unreported results were found. Seven tests were run on binary ore mixtures. Liberation grinds and Davis tubes were run on the individual ore samples. The Davis tube concentrate silicas at a grind of 85 percent passing 270-mesh were calculated for each ore. The ores were combined as 75-25, 50-50 and 25-75 mixes, and liberation grinds and Davis tubes were run on the combined samples. The Davis tube concentrate silicas for a grind of 85 percent passing 270-mesh were calculated for each of the combined samples. A summary of the results is presented in Table 13. In general, liberation grinds and Davis tubes on the combined sample gave different calculated Davis tube concentrate silicas at grind as compared to running liberation grinds and Davis tubes on the individual ores and then combining the individual results mathematically. With the exception of the mixture of ore 1-3 and ore Lo Sil, testing of the combination produced a lower silica than was predicted from the tests on the individual ores.

Conclusions

Results from processing nine different ores in six different blends have shown that liberation grind-Davis tube results are not truly additive. Running liberation grinds and Davis tube tests on a composite of different ores (an ore blend) produces different liberation results at a given grind than predicted by mathematically combining the results from the individual ores. The results match well with previous unpublished data involving seven different ores in various binary blends.

Test work has shown that stage grinding with magnetic separation between stages along with a final elutriation step can be used to simulate plant performance. These test have also shown that the liberation of the blends improve with each stage of grinding and magnetic separation.

Test results indicate why there is some disagreement between the mill predicted concentrate silica calculated from drill core liberation data and the actual plant practice. Clearly a better prediction method is needed. This is not surprising considering the difference between liberation grinding and Davis tube tests and the actual plant operation. In the liberation grinds all of the material is ground, while in the plant it is mainly the magnetite that is ground and some of the poorer liberating particles are rejected, as indicated by the improved liberation characteristics of the magnetic concentrates. The laboratory stage grinding with magnetic separation may produce better agreement. Obviously, the plants are not going to re-do all of their drill core work and will continue to use the drill core liberation data to predict plant performance. Where the laboratory test could be used is when there is a large variation between the mine predicted and the plant performance. The laboratory test could determine if the difference is ore related or plant operations related. More work will be needed to refine the test.

Table 1
Liberation Data for Ore Samples Used to Make Blends 1-3

Sample 1		Sample 2A		Sample 3	
-270%	Dt Silica	-270%	Dt Silica	-270%	Dt Silica
79.7	4.41	78.0	6.86	79.5	6.72
86.9	3.41	84.3	5.95	85.8	5.91
91.1	2.92	88.0	5.26	92.1	4.32
85.0	3.60*	85.0	5.82*	85.0	6.01*

High Silica		Low Silica	
-270%	Dt Silica	-270%	Dt Silica
80.3	14.00	80.1	3.19
83.6	11.51	84.1	3.13
88.2	10.42	90.6	3.04
85.0	11.18*	85.0	3.12*

* Calculated Silica

Table 2
Weight Percentage of Each Sample in Blends 1-3

	Blend 1	Blend 2	Blend 3
Sample	Wt %	Wt %	Wt %
Low Silica	25.0	83.4	50.0
Sample 1	30.6	0.0	8.3
Sample 2A	19.4	0.0	0.0
Sample 3	19.5	0.0	41.7
High Silica	5.6	16.6	0.0
Calc Silica at 85 -270M	4.80	4.46	4.36

Table 3
Liberation Data for Blends 1-3

Blend 1		Blend 2		Blend 3	
-270%	Dt Silica	-270%	Dt Silica	-270%	Dt Silica
79.6	4.96	79.4	4.38	79.5	6.72
84.7	4.31	82.9	4.07	85.8	5.91
87.0	4.04	88.5	3.54	92.1	4.32
85.0	4.15*	85.0	3.87*	85.0	3.95*

*Calcluated Silica at 85 % -270 M

Table 4
Magnetic Separator Tests on
Minus 6 mesh Samples
of Blends 1, 2 and 3

				Satmagan
Blend 1	Wt %	% Fe	% SiO2	Iron
Mag Conc	66.5	38.9	38.11	31.84
Mag Tail	33.5	17.0	64.04	1.75
Blend 2				
Mag Conc	71.8	35.5	42.61	29.60
Mag Tail	28.2	15.6	66.30	1.60
Blend 3				
Mag Conc	67.8	35.7	40.77	30.88
Mag Tail	32.2	17.8	59.30	1.78

Table 5
Liberation Data for Blends 1-3 Magnetic Concentrates

Blend 1		Blend 2		Blend 3	
-270%	Dt Silica	-270%	Dt Silica	-270%	Dt Silica
77.9	4.90	77.9	4.57	76.8	4.78
85.0	4.03	85.2	3.72	83.7	3.81
90.5	3.42	90.0	3.13	90.7	3.14

Table 6
Screen Analyses of Magnetic Concentrates from Blends 1-3

	Blend 1 Magnetic Conc		Blend 2 Magnetic Conc		Blend 3 Magnetic Conc	
Mesh	Wt %	% Passing	Wt %	% Passing	Wt %	% Passing
6	1.1	98.8	0.7	99.3	0.8	99.2
8	11.6	87.3	12.2	87.1	12.4	86.8
10	15.2	72.1	16.2	70.9	16.7	70.1
14	14.5	57.6	16.1	54.8	15.3	54.8
20	14.4	43.2	14.7	40.1	14.5	40.3
28	11.2	32.0	11.1	29.0	11.2	29.1
35	8.4	23.6	7.9	21.1	8.1	21.0
48	5.4	18.2	5.0	16.1	5.1	15.9
65	4.0	14.2	3.6	12.5	3.7	12.2
100	2.9	11.3	2.6	9.9	2.6	9.6
150	2.5	8.8	2.4	7.5	2.3	7.3
200	1.4	7.4	1.4	6.1	1.3	6.0
270	1.8	5.6	1.8	4.3	1.6	4.4
325	0.7	4.9	0.6	3.7	0.6	3.8
400	0.7	4.2	0.6	3.1	0.6	3.2
500	1.0	3.2	0.8	2.3	0.8	2.4
-500	3.2		2.3		2.4	

Table 7
Second Stage Magnetic Separator Tests
on Ground Mag Conc from Blends 1-3

				Davis Tube
Blend 1	Wt %	% Fe	% SiO2	% SiO2
Mag Conc	51.7	65.0	9.03	3.59
Mag Tails	48.3	14.8	69.22	
Blend 2				
Mag Conc	52.4	63.2	10.29	3.26
Mag Tails	47.6	12.4	78.19	
Blend 3				
Mag Conc	52.8	64.3	8.74	3.14
Mag Tails	47.2	13.5	76.57	

Table 8
Screen Analyses of Second Stage Magnetic Concentrate

	Blend 1 Magnetic Conc		Blend 2 Magnetic Conc		Blend 3 Magnetic Conc	
Mesh	Wt %	% Passing	Wt %	% Passing	Wt %	% Passing
48	0.1	99.9	0.1	99.9	0.1	99.9
65	0.1	99.8	0.1	99.8	0.1	99.8
100	0.1	99.7	0.1	99.7	0.1	99.7
150	0.3	99.4	0.2	99.5	0.3	99.4
200	1.4	98.0	1.1	98.4	1.4	98.0
270	9.9	88.1	10.3	88.1	11.1	86.9
325	8.6	79.5	8.8	79.3	8.7	78.2
400	9.2	70.3	10.2	69.1	10.3	67.9
500	17.9	52.4	18.2	50.9	16.4	51.5
-500	52.4		50.9		51.5	

Table 9
Elutriation Tests on Second Stage Magnetic Concentrates

				Davis Tube
Blend 1	Wt %	% Fe	% SiO2	% SiO2
Underflow	92.2	67.8	4.90	3.64
Overflow	7.8	21.3	57.82	
Blend 2				
Underflow	90.7	68.3	4.65	3.23
Overflow	9.3	19.5	65.22	
Blend 3				
Underflow	92.4	67.6	4.55	3.08
Overflow	7.6	19.6	59.96	

Table 10
Liberation Grinds for Samples used for Blends 4, 5, and 6

LS 69-01		LC 34 16-01		LC 34 63-01		IBC 74-01	
-270%	DT SiO2	-270%	DT SiO2	-270%	DT SiO2	-270%	DT SiO2
80.1	9.82	81.0	2.92	82.7	1.57	79.0	5.22
84.7	8.45	84.0	2.73	87.1	1.36	85.1	4.52
89.6	7.63	89.9	2.38	94.1	1.31	91.8	3.10
85.0	8.40*	85.0	2.67*	85.0	1.46*	85.0	4.54*
* Calculated % SiO2 at 85 grind							

Table 11
Make-up of Blends 4, 5 and 6

	Blend 4	Blend 5	Blend 6
Sample	Wt %	Wt %	Wt %
LS 69-01	50.0	39.0	20.0
LC 34 16-01	0.0	61.0	0.0
LC 34 63-01	50.0	0.0	12.0
IBC 74-01	0.0	0.0	68.0

Table 12
Liberation Grinds on Blends 4, 5 and 6

Blend 4		Blend 5		Blend 6	
-270%	DT SiO2	-270%	DT SiO2	-270%	DT SiO2
77.7	4.59	78.4	6.05	81.5	5.49
85.0	3.99	83.8	5.20	84.0	4.48
89.3	3.35	92.9	3.76	89.8	3.72
85.0	3.99*	85.0	5.00*	85.0	4.35*
85.0	4.93**	85.0	4.91**	85.0	4.94**
*Calculated % Silica at 85 % -270 mesh from liberation curves					
**Calculated % Silica at 85 % -270 mesh from weight % of each ore in blend					

Table 13
Summary of Unreported Liberation Grinds on Various Binary Ore Blends

Ore Blend	Percent of first ore	Test SiO2	Calc SiO2	Ore Blend	Percent of first ore	Test SiO2	Calc SiO2
13	100.0	10.16	10.16	17	100.0	7.11	7.11
&	75.0	7.33	8.46	&	75.0	5.90	6.22
10	50.0	5.63	6.77	16	50.0	5.31	5.33
	25.0	4.50	5.07		25.0	4.28	4.43
	0.0	3.38	3.38		0.0	3.54	3.54
18	100.0	7.84	7.84	17	100.0	7.11	7.11
&	75.0	5.99	6.62	&	75.0	5.94	6.45
28	50.0	4.98	5.39	34	50.0	5.45	5.79
	25.0	3.81	4.17		25.0	5.07	5.12
	0.0	2.94	2.94		0.0	4.46	4.46
10	0.0	3.38	3.38	1-3	100.0	14.73	14.73
&	25.0	4.68	4.50	&	75.0	13.34	11.63
18	50.0	5.38	5.61	Lo Sil	50.0	9.74	8.54
	75.0	6.35	6.73		25.0	5.75	5.44
	100.0	7.84	7.84		0.0	2.34	2.34
28	0.0	2.94	2.94				
&	25.0	3.87	4.75				
13	50.0	5.12	6.55				
	75.0	6.85	8.36				
	100.0	10.16	10.16				

Figure 1 - Liberation Grinds on Blend Constituants

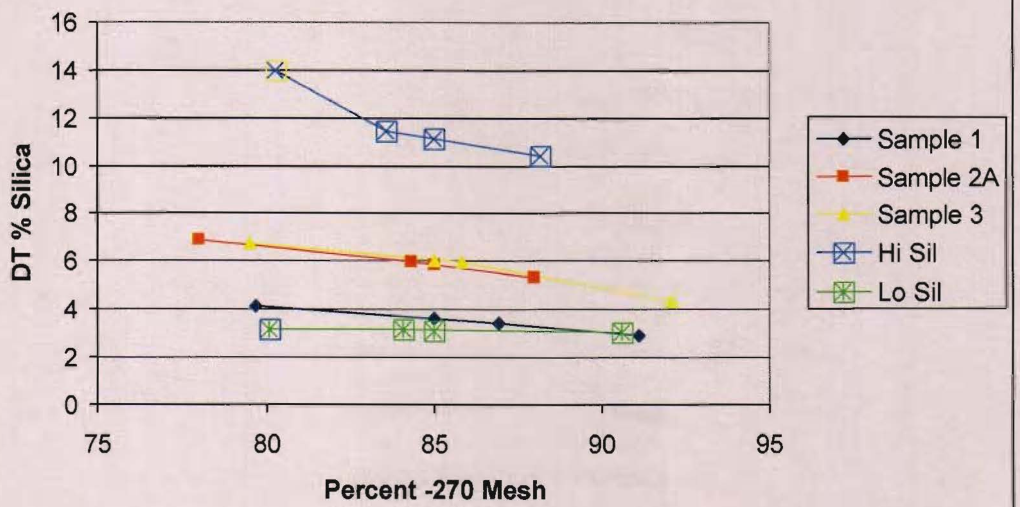


Figure 2 - Liberation Curves for Blends 1-3

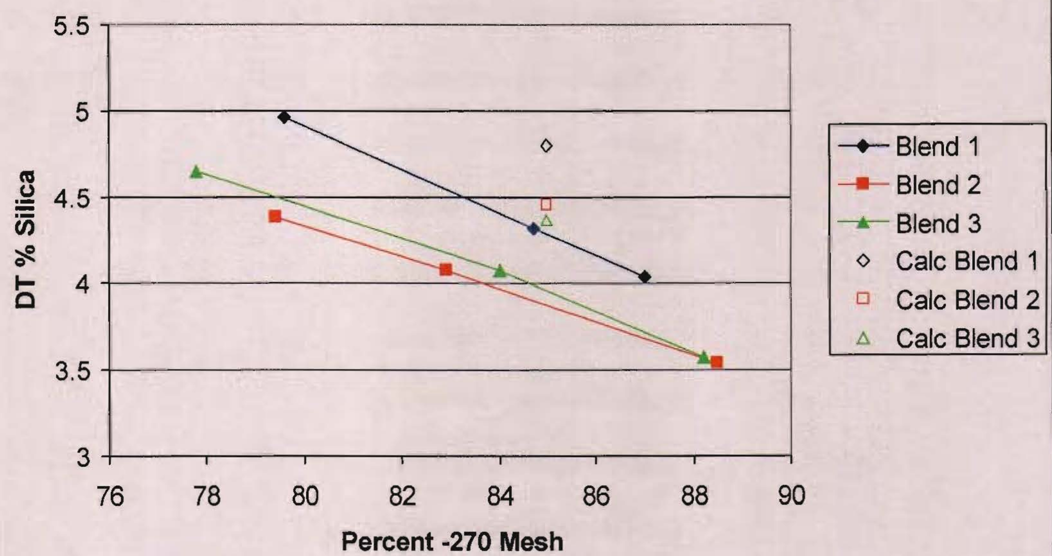


Figure 3 - Liberation Curves for Blends 1-3 and for Magnetic Concentrates from the Blends

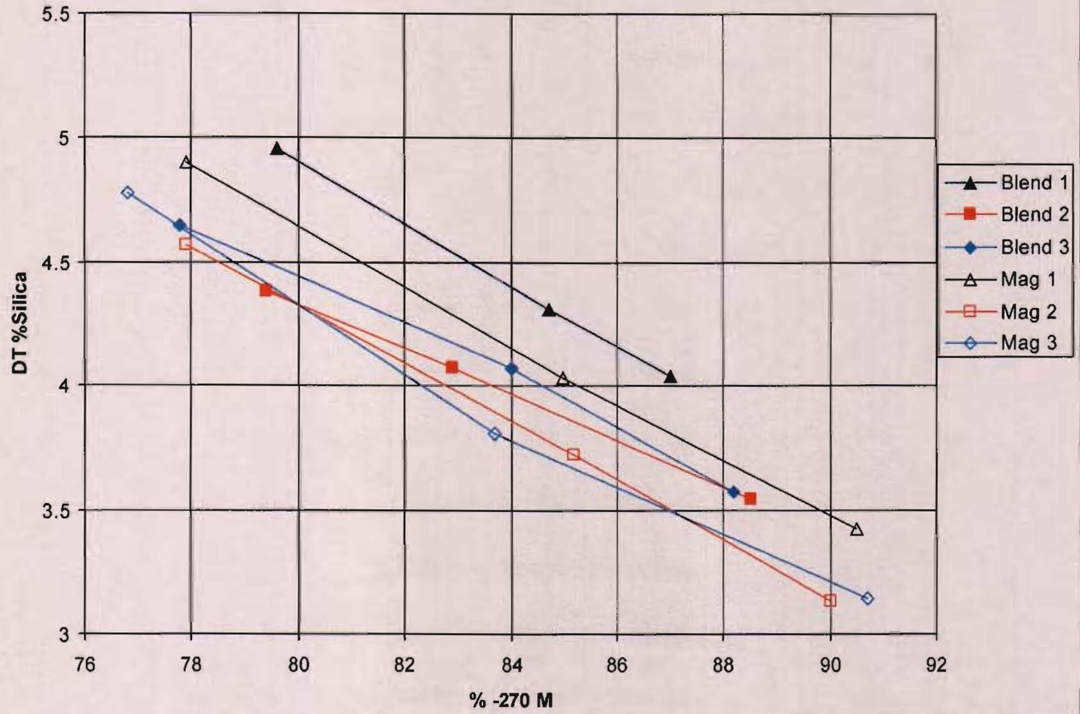
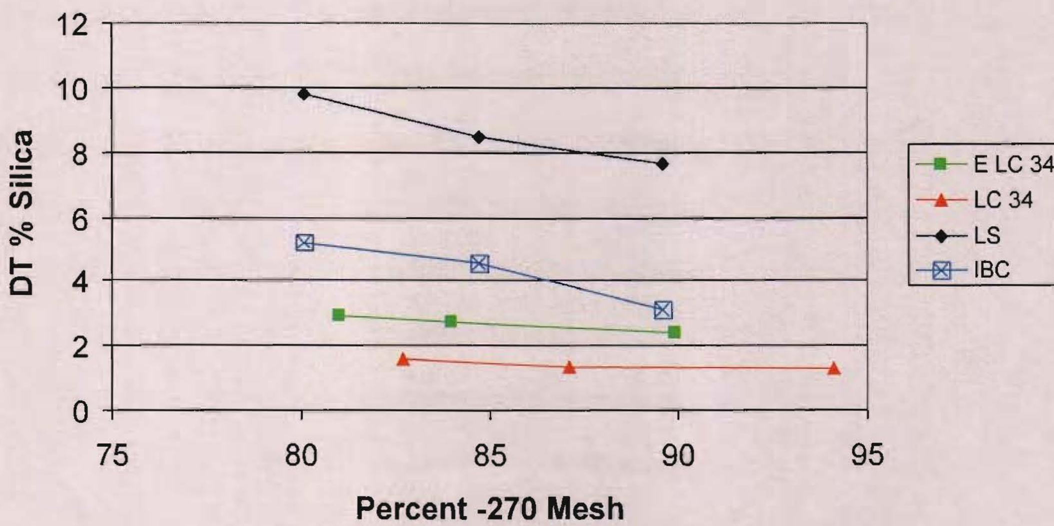


Figure 4 - Liberation Curves for Second Set of Ores



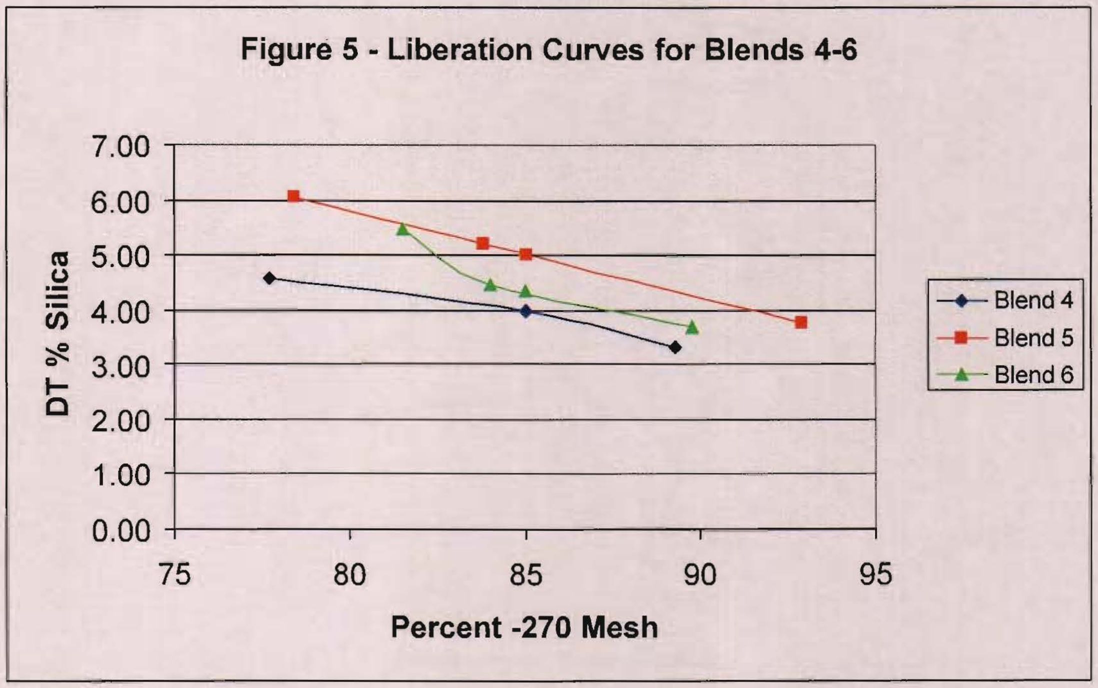


Figure 5 - Liberation Curves for Blends 4-6
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
DT % Silica
75
80
85
90
95
Percent -270 Mesh
Blend 4
Blend 5
Blend 6