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Pilot-Scale Demonstration of Deep Cone™ Paste Thickening Process for Phosphatic Clay/Sand Disposal

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A pilot-scale Deep Cone™ thickener (DCT) from Dorr-Oliver EIMCO has been employed at a phosphate mine in central Florida to investigate the effects of key operating parameters, including feed rate, sand addition rate, flocculant dosage, and bed depth on waste clay thickening performance. The pilot-scale field testing successfully demonstrated the simultaneous production of an underflow paste product and a clear overflow water stream. Typical overflow water recovery and underflow solids recovery were more than 88% and 98%, respectively with a residence time of about 2 hours. The highest clay content and total solids content in the paste were higher than 25% and 35%, respectively, when the flotation sand tailing was added to the clay slurry at a clay/sand ratio of 2:1 by weight.

Keywords clay waste; flocculation; paste; phosphate flotation; slurry thickening

INTRODUCTION

Phosphate mining and beneficiation in Florida produces huge amounts of waste clays. Approximately one ton of clay mixture is generated for each ton of phosphate product. About 100,000 tons of waste clays are currently produced each day by phosphate mines in Florida. The flow rate of phosphatic clay slurry ranges between 80,000 and 240,000 lpm for each phosphate mine. To accommodate the slow settling clay waste, large impoundments covering 400 to 800 acres, with dam heights ranging from 7 to 20 m, are required (1,2). When existing impoundments become filled with phosphate waste, new ones are built to keep phosphate companies operating. There are more than 85,000 acres of phosphatic clay ponds and clay-filled mine cuts in central Florida, with approximately 5,000 acres of additional ponds created each year by on-going phosphate mining and beneficiation operations (3). As a result, large areas of land is occupied by clay waste and potential dam failures may cause environmental disaster and public outrage.

To overcome the problems associated with phosphatic clay impounding, many mechanical, electrical, biological, and chemical processes have been tested. They include use of enzyme and bacteria (4,5), the addition of chemicals (6,7), coagulation and flocculation (8,2,9,10), mechanical dewatering (11–13) and thickening (14–16), etc. However, these clay disposal methods are not cost-effective in consolidating phosphatic clay waste.

The present study was conducted to evaluate the feasibility of using Dorr-Oliver EIMCO's Deep Cone™ thickener (DCT) technology to thicken the Florida phosphatic clay to a paste that can be disposed of in mine cuts, eliminating the conventional slurry impoundments that occupy thousands of acres of land and pose environmental risks.

EXPERIMENTAL

Pilot-Scale DCT System

The pilot-scale deep cone (DCT) paste making system employed in this study is shown in Fig. 1. The clay slurry to the testing site was acquired from a 36″ (0.9 m) slurry pipe from the SFM phosphate beneficiation plant of Mosaic Company. The clay slurry was fed to the primary clay tank or surge tank with a diameter of 9′ (2.7 m) and a height of 8′ (2.4 m) and a volume of 13.7 m^3 to achieve relatively constant feed to the thickener. The slurry was then pumped to the mixing tank with a dimension of 4′ (1.2 m) × 5′ (1.5 m) × 4′ (1.2 m) and a volume of 2 m^3 where flocculant and sand were added to condition the slurry. The flocculated clay slurry in the mixing tank was pumped to a small conditioning tank (0.3 m in diameter and 0.6 m in height) mounted on top of the DCT thickener where another type of flocculant was added to the slurry prior to entry to the feeding well inside the thickener. The DCT thickener from Dorr Oliver EIMCO was 1.5 m in diameter and 4.5 m in height with a volume of approximately 8 m^3. The thickener rake rotated at a speed of 0.2 rpm during operation. The 0.2% by weight anionic and cationic flocculant solutions were prepared in two

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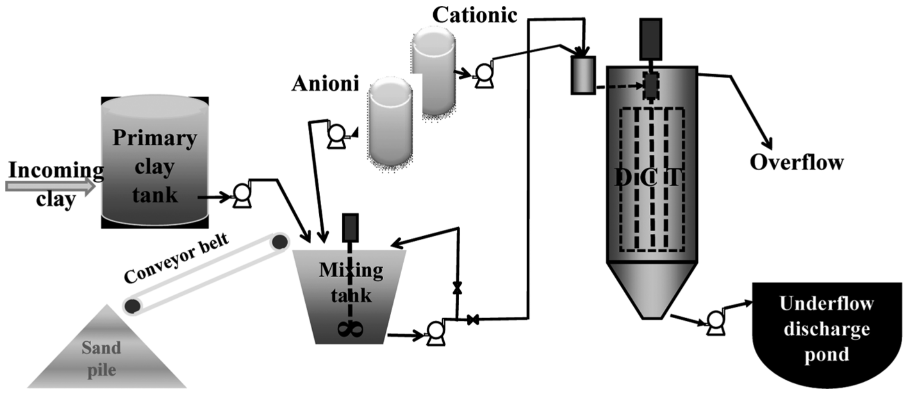


FIG. 1. Illustration of DCT testing system used at SFM mine.

separate tanks by mixing the powder with water. The sand tailing added to the mixing tank was transported via a conveyor belt and its flow rate was controlled by a screw feeder. The dosage of flocculant was controlled by adjusting the flow rate to the tank by the peristaltic pump. The testing system was controlled by a computer system, using a number of sensors, flow meters, and pinch valves installed in the circuit. The control scheme for the system is shown in Fig. 2.

The DCT testing system operated under the following conditions, unless otherwise specified:

Clay slurry rate: 120–300 lpm.
Sand addition: 50–150% clay weight in the slurry
Bed height inside the DCT: 1–2 m
Anionic flocculant: Hengfloc 64014, 0.27–2.15 kg/t of clay solids
Cationic flocculant: Hengfloc 80607, 0–0.45 kg/t of clay solids

Figure 3 shows the DCT testing system that was employed for the pilot scale testing and evaluation study. The clear water was discharged from DCT as overflow and the solids were removed from the bottom as underflow, which was pumped out using a Bredel peristaltic pump to a waste pond about thirty meters away. The DCT apparatus was installed on a 3 m (L) $\times$ 3 m (W) $\times$ 0.3 m (H) concrete pad with one bolt at each corner.

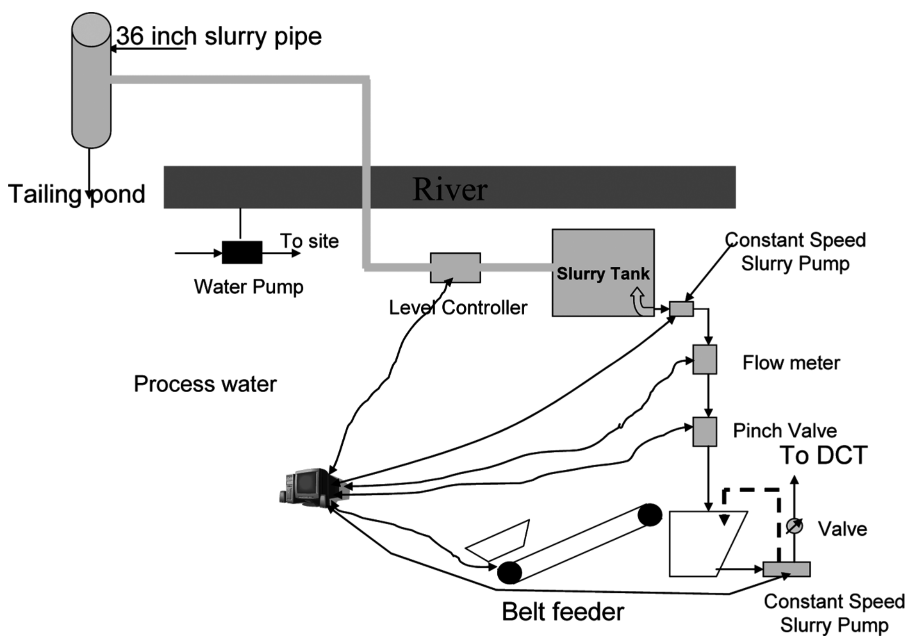


FIG. 2. DCT system control scheme.

FIG. 3. Picture of DCT testing system.

TABLE 1
Clay slurry feed solids percentage in different tests

Test #	1	2	3	4	5	6	7
Solids %	2.33	1.06	1.88	2.07	2.54	0.91	1.26
Test #	8	9	10	11	12	13	14
Solids %	2.11	2.05	1.95	2.54	2.75	2.31	1.78
Test #	15	16	17	18	19	20	21
Solids %	2.98	3.66	3.43	2.83	2.51	2.34	2.59
Test #	22	23	24	25	26	27	28
Solids %	1.98	2.68	3.03	3.04	2.90	2.63	2.34
Test #	29	30	31	32	33	34	35
Solids %	2.02	2.83	3.79	2.84	2.78	2.39	2.43

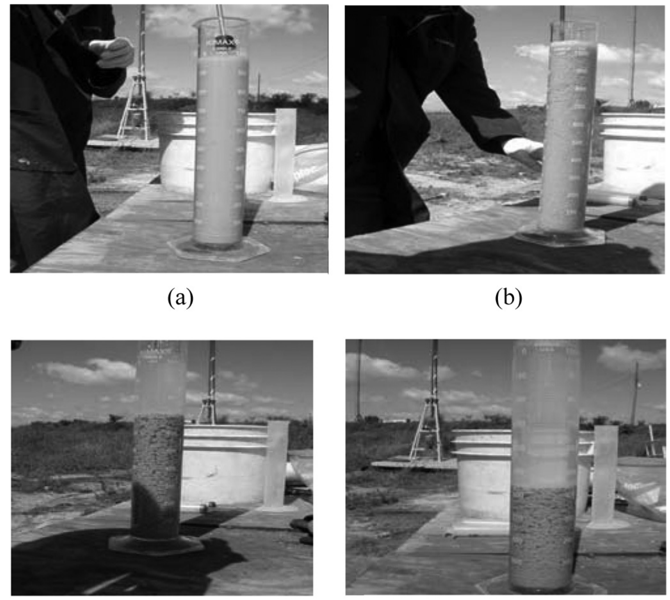
Clay and Sand Samples

The clay slurry from the plant varied in the solids percentage and particle size. Analysis of thirty five samples collected during the testing program indicated that the solids percentage in twenty nine samples varied from 1.88 to 3.04%, which was considered to be the normal range. However, three samples had solids % significantly higher than 3.04% and three significantly lower than 1.88%. Table 1 shows the individual solids percentage in different tests. The waste clay samples all had an approximate D_{50} size of 6 μm. The sand tailing used in the pilot scale DCT testing was also analyzed, showing a D_{50} size of about 230 μm.

RESULTS AND DISCUSSION

Initial Testing of DCT

On-site flocculant screening tests were performed with 1000 ml graduated glass cylinders. The flocculation procedure is shown in Fig. 4 and the settling rate results are



(a) (b) (c) (d)

FIG. 4. Illustration of on-site flocculation tests: (a) stirring and mixing slurry; (b) mixing slurry with flocculant; (c) clay settling; (d) after settling for about two minutes.

shown in Fig. 5 as a function of flocculant dosage. The settling rate increased with increasing flocculant dosage initially and then leveled out. Hengfloc 64014 showed the highest settling rate of 1.5 m/min at a dosage of about 240 g/t. All other flocculants except MF1011 showed much lower settling rates, especially at lower dosages. The supernatant in the cylinder was clear and appeared to be free of solids.

Figure 6 shows an image of flocculated clay slurry inside the conditioning tank just outside the DCT when cationic flocculant was being added into it. Clay particles were

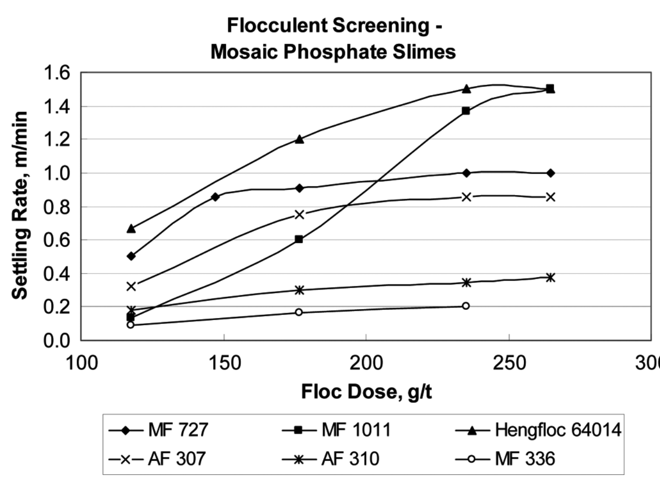


FIG. 5. Clay slurry settling rates as a function of flocculant dosage.

FIG. 6. Flocculation inside conditioning tank beside DCT where Hengfloc 80607 was added.

flocculated effectively with large flocs. When flocculated clay particles entered the DCT, they settled quickly and the overflow of the thickener appeared very clear with no visible solids, as shown in Fig. 7.

Figure 8 shows the on-site demonstration of the effect of sand addition on clay consolidation. With sand added at a sand/clay ratio of 1:1, the solids compacted much better, as evidenced by the shorter bed height. This is believed to be caused by the weight of sand particles that had a much greater density than clay flocks. This indicated that the underflow solids percentage could be increased by the addition of sand to clay slurry, which was proved later by pilot testing.

Table 2 shows the thickening performance data in the early stage of DCT operation. In these tests, the cationic

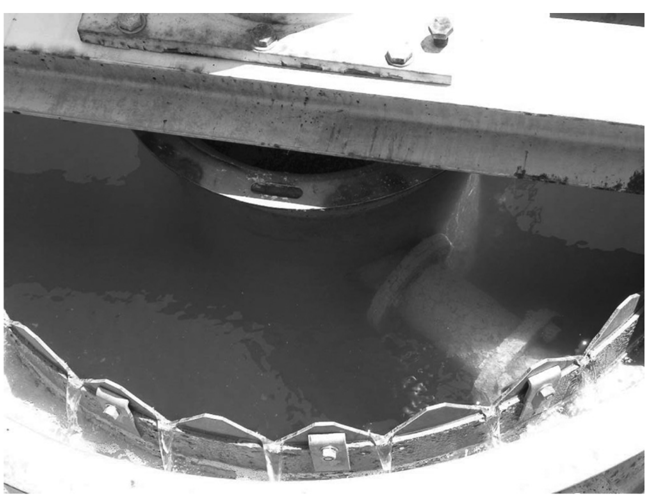


FIG. 7. Image of DCT overflow.

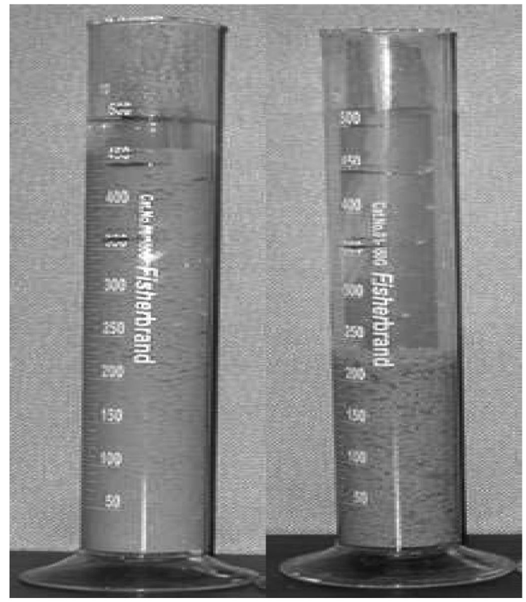


FIG. 8. Effects of sand addition on clay consolidation: no sand (L); sand added (R).

flocculant was added to the mixing tank before the anionic flocculant was added to the smaller conditioning tank outside the DCT. Variables examined in the tests included feed slurry rate, dosages of cationic and anionic flocculant, bed height inside DCT, residence time of solids. The solids percentage in feed, overflow (OF), and underflow (UF) was determined from samples collected. As can be seen from this table, the feed solids varied from 0.91% to 2.98% but mostly in the range of 2–3% which is considered normal. The solids % in the overflow was low, from 0.021% to 0.08%. However, the underflow solids percentage varied from 3.27% to 8.63%, and the undeflow was still in the form of slurry rather than paste.

Key Factors for Paste Formation

Table 2 indicates that the DCT was unable to make paste from clay slurry when cationic flocculant was added before anionic flocculant even though the clay particles were flocculated well. It was, therefore, decided to switch the order of flocculant addition by adding the anionic flocculant first in the mixing sump, followed by the cationic flocculant in the conditioning tank outside the DCT. Table 3 shows the results under different conditions. In Test 15, both anionic and cationic flocculant were added at a dosage of 0.45 kg per ton of clay without use of sand tailing, and the bed height and residence time were kept the same as in previous tests shown in Table 2. The underflow solids content reached 10.33%, higher than that achieved in any test shown in Table 2. When sand tailing was added at a sand/clay ratio of 1:2, the underflow solids percentage increased up to 19.89%, with underflow clay

TABLE 2
Initial DCT thickening test results under various operating conditions

Test #	Feed slurry (gpm)	Cat floc (kg/ton)	Ani floc (kg/t)	Bed height (m)	Residence time (h)	Feed solids (%)	OF solids (%)	UF solids (%)
1	40	0.00	0.50	1	16	2.07	0.021	3.27
2	40	0.00	1.45	1	2	1.06	0.026	8.19
3	40	0.00	2.15	1	4	1.88	0.08	7.87
4	40	0.17	0.67	1	2	2.33	0.066	6.79
5	40	0.17	0.67	2	3	2.54	0.026	5.88
6	40	0.40	0.53	1.5	2	2.54	0.064	5.03
7	40	0.39	0.53	1.5	4	0.91	0.051	5.58
8	40	0.40	0.53	1.5	5	1.26	0.051	6.44
9	40	0.37	0.53	1.5	6	2.11	0.04	5.85
10	40	0.22	0.89	2	2	1.95	0.047	5.02
11	40	0.40	1.60	1.5	15	2.05	0.04	5.99
12	30	0.20	0.80	2	2	2.31	0.057	8.42
13	30	0.20	0.80	2	5	1.78	0.039	6.04
14	30	0.20	0.80	2	6	2.98	0.021	8.63

TABLE 3
DCT thickening test results obtained when anionic floc was added before cationic floc

Test #	Feed slurry (gpm)	Ani floc (kg/t)	Cat floc (kg/ton)	Bed height (m)	Residence time (h)	Sand addition (%)	Feed solids (%)	OF solids (%)	UF solids (%)	UF clay (%)
15	75	0.45	0.45	2	2	0	3.66	0.034	10.33	10.33
16	75	0.45	0.45	2	2	50	3.43	0.028	16.37	14.96
17	30	0.45	0.45	1.8	2	50	3.03	0.059	19.89	15.17
18	30	0.45	0.45	1.9	4	50	3.04	0.025	17.42	13.82
19	30	0.32	0.23	2	4	50	2.34	0.033	19.79	15.87
20	30	0.32	0.23	2	6	50	2.02	0.014	24.58	19.43

solids reaching up to 15.17%. Obviously, the sand addition helped solids bed consolidation inside the DCT. It was also very interesting to observe that when anionic and cationic flocculant dosages were reduced from 0.45 kg/t to 0.32 and 0.23 kg/t, respectively, in Tests 19 and 20, the total solids content and clay solids content in underflow did not decrease. When the total solids concentration and clay solids concentration were about 20% and 15%, respectively, the underflow became a paste with limited flowability, as shown in Fig. 9. In summary, Table 3 clearly indicates that a paste can be generated from clay slurry when anionic flocculant was added before cationic flocculant with the help of sand addition. It is believed that the cationic flocculant added after the anionic flocculant neutralized the surface charge on clay particles and reduced electrostatic repulsion, which enhanced bed consolidation. Bed consolidation is essential to produce a paste from the

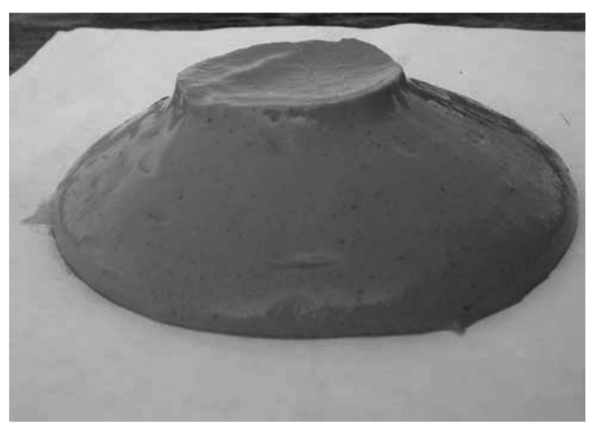


FIG. 9. Paste from Test 19 with 19.79% total solids and 15.87% clay solids.

TABLE 4
DCT thickening test results obtained at different sand addition dosage

Sand addition (%)	Feed solids (%)	OF solids (%)	UF solids (%)	UF clay (%)
0	3.66	0.034	10.33	10.33
50	3.43	0.028	16.37	14.96
150	2.68	0.029	30.08	20.72

DCT by squeezing out the interstitial moisture between clay particles.

Effects of Process Parameters

A number of DCT thickening tests were performed to study the effects of several process parameters on paste formation.

Effect of Sand Addition Dosage

Table 4 shows the effect of sand addition on thickening performance while the feed slurry rate was kept at 300 lpm, anionic and cationic flocculant dosage at 0.45 kg/t, bed height at 2 m and residence time at 2 hour. Obviously, more sand added to the slurry helped bed consolidation, resulting in higher total underflow solids % and clay solids %.

Effect of Solids Retention Time

Figure 10 shows the effect of solids retention time inside DCT on total solids content and clay solids content in the underflow product. Both solids content increased almost linearly with retention time in the range tested. Figure 11 shows similar data obtained at higher flocculant dosage. At higher flocculant dosage, underflow solids content became less dependent on retention time, as evidenced by the smaller slope value. This was because higher flocculant dosage produced larger and denser flocs which consolidated faster initially during the first two hours (as suggested by higher solids content at 2 hours) and slower thereafter.

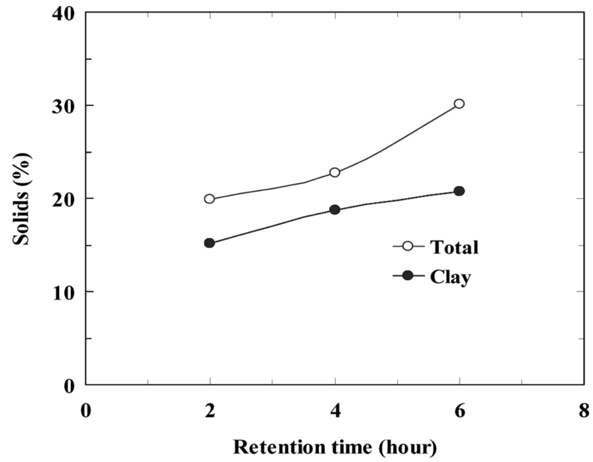


FIG. 11. Dependence of total solids % and clay solids % on solids retention time (Anionic floc 0.45 kg/t; cationic floc 0.45 kg/t; clay:sand = 2:1; bed height: 2 m; feed slurry: 120 lpm).

Effect of Total Flocculant Dosage

A large portion of DCT operational costs is the flocculant expense. Figure 12 shows the effect of total flocculant (anionic + cationic) dosage (in kg/ton clay) on paste solids content. The anionic/cationic ratio was 3:2 in the first two tests but 1:1 in the third test. As can be seen from Fig. 12, a total dosage of 0.45 kg/t produced almost as high paste solids content as the 0.90 kg/t dosage did.

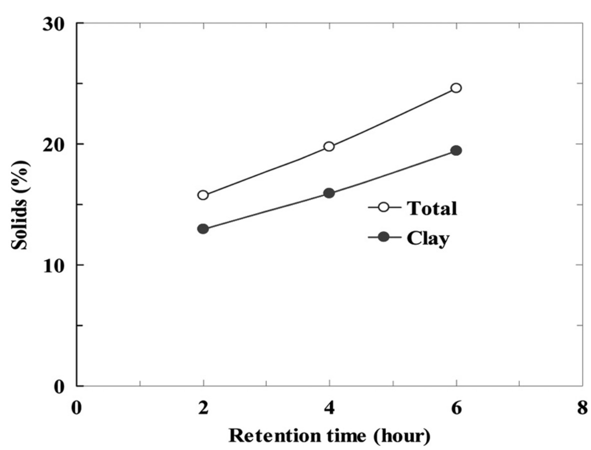


FIG. 10. Dependence of total solids % and clay solids % on solids retention time (anionic floc: 0.32 kg/t; cationic floc: 0.23 kg/t; clay:sand = 2:1; bed height: 2 m; feed slurry: 120 lpm).

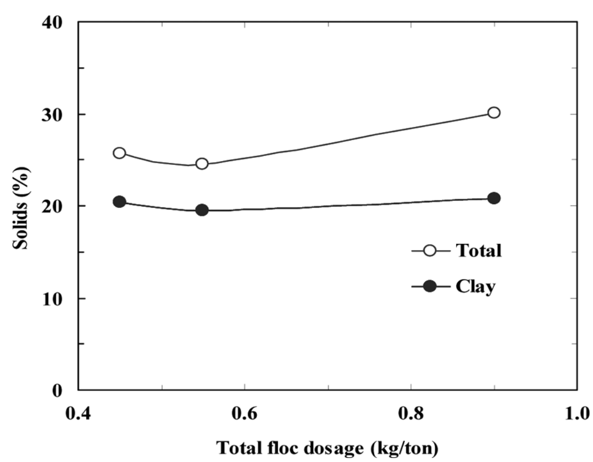


FIG. 12. Effects of flocculant dosage on paste solids content (Clay:sand = 2:1; bed height: 2 m; feed slurry: 120 lpm; residence time: 2 h).

TABLE 5
Highest paste solids content

Ani floc (kg/t)	Cat floc (kg/ton)	Residence time (h)	Sand addition (%)	Feed solids (%)	OF solids (%)	UF solids (%)	UF clay (%)
0.32	0.32	3	50	2.68	0.029	30.08	20.72
0.45	0.45	6	50	2.90	0.122	22.71	18.70
0.32	0.23	6	50	2.02	0.014	24.58	19.43
0.32	0.23	6	50	2.83	0.036	27.28	20.21
0.27	0.14	6	50	2.84	0.038	35.44	25.81
0.27	0.18	4	50	2.39	0.045	25.33	20.56

FIG. 13. Pictures of paste products with high solids.

Optimization Tests to Achieve High Solids Paste

Table 5 shows the highest paste solids contents obtained under various operating conditions. All tests generated total solids content greater than 22.71% and clay solids content higher than 18.7%. It should be noted that the thickest paste with 35.44% total solids content and 25.81% clay solids content was obtained with a fairly low dosage of anionic flocculant of 0.27 kg/t and cationic flocculant dosage of 0.14 kg/t. Figure 13 shows pictures of some paste samples produced. The products appear to be good pastes with yield stress in the range of 300–450 Pa determined from the paste slump tests.

Material Balance in DCT Process

The material balance in the DCT process is determined using the following typical test data:

120 lpm overflow
0.059% solids in overflow
20 lpm underflow
19.9% solids in underflow

As a result, the water recovery in overflow was 88.2% and the solids recovery in underflow was 98.3%. In other words, about 12% water went to paste and only 1.7% solids went to overflow.

CONCLUSIONS

Based on the above results and discussions, the following conclusions can be made:

1. The DCT was capable of producing clay paste with sand added to the clay slurry at a clay to sand ratio of 2:1. Higher sands addition helped paste formation in terms of both paste formation rate and paste solids content.
2. Approximately 90% water in the clay slurry was recovered as clear overflow of DCT with solids content between 0.02% to 0.05% while more than 98% solids reported to the paste or DCT underflow stream.
3. The highest clay solids and total solids content in the paste were about 25% and 35%, respectively.
4. Flocculation scheme was critical for the formation of the paste. Anionic flocculant Hengfloc 64014 must be added to the slurry before cationic flocculant Hengfloc 80607.
5. Flocculant dosage and sand addition were the most important parameters for paste thickening process.

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REFERENCES

1. Bromwell, L.G. (1982) Physico-chemical properties of Florida phosphatic clays, Final Report on FIPR 83-02-003. Florida Institute of Phosphate Research.
2. Scheiner, B.J.; Stanley, D.A. (1995) Dewatering of phosphatic clay waste using polyethylene oxide: Theory and practice. *Fluid/Particle Separation Journal*, 8: 96–105.
3. Hardianto, F.S.; Ericson, W.A. (1994) Stabilization of phosphatic clay using lime columns, Publication No. 02-088-102, Florida Institute of Phosphate Research.
4. Anazia, I.; Misra, M. (1989) Enzymatic dewatering of Florida phosphate slimes. *Minerals and Metallurgical Processing*, 6 (2): 93–95.
5. Smith, R.W.; Misra, M.; Dubel, J. (1992) Bacterial Flocculation of Phosphate Wastes Using a Hydrophobic Bacterium. In *Residues Effluents: Process. Environ. Cosid., Proc. Ins. Symposium*, Ramana G. Reddy, William P. Imrie, and Paul B. Queneau, eds.; Warrendale, PA.: Miner. Met. Mater. Soc., pp. 747–56.
6. Nair, K.V.; Somasundaran, P. (1986) Dewatering phosphate slimes, U.S. Patent No. 4,563,285.
7. Pearse, M.J.; Weir, S.; Adkins, S.J.; Moody, G.M. (2001) Advances in mineral flocculation source. *Minerals Engineering*, 14 (11): 505–1511.
8. El-Shall, H.; McFarlin, R. (1992) Rapid dewatering of phosphatic clay slurries using fibers. *Adv. Filtr. Sep. Technol.*, 5: 154–161.
9. El-Shall, H. (1995) Development and evaluation of a rapid clay-dewatering (FIPR/DIPR) process as a reclamation technique, FIPR 93-02-93R, Florida Institute of Phosphate Research.
10. Nguyen, Q.D.; Boger, D.V. (1998) Application of rheology to solving tailings disposal problems. *International Journal of Mineral Processing*, 54: 217–233.
11. Freeman, M.P. (1982) Vacuum electrofiltration. *Chemical Engineering Progress*, 78 (8): 74–79.
12. Laros, T.J. (1990) Flocculating agent combinations for mineral slime filtration systems, U.S. Patent No. 4,931,190.
13. Agerbaek, M.L.; Keiding, K. (1993) On the origin of specific resistance to filtration. *Water Sci. Technol.*, 28 (1): 159–168.
14. Raden, D.J. (1982) Dewatering phosphate clay waste using the Enviro-clear thickener. In *Proceedings of the Consolidation and Dewatering of Fine Particles Conference*, University of Alabama, August 10–12, Tuscoloosa, AL, U.S. Bureau of Mines, pp. 205–224.
15. Ghalambor, A.; Foreman, W.E.; Hayatdavoudi, A. (1990) Optimization of thickener performance. *Miner. Metall. Process*, 7 (4): 189–197.
16. Hoff, R.; Bunnaul, P. (1992) Sediment compressibility in thickening of flocculated suspensions. *Miner. Metall. Process*, 9 (4): 184–188.