DISPOSAL OF SLUDGE FROM ACID MINE WATER NEUTRALIZATION

Show-Jong Yeh and Charles R. Jenkins

Acid mine drainage associated with coal mining from either surface or deep mines, whether active or abandoned, causes a very serious problem of stream pollution especially in northern West Virginia and western Pennyslvania. Drainage has detrimental effects on domestic and industrial water supplies, river craft, power plants, and river and harbor structures. Several processes have been investigated and proposed for treating of acid mine drainage including neutralization, biological treatment, reverse osmosis, electrodialysis, crystallization, ion exchange, and distillation. Of these processes, neutralization, usually coupled with aeration and sedimentation, is the most commonly used, as well as being the oldest. A major problem in this treatment process is the handling and disposal of the sludge that remains after neutralization. As a result of recent and future construction of a number of these neutralization plants, the problem of sludge disposal is becoming more significant.

The objective of this study was to apply the methods of conventional domestic wastewater sludge-handling processes to sludge produced by acid mine water neutralization and to develop necessary design data. Investigation was also made of the possibility of using acid mine water neutralization sludge mixed with domestic wastewater sludge to improve conditions for strip mine reclamation.

Show-Jong Yeh and Charles R. Jenkins are, respectively, instructor and associate professor, Department of Civil Engineering, West Virginia Univ., Morgantown.

The paper was presented at the Annual Meeting of the West Virginia Water Pollution Control Association, Parkersburg, W. Va., Mar. 30–31, 1970.

Methods and Equipment

Dewatering Studies

The neutralization sludge used in the dewatering studies was taken from the Christopher Coal Co. acid mine drainage treatment plant located south of Mount Morris, Pa. At the time of this study, the plant was treating about 1,800 gpm (113 l/sec) of mine water. Approximately 800 gpm (50 l/sec) of a 1 percent solids sludge was discharged to a lagoon, and the remaining 1,000 gpm (63 l/sec) of treated water was discharged to a stream. In this plant, acid mine drainage was neutralized with lime, aerated for iron removal, and passed through a settling basin. The sludge used in this study was drawn from the bottom of the settling basin.

The apparatus utilized in the thickening study consisted of an 8-ft (2.4-m) plastic settling column as designed by Eckenfelder[1] with an inside diameter (ID) of 5.5 in. (13.9 cm). A stirrer was installed to eliminate stratification of the sludge and to encourage upflow of liquid. This column was used to evaluate the settling characteristics of neutralization sludge.

The equipment used for sand-bed dewatering studies was a four-compartment bench-scale sand drying bed as shown in Figure 1. The unit was modified from the model used in Research Report No. 15, New York State Department of Health.[2] A fan producing a wind speed of 5 mph (8.0 km/hr), calibrated with an Alnor Velometer, was set to serve ventilation purposes.

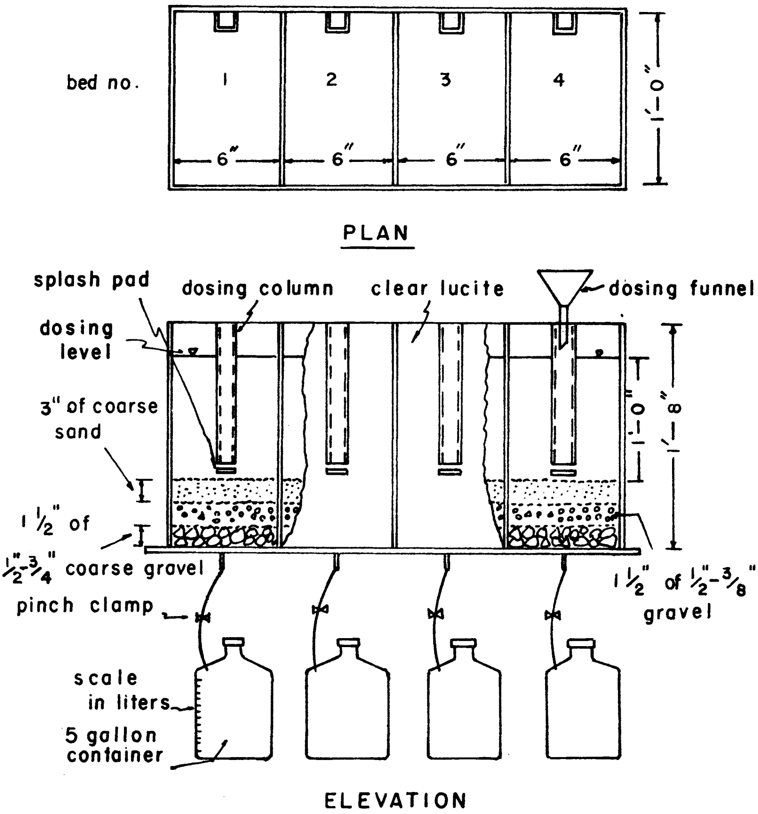

FIGURE 1.—Sand drying bed laboratory apparatus. (In. × 2.54 = cm.)

From this study drying time and solids yield were determined for different sludge-loading conditions.

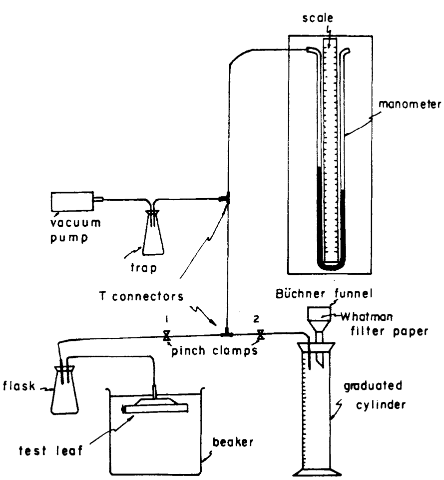

FIGURE 2.—Vacuum filter laboratory apparatus.

For vacuum filtration evaluation, a combination of the Buchner funnel test and leaf test using equipment as shown in Figure 2 was used. The data collected for this investigation were used to determine loading rates and final solids concentrations under different conditions of vacuum filtration.

Greenhouse Experiments

The soil used in this study was a mixture of mine spoil, neutralization sludge, and domestic wastewater sludge in different proportions to make up 500-g test quantities on the basis of oven dry weights. The mine spoil was collected from a surface mine located 1 mile (1.6 km) west of Smithtown, W. Va. No vegetation grew in this area. Neutralization sludge was taken from the settling pond of the acid mine water neutralization pilot plant operated by the School of Mines at West Virginia University. Digested primary domestic wastewater sludge was taken after vacuum filtration from the Morgantown wastewater treatment plant. This plant used lime and ferric chloride for sludge conditioning. After air drying, the soil was ground into fine particles and further mixed. Kentucky 31 tall fescue seed was planted. The temperature in the greenhouse was maintained at 20° to 25°C.

Results and Discussion

Thickening Test

The initial concentration of sludge (C_o) was 1.2 percent and was considered typical for the Christopher Coal Co. neutralization plant. An interface settling curve was made (Figure 3) for the 8-ft (2.4-m) column. The hindered settling curve was used for determining the design parameters as discussed by Eckenfelder.[1] Using this approach the relationship of unit area, U_A, and interfacial settling velocity, U_i, for a series of underflow concentrations, C_u, were determined as shown in Figure 4.

It may be observed that a maximum unit area exists for each underflow concentration as related to a critical interfacial settling velocity in Figure 4. The maximum unit areas would be used for design purposes, and the results developed from them are summarized in Table I. In this table, mass loading, ML, is the reciprocal of the unit area and C_o, the initial solids concentration in grams per liter. The ML and

$$\frac{C_u}{C_o} - 1$$

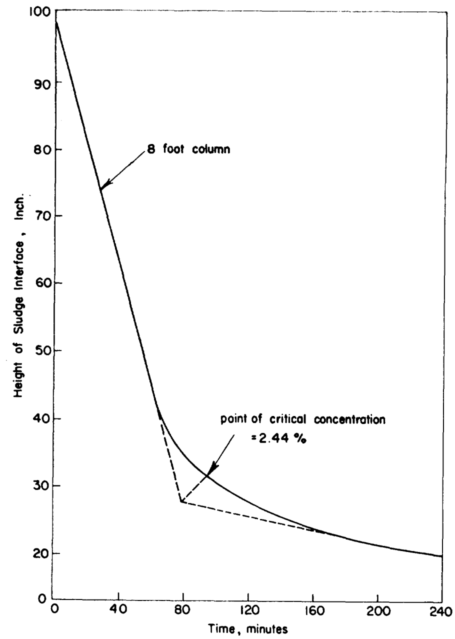

FIGURE 3.—Interface settling curve. (Ft × 0.3048 = m.)

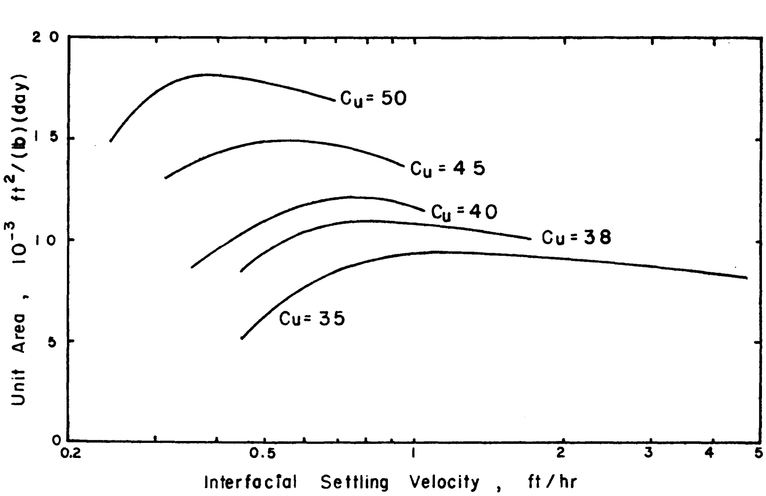

FIGURE 4.—Relationship between unit area and interfacial settling velocity. (Ft/hr × 0.3048 = m/hr; sq ft/lb × 0.204 = kg/sq m.)

TABLE I.—Maximum Unit Area Requirements for Different Underflow Concentrations

Underflow Concentration (C_u) (g/l)	Maximum Unit Area (UMA) (sq ft/day/lb)	Mass Loading (ML) (lb/day/sq ft)	$\frac{C_u}{C_o^*} - 1$
35	0.0095	105	1.92
38	0.0110	91	2.17
40	0.0121	83	2.34
45	0.0150	67	2.75
50	0.0181	55	3.17

* Initial concentration, C_o, = 12 g/l
Note: Sq ft/day/lb × 0.204 = sq m/day/kg; lb/sq ft/day × 4.88 = kg/sq m/day.

values are used to plot the line in Figure 5.

The constant K and n in the relationship

$$\frac{C_u}{C_o} - 1 = \frac{K}{ML^n}$$

are, respectively, the coordinate intercept and the slope of the line shown in Figure 5. The final design equation was obtained.

$$\frac{C_u}{C_o} - 1 = 55 \text{ (mass loading)}^{-0.72} \quad (1)$$

This equation may be used for designing a thickener when the C_o = 1.2 percent. If the sludge concentration varies

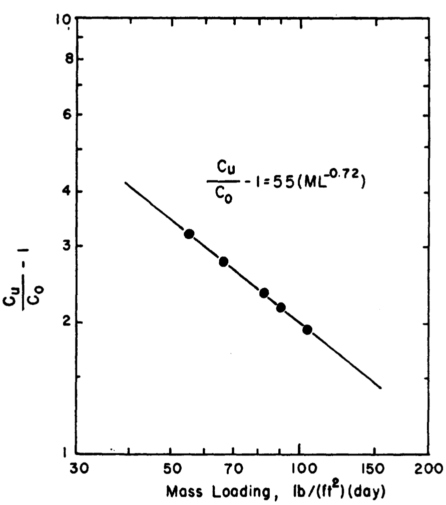

FIGURE 5.—Relationship between mass loading and sludge underflow concentration. (Lb/sq ft × 4.88 = kg/sq m.)

greatly from this value, a different equation would have to be determined. When designing a thickener, an underflow concentration C_u would be selected at a sludge inflow rate of Q_o in gallons per day. A mass loading, therefore, can be obtained using Equation 1. The reciprocal of this mass loading is the corresponding maximum unit area. The surface area, A, in square feet, of the desired thickener may be calculated by the equation $A = (8.34 \times 10^{-3}) Q_o C_o U_A$.

The procedure for sizing a thickener to treat an inflow of 800 gpm (50 l/sec) having an initial sludge concentration (C_o) of 12 g/l would be as follows. Select a desired underflow C_u of 35 g/l shown in Table I.

Surface area of the thickener

$$A = (8.34 \times 10^{-3}) \times (800 \times 24 \times 60)(12)(0.0095)$$

A = 1,100 sq ft (102.2 sq m)

Diameter of a circular thickener

$$D = \sqrt{\frac{4 \times 1{,}100}{\pi}}$$

D = 37.4 ft (11.4 m), use 38 ft and A = 1,140 sq ft (105.9 cu m)

Volume of settling zone if tank is 10 ft (3.0 m) deep allowing 2 ft (0.6 m) for sludge storage

V = (8)(1,140)
= 9,120 cu ft (255.4 cu m)

Detention time in the thickener

$$t = \frac{(9{,}120)(7.48)}{800}$$

t = 85 min

Sand-Bed Drying Test

It was observed that dewatering of neutralization sludge undergoes two distinct phases. The first phase is a liquid-solids separation by the filtering action of the sand media (Figure 6). The second phase of dewatering is drying of the sludge cake by evaporation (Figure 7). Tables II and III are summaries of sand-bed filtering phase results and drying phase results, respectively. The solids yield and solids loading in Table III were computed using the method described in Research Report No. 15, New York State Department of Health.[2] A sand filter designed to treat a 2.34 percent sludge concentration from an inflow of 800 gpm (50 l/sec) having a sludge concentration of 1.2 percent would be as follows:

Volume of concentrated sludge, assuming specific gravity of sludge to be 1.00

$$V = \frac{(800)(1.2)}{2.34}$$

$$V = \frac{(410)}{(7.48)}$$

$$= 55 \text{ cu ft/min } (1.54 \text{ cu m/min})$$

Filter area required for 1 day of sludge production with sludge applied to filter at a 1-ft (0.3-m) depth

$$A = \frac{(55)(60)(24)}{43{,}560}$$

$$A = 1.8 \text{ acre } (0.73 \text{ ha})$$

Drying time would be approximately 10 days if weather conditions approximated laboratory conditions.

TABLE II.—Summary of Filtering Phase Results

Bed No.	Sand Sizes (mm)	Feed Sludge Concentration (%)	Average Solids Concentration of Filtrate (%)	Drainage Time (hr)
1	0.50	1.20	0.93	2.5
3	0.50	1.64	0.98	3.0
1	0.50	2.12	0.79	22.0
3	0.50	2.34	0.89	25.0
2	0.25	1.43	0.93	9.0
4	0.25	1.80	1.01	12.0

The results of the vacuum filtration test are shown in Table IV. The test procedure and method of calculating values found in the table were described by Eckenfelder.[1,4] The purpose of the Buchner funnel test was to determine specific resistance and compressibility. Specific resistance is a factor that is a measure of the filterability and is numerically equal to the pressure difference needed to produce a unit rate of filtrate flow of unit viscosity through a unit weight of filter cake.[3] It is therefore a parameter that allows an unbiased comparison of the resistance to filtration of various types of sludge. The greater the value of compressibility coefficient, the more compressible is the sludge. When it is zero, the specific resistance is independent of pressure, and the sludge is incompressible.[1]

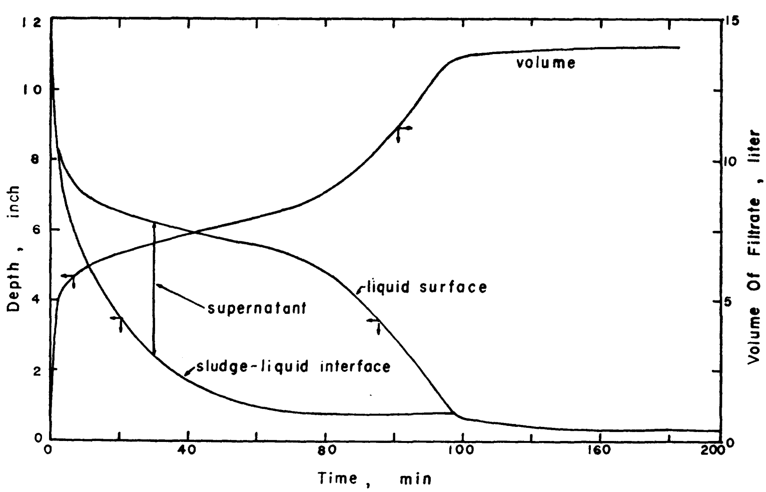

FIGURE 6.—Representative curves of volume of filtrate and depth versus time. (In. × 2.54 = cm.)

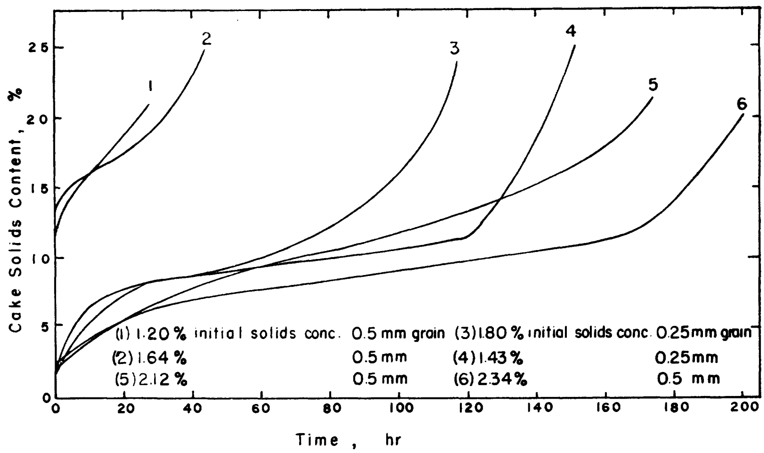

FIGURE 7.—Drying characteristics of sludge.

The loading rates shown in Table IV were calculated by three different equations. One was suggested by Jones,[5] the other two by Eckenfelder.[4] For one of the Eckenfelder equations, the compressibility coefficient, S, is used. This value was determined from the slope of the line obtained by plotting specific resistance versus pressure as shown in Figure 8. The values for specific resistance at various loading rates show that specific resistance of neutralization sludge at solids concentrations of 1.13 percent to 1.72 percent were 26.5×10^7 to 43.2×10^7 sec^2/g. These values for specific resistance fall within the range of 4.3×10^7 sec^2/g (primary paper mill sludge) up to 66×10^7 sec^2/g (digested sludge).

The values of specific resistance for neutralization sludge increased with increasing solids concentration. This contradicts the theory that specific resistance is independent of solids content, but it is in close agreement with Coackley's report that the specific resistance decreased with decreasing solids content.[3] Because of this, the loading rates in Table IV, as calculated by any of the three equations, did not exhibit the positive proportionality between feed solids concentration and filter loading.

The compressibility coefficient has a value of 0.77, which indicates that this sludge is compressible. This value falls within the range of the compressibility coefficients of domestic wastewater sludges, 0.54 (raw wastewater) to 1.19 (digested-conditioned). The values of filter loading rates calculated by the equation incorporating the S value are only about 40 percent of those calcu-

TABLE III.—Summary of Drying Phase Results

Bed No.	Sand Sizes (mm)	Feed Sludge Concentration (%)	Drying Time* (hr)	Average Temperature (°F)	Average Relative Humidity (%)	Solids Yield (lb/sq ft/cycle)	Solids Loading (lb/sq ft/cycle)	Total Dewatering time (hr)
1	0.50	1.20	22.5	80.5	15.5	0.232	0.85	25
3	0.50	1.64	29.0	77.1	28.7	0.554	1.16	32
1	0.50	2.12	148.0	71.7	29.6	1.078	1.50	170
3	0.50	2.34	175.0	71.7	29.6	1.202	1.65	200
2	0.25	1.43	134.0	73.0	39.4	0.446	1.01	143
4	0.25	1.80	100.0	73.2	34.2	0.700	1.27	112

* Time required to achieve 20 percent solids content in the cake.
Note: 0.555 (°F−32) = °C; lb/sq ft/cycle × 4.89 = kg/sq m/cycle.

TABLE IV.—Summary of Results of Vacuum Filtration Test

Base Conditions			Buchner Funnel Test		Leaf Test	Loading Rate (lb/hr/sq ft)		
Purpose	Vacuum (in. Hg)	Initial Solids Concentration (%)	Final Cake Solids Concentration (%)	Specific Resistance (10^7 sec²/g)	Final Solids Content 100-C_f(%)	Jones' Equation	Eckenfelder's Equation with $S=0$	Eckenfelder's Equation with $S=0.77$
Loading rate test	20	1.13	10.03	26.50	12.9	0.59	0.57	0.24
	20	1.37	12.25	34.50	12.7	0.58	0.55	0.23
	20	1.42	11.67	37.10	12.1	0.58	0.56	0.23
	20	1.72	10.80	43.20	11.8	0.61	0.57	0.24
Compressibility test	10	1.20	8.01	36.30				
	75	1.20	10.55	50.30				
	20	1.20	12.64	62.50				
	25	1.20	12.10	70.40				

Note: Lb/day/sq ft × 4.89 = kg/day/sq m.

lated by other two equations. In designing a vacuum filter, the loading rates calculated by considering the S value should be used. However, when compared with the values of loading rates, 1.24 lb/hr/sq ft (activated sludge) to 10.0 lb/hr/sq ft (16.1 to 48.9 kg/hr/sq m) (primary paper mill sludge), the filter loading rates of this sludge are quite low. The final solids concentrations of the cake formed in the vacuum filtration test were about 12 percent, which is not acceptable for the disposal purposes. This dewatering method would not be satisfactory for dewatering the neutralization sludge unless proper sludge conditioning chemicals or coagulant aids could be found.

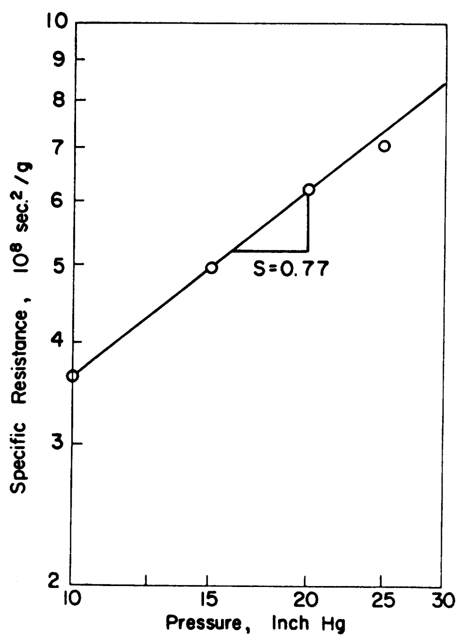

FIGURE 8.—Determination of sludge compressibility coefficient.

Greenhouse Experiments

Figures 9, 10, and 11 show results taken from the greenhouse experiments.

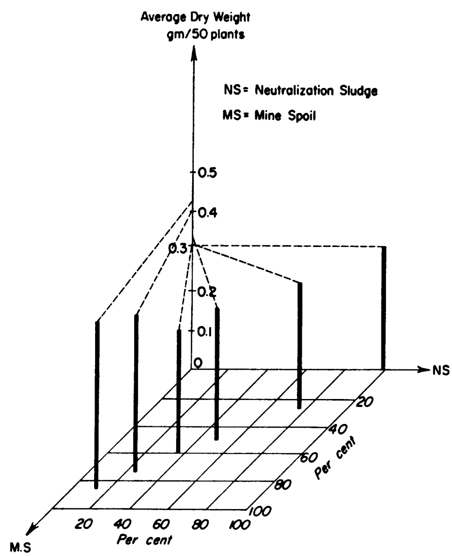

FIGURE 9.—Plant production in mine spoil and neutralization sludge.

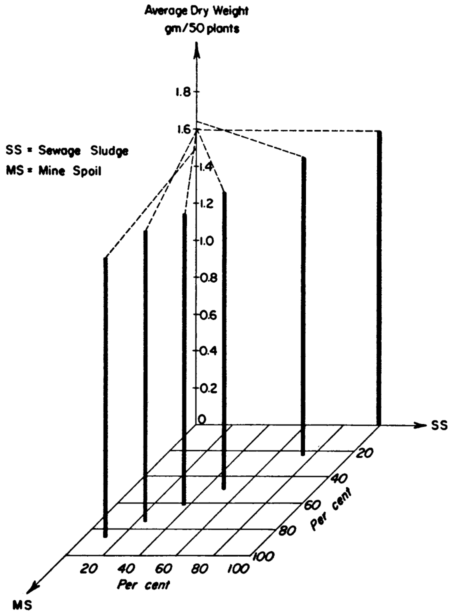

FIGURE 10.—Plant production in mine spoil and wastewater sludge.

The pH of the soil was measured 10 days after seeding and at the time of harvesting for 24 different treatments. Except for the 100 percent mine spoil, which had an average pH of 3.2, the combinations of mine spoil, neutralization sludge and/or domestic wastewater sludge maintained pH values in the range of 7.0 to 8.0, which is satisfactory for plant growth. In Figure 9 various combinations of mine spoil and neutralization sludge were shown to produce a maximum dry plant weight of 0.44 g/50 plants at 87.5 percent mine spoil and 12.5 percent neutralization sludge. The maximum dry weight produced on mine spoil and domestic wastewater sludge was 1.63 g/50 plants at 25 and 75 percent, respectively, as shown in Figure 10. The greatest plant production resulted from a combination of 45 percent mine spoil, 25 percent neutralization sludge, and 30 percent domestic wastewater sludge. This production is shown to be 2.49 g/50 plants in Figure 11. The control, which consisted of a high quality potting soil, produced 1.13 g/50 plants. Therefore, it was found that a proper amount of neutralization sludge could result in better conditions for strip mine reclamation than the use of domestic wastewater sludge alone.

Observations of the germination in each can showed that seed in those cans containing the greatest portion of neutralization sludge germinated about 5 days after seeding. However, seed in the remaining cans germinated in about 8 days, except in those cans containing 100 percent of mine spoil with an average pH value of 3.2; only about three seeds in these three cans germinated and growth was severely inhibited. Because so little success was observed in these samples, they were considered to have zero productivity.

In the cans containing only neutralization sludge and mine spoil, and neutralization sludge alone, the plants, though successful at germination, demonstrated symptoms of nutrient deficiency such as yellow coloration and retarded growth.

Figure 12 shows the relative growth at the end of the test period in the vari-

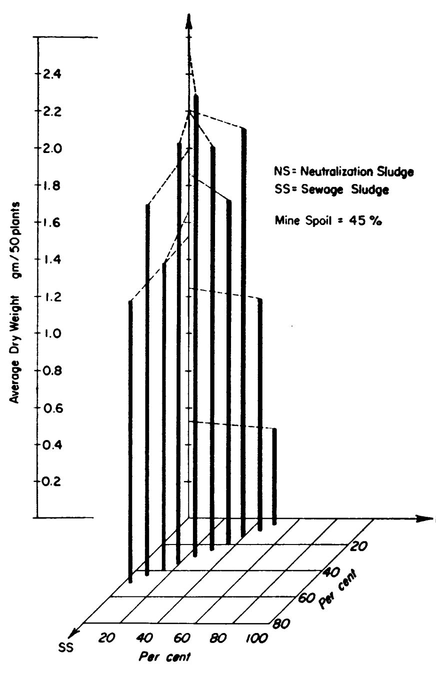

FIGURE 11.—Plant production in mine spoil, neutralization sludge, and wastewater sludge.

ous combinations of soil containing mine spoil. The plants in those cans containing domestic wastewater sludge and mine spoil and in those cans containing domestic wastewater sludge, mine spoil, and neutralization sludge had better growth than those in the control. The plants in the mixtures of neutralization sludge and mine spoil were stunted. Plants in mine spoil were essentially unsuccessful.

The amounts of sludge required for reclamation based on the conditions observed in the greenhouse studies may be estimated as follows:

Assume that the density of mine spoil is 4 mil lb/acre-ft (1,470 kg/cu m) (dry weight).

Assume that the top 6 in. (15.2 cm) of mine spoil is mixed with neutralization sludge and domestic wastewater sludge at 45, 25, and 30 percent, respectively.

Dry weight of neutralization sludge required per acre

$$Wt = 2,000,000 \times \frac{25}{45}$$

$$Wt = 1,110,000 \text{ lb/acre}$$
(124,320 g/sq m)

Dry weight of wastewater sludge required per acre

$$Wt = 2,000,000 \times \frac{30}{45}$$

$$Wt = 1,330,000 \text{ lb/acre}$$
(149,000 g/sq m)

Assume that both neutralization sludge and domestic wastewater sludge are dewatered to 80 percent moisture prior to mixing into mine spoil.

Weight of neutralization sludge required per acre

$$Wt = \frac{1,110,000}{2,000} \times \frac{100}{20}$$

$$Wt = 2,780 \text{ tons/acre}$$
(6,220 metric tons/ha)

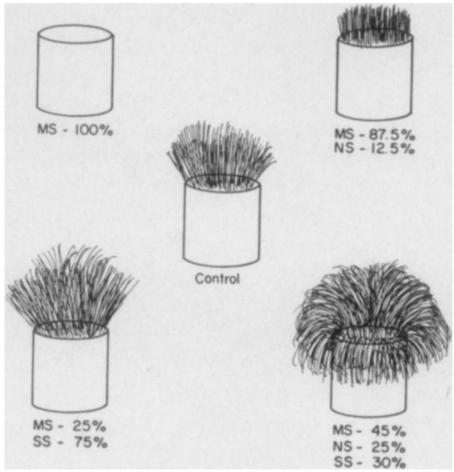

FIGURE 12.—Relative growth in various soil conditions.

Weight of wastewater sludge required per acre

$$Wt = \frac{1,330,000}{2,000} \times \frac{100}{20}$$

$$Wt = 3,325 \text{ tons/acre}$$
(7,446 metric tons/ha)

Conclusions

The parameters used in design of a thickener, a vacuum filter, and a sand drying bed were determined by use of bench-scale laboratory setups. Thickening followed by sand-bed drying may offer a reasonable process in dewatering neutralization sludge. Vacuum filtration was unsuccessful for achieving high dewaterability because the high compressibility of this sludge causes a reduction of filter loading rates. Consequently vacuum filtration offers little promise as a method of dewatering.

In greenhouse experiments, the addition of neutralization sludge and/or domestic wastewater sludge to mine spoil raised the pH to the 7.0 to 8.0 range, but the mixture of neutralization sludge and mine spoil showed symptoms of nutrient deficiency and stunted growth. With 45 percent mine spoil, it was shown that equal amounts of neutralization sludge and domestic wastewater sludge produced a higher yield of plants. A mixture of neutralization sludge and domestic wastewater sludge in mine spoil apparently could be used in strip mine reclamation to promote revegetation and would also provide a disposal site for both neutralization sludge and digested domestic wastewater sludge.

References

1. Eckenfelder, W. W., Jr., "Industrial Water Pollution Control." McGraw-Hill Book Co., Inc., New York, N. Y. (1966).
2. "Waste Alum Sludge Characteristics and Treatment." Research Rept. No. 15, New York State Dept. of Health, Albany (1966).
3. Coackley, P., and Jones, B. R. S., "Vacuum Sludge Filtration, Part I—Interpretation of Results by the Concept of Specific Resistance." *Sew. & Ind. Wastes,* **28,** 8 (1956).
4. Eckenfelder, W. W., Jr., and O'Connor, D. J., "Biological Waste Treatment." Pergamon Press, New York, N. Y. (1961).
5. Jones, B. R. S., "Vacuum Sludge Filtration, Part II—Prediction Filter Performance." *Sew. & Ind. Wastes,* **28,** 9 (1956).

"WATER, MAN, AND NATURE" SEMINAR

A symposium on "Water, Man, and Nature" will be held during the first two days of the annual American Institute of Biological Sciences convention at Colorado State University, Fort Collins, Colorado, August 30–September 3, 1971. The symposium is being cosponsored by the Bureau of Reclamation and AIBS. Each of some ten workshop sessions will be chaired by an ecologist and an engineer to encourage joint involvement between disciplines. The workshops will consider ecological effects of such things as recreational use of reservoirs, water resource project operations, development of atmospheric water resources, coal-fired power plants, river basin development, and construction operations. Delegates will tour portions of the Bureau of Reclamation's Colorado–Big Thompson project during the meeting, and three water resource scientists will speak on the past, present, and future of water resource development during a plenary session.

Information regarding the symposium may be obtained from Dr. Dale A. Hoffman, Environmental Sciences Section, Division of General Research, Bureau of Reclamation, Building 56, Denver Federal Center, Denver, Colorado 80225.