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Fine Coal-Refuse Slurry Dewatering

By R. R. Backer and R. A. Busch

UNITED STATES DEPARTMENT OF THE INTERIOR

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FINE COAL-REFUSE SLURRY DEWATERING

by

R. R. Backer[1] and R. A. Busch[2]

ABSTRACT

The Bureau of Mines, in cooperation with Washington Irrigation and Development Co. (WIDCO), evaluated the dewatering of fine coal-refuse slurry using chemicals and various types and combinations of drains in natural earth impoundments.

About 40 lb of lime and 2 lb of polymer per ton of dry solids were mixed with the underflow from the preparation-plant thickener. Clear, free water was immediately liberated from the slurry. The percent solids by weight of the slurry increased from about 17 to 30 immediately, and after 5 days increased to 45 wt-pct. This indicates a threefold reduction in total volume after 5 days from 172 cu ft/ton solids originally to 56 cu ft/ton solids.

INTRODUCTION

Under normal operating conditions and with state-of-the-art decant construction, current impoundments never achieve adequate dewatering and stabilization of fine coal-refuse slurry. This has prompted many companies to investigate various dewatering methods, including centrifuging, filtration, belt pressing, and thermal drying. Although all of these methods work to some degree, their effectiveness has been limited by technical difficulties and inadequate, costly equipment. The Bureau of Mines has been investigating the effectiveness of chemically treating the slurry and equipping impoundments with vertical and bottom drains. This report discusses the results and suggests additional research.

LABORATORY INVESTIGATION

Dewatering tests were run on coal-refuse slurry samples at the Spokane Research Center. The samples were treated with lime and American Cyanamid

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Superfloc 1202[3] polymer in varying proportions. As shown in figure 1, the treated samples were then poured into 5-gal buckets equipped with a bottom sand drain and a vertical drain of either filter fabric (hereinafter called vertical fabric drain) or perforated pipe filled with filter sand (hereinafter called vertical sand drain). The purpose of the vertical drains was to provide a channel through which the water could drain more rapidly from the slurry to the bottom drain.

FIGURE 1. - Laboratory slurry-dewatering test equipment.

[3]Reference to specific trade names or manufacturers does not imply endorsement by the Bureau of Mines.

Only enough tests were run on treated and untreated samples to show that chemical treatment had potential and warranted testing.

While the bench-scale laboratory tests were being performed, a 1,000-gal mixing tank was constructed and a mixing-and-pumping system was designed to treat the slurry with lime and polymer for large-scale field tests. Four 55-gal oil drums were equipped with a jet pump system to mix lime and polymer for the slurry treatment (fig. 2). One pair of drums was used for mixing lime and water at a ratio of 4 lb of lime to 2.7 gal of water. The other pair similarly mixed the flocculent and water at a ratio of 0.2 lb of flocculent to 4 gal of water. The two lime-mixture pumps were joined by one manifold and the two polymer pumps by another. By alternating mixing and supply functions between each barrel pair, the manifolds made possible a continuous, metered flow of lime and polymer to the mixing tank.

The mixing tank (fig. 3) was used to mix and condition the chemicals and slurry. A combination of a 100-gal/min centrifugal recirculation pump, jets, and baffles continuously agitated the slurry to prevent settlement. At the head of the mixing tank, the lime-mixture feedline and a 4-inch-diameter, 100-gal/min slurry feedline (scavenged from the slurry delivery line to the

FIGURE 2. - Chemical treatment mixing drums.

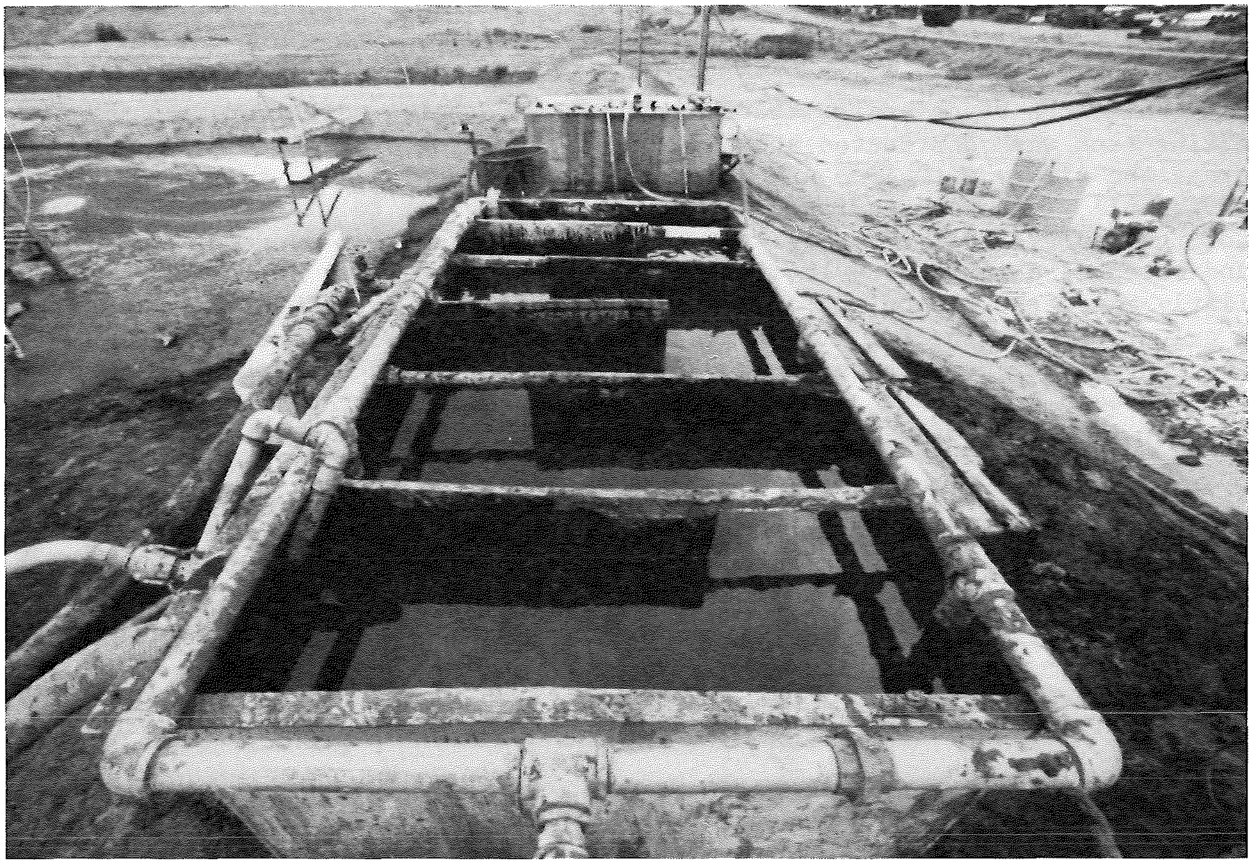

FIGURE 3. - Chemical and slurry mixing tank.

impoundment) were connected to a common manifold to guarantee intimate mixing of the lime and slurry. The slurry-and-lime mixture had to be retained in the tank for 10 min to allow the lime to thoroughly condition the slurry. The relatively low feed rate (100 gal/min) to the mixing tank provided the time needed to condition the slurry while maintaining a constant flow of treated slurry to cells 2 and 3. The feed rate was continually monitored to insure proper conditioning of the slurry. The polymer was introduced at the tank exit to mix with the treated slurry in the discharge line. Cell 4, the control cell, was filled with untreated slurry at a higher feed rate (165 gal/min).

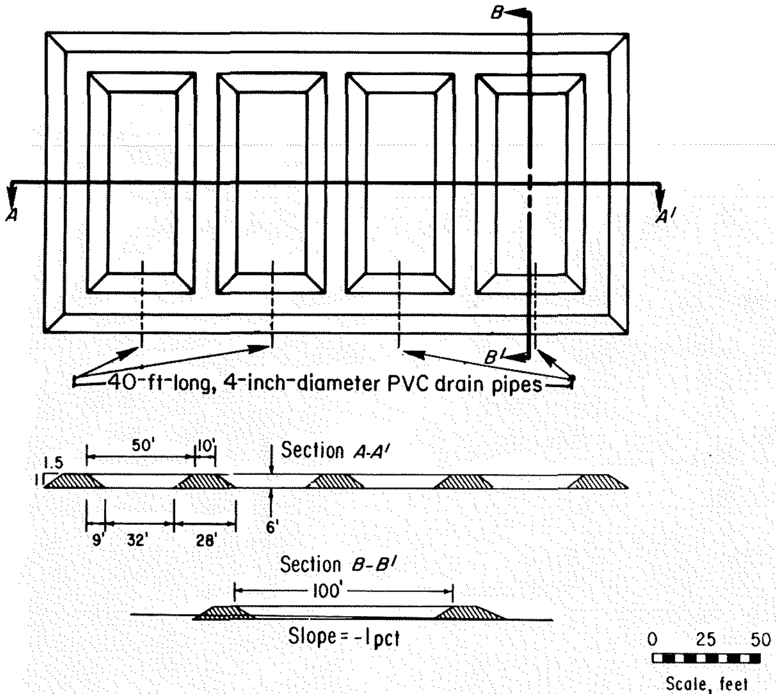

FIGURE 4. - Schematic of field test cells.

FIELD TEST

WIDCO, in cooperation with the Bureau of Mines, constructed four 50- by 6-foot dewatering test cells (fig. 4). The cells were adjacent to the present impoundment and next to the slurry delivery line running from the preparation plant to the impoundment. These cells were constructed with bottom drains of 4-inch-diameter, perforated PVC pipe buried in gravel and covered with 6 inches of steamplant bottom ash and 6 inches of sand to act as a filter and drain. Each bottom brain was connected to a solid, 4-inch-diameter PVC pipe equipped with seepage rings) that passed through the test cell embankment. These pipes were used to drain water from the test cells. Plugs were placed on the pipe ends to retain the water until drainage was desired.

Test Cell Layout and Equipment Setup

The equipment was loaded on a truck and transported from Spokane to the WIDCO mine near Centralia, Wash. The mixing tank was set up at the head end and midway between the four test cells (fig. 5). The mining company provided the necessary plumbing and electrical service. Reinforcing-steel electrodes were buried in the bottom ash of all cells for possible subsequent electrokinetic testing.

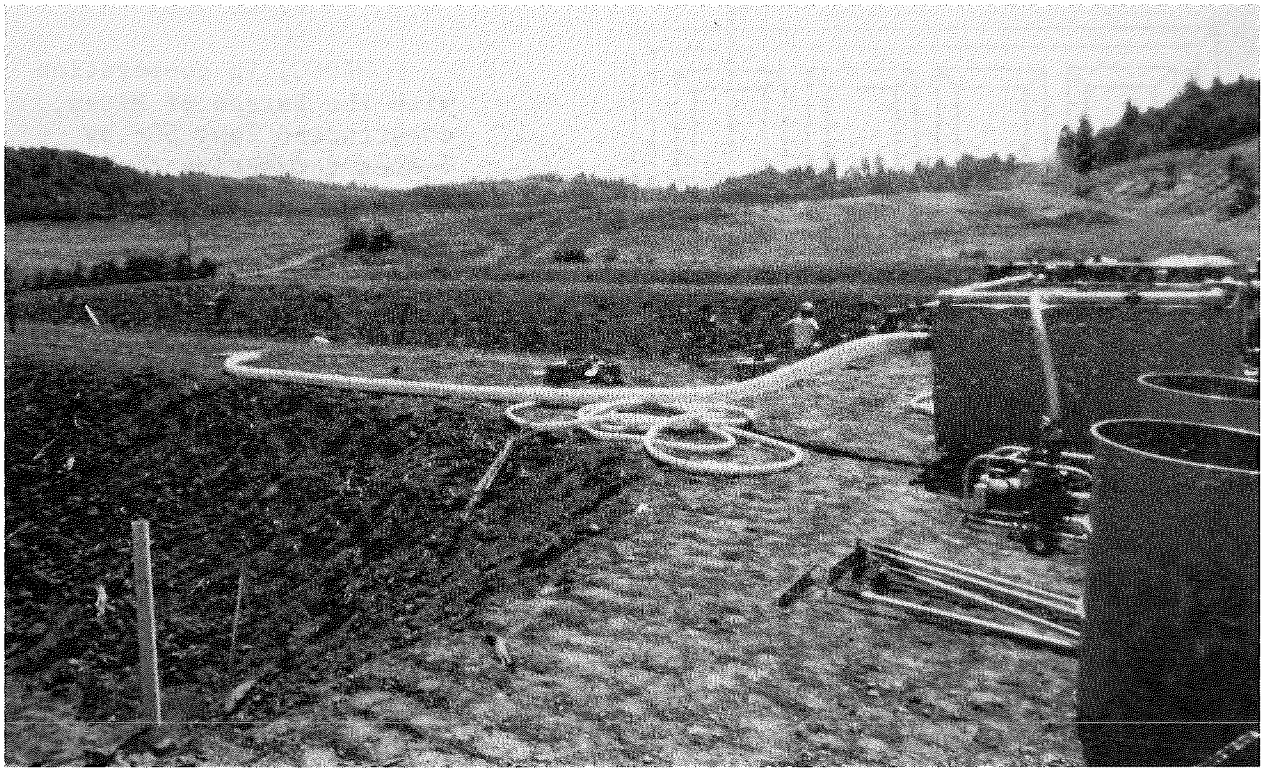

FIGURE 5. - Test cell and mixing-tank layout.

Experimental Data, First Run

Cell 1 was filled with slurry directly from the thickener with no further treatment, but was later subjected to electrokinetic treatment by other experimentors. Therefore, the experimental data for cell 1 are not included in this report. However, the fill time for cell 1 was about 1.92 hours; no slurry density values were recorded, but average slurry density was about 19 wt-pct solids.

For cell 2, 5-foot-long, vertical sand drains were constructed of 4-inch-diameter, perforated PVC pipes filled with filter sand to prevent blockage of the drains by the slurry. These drains were placed on the sand bottom of cell 2 and wired in placed 10 feet apart in nine rows spaced at 10 feet (fig. 6). The cell was then filled to capacity with treated slurry from the mixing tank.

FIGURE 6. - Vertical sand drains.

In cell 3, nine rows of vertical fabric drains were suspended from transverse wires and embedded in the bottom sand (fig. 7). The drains, constructed of filter fabric measuring 190 mils thick, 1 foot wide, and 5 feet 8 inches long, were placed about 4 feet apart in rows spaced at 10 feet. Treated slurry was then discharged into the cell until it was filled to capacity (fig. 8).

FIGURE 7. - Vertical fabric drains.

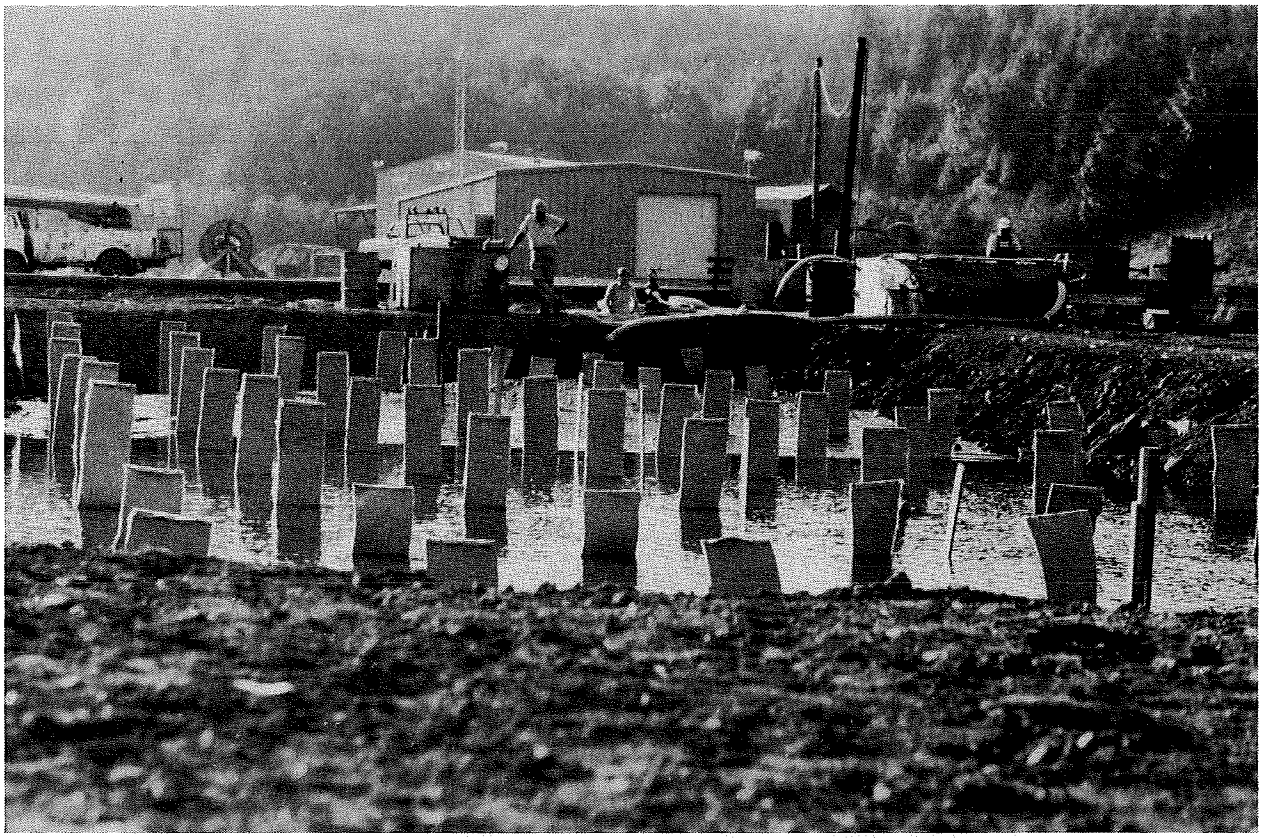

FIGURE 8. - Filling test cell.

Cell 4 was filled with underflow from the plant thickener with no further treatment for a standard practice comparison. An average slurry density of 19 wt-pct solids is assumed. The fill time for this cell was about 11 hours.

Table 1 presents the operational data for cells 2, 3, and 4. The operational data for cells 2 and 3 were continually monitored, but the data for cell 4 were obtained at the beginning of filling operations and are approximate because of possible fluctuations in the feed rate, weight-percent solids, and the amount of solids per ton.

TABLE 1. - Operational data, first run

	Cell2[1]	Cell 3[2]	Cell 4[3]
Fill time.............hours..	15.85	16.75	11
Feed:			
Rate...............gal/min..	100	100	165
Total..................gal..	95,100	100,500	108,900
Solids.............wt-pct..	21.0	17.3	19
Specific gravity...........	1.19	1.10	1.10
Solids.................tons..	99.36	79.50	95.40
Limes:			
Pounds.....................	4,050	3,150	NAp
Pounds per ton solids.......	40.8	39.6	NAp
Polymer:			
Pounds.....................	164	136	NAp
Pounds per ton solids.......	1.65	1.71	NAp
Mix water...............gal..	12,062	9,694	NAp
Mix water and feed.......gal..	107,162	110,194	NAp

NAp Not applicable; untreated control cell.
[1]Vertical sand drain and/or bottom drain.
[2]Vertical fabric drain and/or bottom drain.
[3]Bottom drain only. Data are approximate.

All of the cells were filled with the drain pipes closed to provide a comparison of outflow rates through the bottom drains. During filling operations the treated slurry displayed a dramatic flocculation and immediate separation of clear water from the solids. The surface water in the untreated cells (cells 1 and 4) remained turbid throughout the remaining days of record. After all cells were filled, the bottom drains on cells 2, 3, and 4 were opened. Initially, cells 2 and 3 drained at a rate of about 150 gal/min. This was caused by the water which was held in the sand under drain and very quickly tapered off to about 20 gal/min, and after 4 days had decreased to about 1 gal/min. Cell 4 drained at a rate of about 10 gal/min initially, but soon decreased to about 1 gal/min, and maintained this rate of flow for the remaining days of record. Table 2 shows the flow rates for effluent from cells 2, 3, and 4. The effluent from the two treated cells (cells 2 and 3) appeared fairly clear, and test results showed it to have a relatively high pH (table 3). The water quality tests were performed by the WIDCO chemistry lab and since the quantity of flow in cells 2 and 3 was so erratic for the first 2 days, they did not test it.

TABLE 2. - Effluent flow rate, first run, gallons per minute

Day	Cell 2[1]	Cell 3[2]	Cell 4[3]	Day	Cell 2[1]	Cell 3[2]	Cell 4[3]
1.........	[4]60.00	[4]60.00	NM	9.........	NM	NM	NM
2.........	15.00	15.00	2.30	10.........	0.36	0.63	1.36
3.........	NM	NM	NM	11.........	NM	NM	NM
4.........	NM	NM	NM	12.........	.23	.23	1.58
5.........	1.34	.83	1.36	13.........	.23	.27	.69
6.........	1.27	.77	1.30	14.........	.19	.22	.71
7.........	.80	.58	1.10	15.........	.19	.19	.65
8.........	.51	.45	1.02				

NM Not measured.
[1]Vertical sand drain and/or bottom drain.
[2]Vertical fabric drain and/or bottom drain.
[3]Bottom drain only.
[4]Average for first day.

TABLE 3. - Effluent water quality, first run

	Cell 2	Cell 3	Cell 4
Day 1:			
pH..	NT	NT	7.74
Conductivity.........................microohms..	NT	NT	143.7
Turbidity................................mg/l..	NT	NT	1.7
Alkalinity...............................mg/l..	NT	NT	80.0
Day 2:			
pH..	NT	NT	7.73
Conductivity.........................microohms..	NT	NT	137.1
Turbidity................................mg/l..	NT	NT	2.0
Alkalinity...............................mg/l..	NT	NT	103.0
Day 3:			
pH..	11.75	11.18	7.8
Conductivity.........................microohms..	2,324.0	1,598.0	1,361.0
Turbidity................................mg/l..	32.5	45.0	14.0
Alkalinity...............................mg/l..	377.0	260.0	148.0
Day 4:			
pH..	11.82	8.22	8.03
Conductivity.........................microohms..	2,590.0	1,022.0	1,385.0
Turbidity................................mg/l..	18.0	18.0	17.0
Alkalinity...............................mg/l..	484.0	156.0	144.0
Day 5:			
pH..	9.25	8.06	8.16
Conductivity.........................microohms..	1,400.0	1,190.0	1,462.0
Turbidity................................mg/l..	13.0	9.8	9.7
Alkalinity...............................mg/l..	128.0	176.0	140.0
Day 6:			
pH..	8.86	8.09	8.03
Conductivity.........................microohms..	1,431.0	1,188.0	1,401.0
Turbidity................................mg/l..	12.0	9.5	9.2
Alkalinity...............................mg/l..	139.0	185.0	144.0

NT Not tested.

After 14 days, the volume of slurry in cell 2 was 2,720 cu ft compared with the filled volume of 14,320 cu ft. After 15 days, the volume of slurry in cell 3 was 2,320 cu ft compared with the filled volume of 14,730 cu ft. At this stage, the drainage was practically complete, and the consistency of the slurry was such that the surface could be walked on and the slurry could be easily excavated (fig. 9). Table 4 shows the progressive increase in solids content.

TABLE 4. - Solids content, first run

Day	Cell 2[1]		Cell 3[2]	
	Average wt-pct solids	Number of samples	Average wt-pct solids	Number of samples
2...........	31.0	7	NM	0
3...........	NM	0	37.4	9
5...........	36.0	1	NM	0
6...........	37.8	5	43.0	1
7...........	35.5	8	39.0	9
8...........	42.3	3	43.3	9
9...........	NM	0	47.3	3
10...........	45.5	2	NM	0
11...........	NM	0	50.3	3
12...........	45.7	3	NM	0
13...........	45.4	18	58.0	3
14...........	45.4	15	56.8	19
15...........	47.8	6	56.3	15
16...........	NM	0	59.8	6

NM Not measured.
[1]Vertical sand drain and/or bottom drain.
[2]Vertical fabric drain and/or bottom drain.

After the first experiments on dewatering with chemical additives and vertical drains were completed, the material from cells 2 and 3 was removed to perform a second run.

FIGURE 9. - Partially dewatered fine coal-refuse slurry.

Experimental Data, Second Run

Although dewatering of the slurry had been relatively successful, a second run with minor alterations and improved control was deemed necessary. It was apparent that the chemical treatment did expedite the dewatering process. In the first run, vertical fabric drain was also slightly more effective than the vertical sand drain (table 4). To verify the effectiveness of vertical drains and to obtain a more valid comparison of the two types, cell 2 was longitudinally divided with vertical sand drains in one half and vertical fabric drains in the other half (fig. 10). These drains were spaced at 10-foot intervals as in previous tests.

FIGURE 10. - Test cell with vertical sand and fabric drains.

A total of 325,054 gal of treated slurry was pumped into the cell in 50.75 hours, essentially filling it. During this run, water was allowed to exit the test cells during filling operations and cell 2 accepted three times as much slurry as it did in the first run (107,162 gal). The slurry density was much higher initially because of the continuous drainage and the decanting of the free surface water.

Cell 3 was equipped with the same bottom drain as in the first run but with no vertical drains. It was filled with treated slurry and allowed to drain during the fill. This cell took 51.83 hours and 331,971 gal to fill (table 5). Once again, the cell held three times the volume of the first (confined) run (331,971 gal versus 110,194 gal).

TABLE 5. - Operational data, second run

	Cell 2[1]	Cell 3[2]
Fill time..........................hours..	50.75	51.83
Feed:		
Rate..........................gal/min..	107	107
Total...............................gal..	304,500	310,980
Solids..........................wt-pct..	16.9	17.4
Specific gravity.......................	1.20	1.20
Solids.............................tons..	275.40	288.60
Lime:		
Pounds................................	10,750	12,450
Pounds per ton solids..................	39.0	43.1
Polymer:		
Pounds................................	520	598
Pounds per ton solids..................	1.89	2.07
Mix water..........................gal..	20,554	20,991
Mix water and feed..................gal..	325,054	331,971

[1]One-half vertical sand drain and one half vertical fabric drain.

[2]Bottom drain only.

TEST RESULTS

Chemical treatment of the slurry caused the water to immediately separate from the flocculated solids and become free surface water that could easily be removed. As the depth of solids increased, the water could not adequately permeate the solids to the bottom drain, even with the aid of vertical drains. With the flocculation of solids, the mass attained a rather low permeability (5.82×10^{-6} cm/sec), which, coupled with the inability of the vertical drains to accept the drainage rate of 50 gal/min or greater, limited the instantaneous drainage necessary to handle the inflow (table 6). Therefore, it was necessary to aid the drainage by siphoning surface water, which allowed continuous filling of the impoundment rather than the interrupted filling that would occur if the only exit was through the solids to the bottom drain. The water siphoned from the surface, however, was clear and free of solids.

TABLE 6. - Effluent flow rate, second run, gallons per minute

Day	Cell 2[1]	Cell 3[2]	Day	Cell 2[1]	Cell 3[2]
1.........	30.00	NM	25.........	2.50	6.00
2.........	17.00	NM	28.........	NM	1.66
21.........	17.00	NM	29.........	NM	4.00
22.........	12.00	NM	30.........	.60	2.50
23.........	7.00	NM	31.........	.50	2.00
24.........	3.50	14.00			

NM Not measured.
[1]One-half vertical sand drain and one-half vertical fabric drain.
[2]Bottom drain only.

As shown in table 7, cell 2, with the vertical drains, achieved about 46 wt-pct solids after 5 days and only 52 wt-pct solids after 47 days. However, during this period heavy rainfall occurred in the area. Cell 3, without the vertical drains, had a solids content of 44 wt-pct after 5 days and a solids content of 48 wt-pct after 47 days.

TABLE 7. - Solids content, second run

Day	Cell 2[1]				Cell 3, bottom drain only	
	Fabric drain		Sand drain			
	Average wt-pct solids	Number of samples	Average wt-pct solids	Number of samples	Average wt-pct solids	Number of samples
4......................	NM	0	NM	0	43.8	6
5......................	46.3	3	45.3	3	43.0	6
6......................	46.6	3	46.3	3	44.0	6
7......................	48.0	3	47.6	3	44.2	6
8......................	47.6	3	46.6	3	NM	0
9......................	48.6	3	47.6	3	NM	0
10......................	48.6	3	48.3	3	NM	0
47......................	51.7	3	52.5	2	48.0	5
71......................	NM	0	NM	0	48.0	0
78......................	52.0	0	52.0	0	NM	0

NM Not measured.
[1]One-half vertical sand drain and one-half vertical fabric drain.

From the samples taken at various locations and depths of the original WIDCO impoundment, the determination is that, after settlement, the slurry density is about 30 wt-pct solids (90 cu ft/ton solids). Assuming an initial slurry density of 17 wt-pct solids (172 cu ft/ton solids), a total reduction of about 48 vol-pct was achieved by settlement in the impoundment. Our limited experiments indicate that, with chemical treatment, slurry density can be increased to about 45 wt-pct (56 cu ft/ton solids) in 5 days, which represents a total reduction of about 67 vol-pct. This represents an increased storage capacity of about 1-1/2 times that of the untreated material (fig. 11). More significant is the time factor; the experimental values were achieved in 5 days, whereas the impoundment has been settling for years. The curve shown

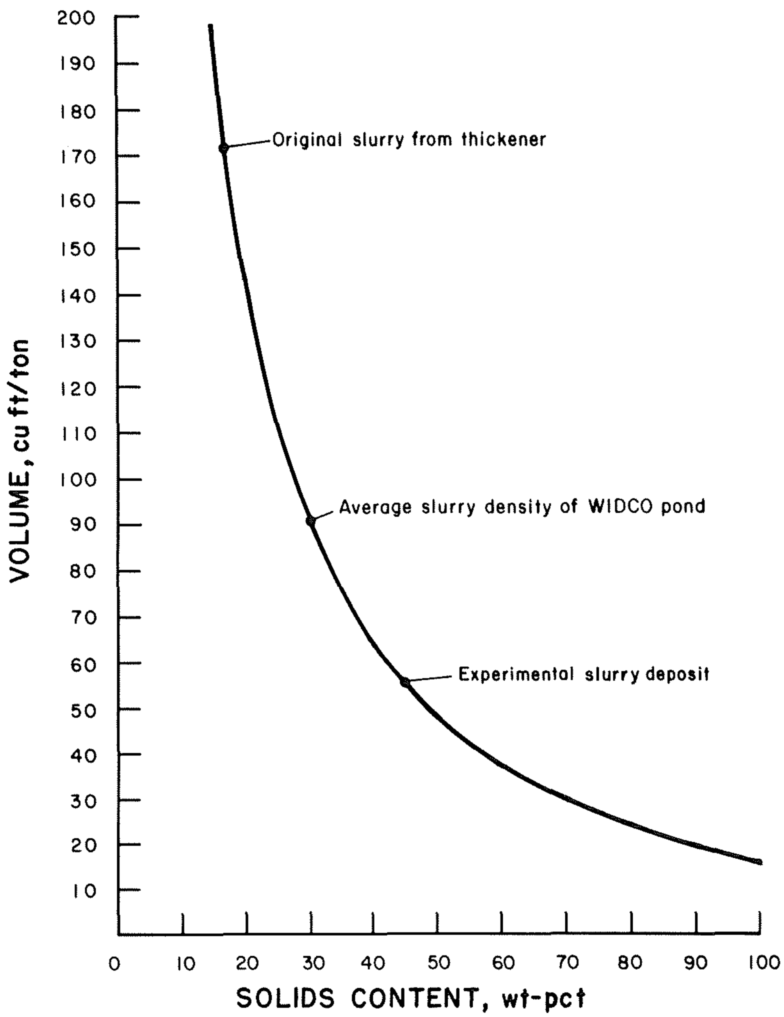

FIGURE 11. - Moisture-volume relationships of slurry.

in figure 11 indicates a beneficial reduction in volume as the slurry density is increased to about 50 wt-pct solids, but further increases in slurry density do not appreciably reduce volume. The experiments show that increasing slurry densities from 50 to 60 wt-pct solids is difficult and expensive, and probably is not feasible considering the relatively small decrease in volume. However, if rehandling the solids is being considered, the higher slurry densities become more important, and possibly necessary. The reduction in volume achieved in the experiments, when applied to the operation of an impoundment, could double the capacity for stored slurry and thereby increase the life of the impoundment.

CONCLUSIONS

Extreme fluctuations of slurry density and several shutdowns during the experiment caused variations in the quality of the treated slurry and condition of the settled slurry. However, even considering operational problems, limited tests, and consequent lack of data, several valid points have been made. The addition of lime and polymer to the slurry in the amounts used in this experiment had a dramatic effect. As the treated slurry reached the test cells, there was an immediate separation of water and solids; the flocculated solids readily settled and relatively clear water was liberated. In contrast, the untreated slurry introduced in the same manner in the control cell (cell 4) took weeks to settle, and the surface water remained turbid throughout the remaining days of record.

The vertical drains that were used to draw water from the slurry were effective, but their usefulness is somewhat proportional to the depth of the slurry deposit. The vertical fabric drains seemed to be a little more effective than the vertical sand drains; on the basis of comparative permeabilities, it is assumed that their advantage was derived from a larger surface-area contact with the slurry. If the openings in the sand drains were expanded, they would probably perform as well.

The low permeability of the flocculated slurry precludes rapid dewatering without some type of drainage system and supplemental surface decanting to remove the clear water at a rate that would permit continuous operation. The rate of flow from the drains in the experiment decreased from the original rate of 50 gal/min to about 2 gal/min in 30 days, indicating the reluctance of the flocculated material to release water beyond the 50 wt-pct sludge density.

Because available data are insufficient, an estimated cost for a full-scale operation using the experimental technique (or a similar one) cannot be established at this time. Although the costs for flocculation and deposition are expected to be high for a full-scale operation, they still would be competitive with other methods, and the costs and preparation of chemmicals would be comparable to those of any process involving chemical treatment such as centrifuging or pressing.

Mixing and disposing of the slurry in cells with intended cyclic rehandling is probably not feasible for a full-scale operation because of such factors as the expense and engineering complexities of cell preparation and drain construction. However, an alternative solution using chemical flocculation and disposal might incorporate a system similar to the experimental method, but using a natural site for disposal. The concept would not require a dam to retain the solids, but a smaller catchment area to intercept the water for recycling. A relatively large, slightly sloping area could be used for deposition; the treated slurry, introduced from spigots, would spread out and allow the water to collect at the downstream end of the deposit as the flocculated material settled out and formed natural deltas. The rapid separation of solids from the water results in a decreased neutral stress, a higher shear strength, and creates a relatively stable deposit. The use of vertical drains would depend on the surface area available for disposal (which controls the deposition depth). If the depth of the deposit is shallow, the shrinkage cracks would penetrate deep enough to allow the water to percolate through the slurry and vertical drains would not be needed.

To insure reclamation of water and prevent possible ground-water contamination, it would be advisable to have an impervious soil base with a bottom drain of sand or bottom ash.

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