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Introduction

The acid mine drainage problem in Pennsylvania is of continuing and growing interest to the coal mining industry, the state government and the citizenry at large. Approximately one-third of the total volume of mine drainage presently polluting the streams of the Commonwealth originates from active coal operations and two-thirds come from "abandoned mine discharges." For this reason the Pennsylvania Department of Mines and Mineral Industries has mounted a significant research and action program seeking solutions to this two-fold problem.

The Coal Research Board of the Department has sponsored a wide variety of research projects in an effort to study the treatment of acidic and highly ferruginous mine waters. A review of the published literature on the treatment of mine waters indicated that many laboratory and theoretical studies had been undertaken on various aspects of the coal mine drainage problem, but little applied, developmental, or engineering study had been undertaken. In January of 1964 the Board commenced a rigorous program using state and industry funds in an effort to find a "least cost" solution or solutions to this vexing problem.

Projects have been undertaken along the following lines: the preparation of an up-to-date annotated bibliography, lime neutralization, ion exchange treatment, coal products interaction with mine drainage, deep well disposal of drainage, flash distillation, inhibition of bacterial action and removal of iron with ozone. The Department has also cooperated with other state and federal agencies in their efforts along similar lines. Legal pressures for clean up of effluents have increased steadily and it was considered advisable to seek short term, technically practicable processes as soon as possible. No basic research was undertaken.

To the best of our knowledge, Pennsylvania is the only state that has undertaken a research program of large magnitude on this vexing problem. In several states, coal associations with limited state governmental financial support are undertaking limited research activities.

Source of Contamination

The acidic contamination of surface drainage and mine drainage water from coal mines is normally caused by the oxidation of iron pyrites. Acidic drainage waters contain dissolved iron salts and varying proportions of other dissolved metals. These waters are slightly cloudy, although suspended iron oxides, coal dust, etc., may also be present.

Chemical Treatment

Technically, any acidic effluent from any coal mine could be purified by chemical processes to any desired standard of purity. Chemical treatment has been applied successfully to similar effluents in other industries in order to make them suitable for discharge to municipal sewers or to natural water courses and investigations have confirmed that these processes could be applied to the acidic effluents under review.

The process which would be most generally applicable would be to correct the state of acidity of the effluent with an alkali which would normally be lime, but could be a water soluble alkali such as caustic soda in those cases where very small doses were required. The effect of the alkali would be to precipitate the polluting metals as gelatinous hydroxides which could be removed from the bulk of the water by sedimentation. At this stage the neutralized effluent could be discharged to a municipal sewer or discharged to a natural water course. The sludge recovered from the sedimentation vessel could be further concentrated by sedimentation and then filtered, either by filter press or on a modified rotary vacuum filter. The Coal Research Board of the Commonwealth's Department of Mines and Mineral Industries awarded Dorr-Oliver, in October 1964, a research grant to design, fabricate and operate a mobile demonstration plant for the treatment of acid mine water. The objectives of this program were to perform unit operations in a mobile pilot plant at various mine sites throughout the Commonwealth and obtain design and economic data that could be used to evaluate the process under examination.

"Operation Yellowboy"

The demonstration plant was designed so that it could be readily moved over existing highways and roads in the Commonwealth without special permits. The pilot plant was constructed in a van type trailer that is 40 feet in length, 8 feet in width, and rises to a height of $12\frac{1}{2}$ feet above the ground.

The flow sheet of the process is presented in Figure 1. Acid mine drainage is brought into the pilot plant by the means of a self-priming centrifugal pump and is pumped through a flow meter into a flash mixer where hydrated lime is added from a screw feeder to neutralize the mine water. By means of gravity the neutralized mine water and suspended solids, consisting primarily of ferrous hydroxide and gypsum, flow into an aerator. Air is brought into contact with the ferrous hydroxide coverting it to ferric hydroxide by the means of a turbine mixer and an air blower. After aeration the slurry, consisting of neutralized mine water and suspended solids, flows by gravity into a thickener. Chemical flocculating agents can be added to this slurry to increase the settling rate of the suspended solids and improve the effluent clarity if desired. The suspended solids in the neutralized mine water slurry settle to the bottom of the thickener while the clear effluent overflows the thickener and is considered treated mine water. The flocculated iron bearing sludge is then pumped to a solid bowl centrifuge.

The centrifuge separates the insoluble solids (Yellowboy) from the liquid (neutralized mine water) based on the density differential within the high speed spinning device. The slurry is fed continuously to the solid bowl centrifuge where the insoluble solids having a higher density than the water are forced to the outer periphery of the centrifuge where they are conveyed to a discharge point. The clear water flows to the center of the unit and then flows out a discharge tap. If the acidity of the water coming from the centrifuge is within the accepted range set forth by the Sanitary Water Board, it is considered treated water, if not, it is reprocessed. Batch type filtration tests were conducted during the testing program on a "filter leaf" in order to acquire data for design of full scale filters. Many variations of the basic process were examined. These included the use of floc control reagents, centrifuges and the use of filter aids. Most of these alternatives were technically inferior to the basic process or else were economically impractical.

Case Histories From "Operation Yellowboy" Pilot Plant

The case histories or examples given in this paper will provide an idea of the size and costs of a chemical treatment plant of this type suitable for a typical acidic effluent from colliery and several "abandoned" mine discharges. These sites were chosen to represent a wide variety of mine drainage compositions and volumes.

The tables presented consist of full scale plant data. These data were calculated and derived as a result of the pilot plant operation at the previously mentioned test sites. Table 1 shows composite chemical analyses of raw mine drainage and treated drainage as produced by the mobile pilot plant. Aerator design data is shown in Table 2. Table 3 shows thickener design data. Filter design data is shown in Table 4. Table 5 shows acid mine drainage treatment plant capital expenditures. Annual costs are shown in Table 6. Table 7 shows total annual unit costs. Figure 2 shows the pilot operating at the Morea site. The flow sheet of a typical scaled up plant is shown in the form of a schematic diagram in Figure 3.

Action Program

An action program has been undertaken recently in Pennsylvania as a start in abating drainage from abandoned mines. Four small treatment plants designed to handle water that has low iron and medium degree of acidity have been authorized. These plants are a direct result of "Operation Yellowboy" research. One of these plants is already in operation near the village of Clintonville in Western Pennsylvania on Little Scrubgrass Creek. The additional plants are being designed and will be put out for bid as soon as possible.

A treatment plant designed to process one half to one million gallons of mine drainage per day will be erected for the Pennsylvania Coal Research Board by the Pennsylvania State University near Tyler, Pennsylvania. The object of this plant is to obtain plant operating experience and reduce the scalar factors involved in the preparation of cost estimates for full scale treatment. Several points are hoped to be resolved during this large scale testing program viz. the response of sedimentation and compression rates under cold weather and freezing conditions, the physical problems involved in routine day to day disposal, of "Yellowboy," and the cost of various de-watering alternatives.

Conclusion

The general pattern to be followed on active and on "abandoned" mine drainage problems should be to minimize acid make through careful mine layout, surface sealing, and strip mine restoration. Only after the water has been reduced to a minimum of volume should this effluent be treated.

It has been shown by test work performed using "Operation Yellowboy" that mine water can be treated by the lime neutralization, aeration, sedimentation, and de-watering process to produce a product containing less than seven parts per million of iron at a neutral pH and with a small degree of free alkalinity.

Field tests confirm that lime can be used to purify acidic mine waters from the most polluting to those which were only slightly acidic. The manganese, alumina and silica are also removed by lime neutralization, resulting in a decrease in total hardness. It can be concluded from the investigation that lime treatment of all acidic mine waters would be technically feasible and that the costs of lime treatment of any acidic mine water can now be estimated.

It is anticipated that the public and private sector will continue to search for novel and cheaper processes for treatment. Until it is clear that such processes can accomplish the results now obtainable with the process described in this paper, it is expected that lime treatment will remain in the forefront of plans submitted to the Sanitary Water Board and similar regulatory agencies in this and other states.

TABLE I
COMPOSITE
CHEMICAL ANALYSES
of
RAW AND TREATED ACID MINE DRAINAGE (Parts per million)

Constituent	Marianna bore hole raw	Marianna bore hole treated	Young & Son gravity raw	Young & Son discharge treated	Morea Strip Pit raw	Morea Strip Pit treated	Loomis bore hole raw	Loomis bore hole treated	Scrubgrass creek raw	Scrubgrass creek treated	Warwick bore hole raw	Warwick bore hole treated
Total Acidity	4,040	0	770	0	190	trace	560	0	86	0	1,250	0
Total iron	815	5.8	225	2.4	5.8	trace	360	6.4	1.3	*	712	2.6
Chloride	1,830	1,790	*	*	*	*	*	*	*	*	*	*
Silica	63	2	*	*	*	*	*	*	*	*	58	5.6
Sulfate	10,000	6,180	1,360	1,530	290	370	3,430	3,240	301	*	5,656	3,740
Manganese	38	12.6	4.4	0.1	4.0	1.3	30	18	10	*	10.3	4.1
Calcium	444	623	138	429	20	140	349	625	89	*	541	625
Magnesium	404	374	58	44	27	10	185	173	0	*	68	160
Sodium	2,420	2,550	*	*	*	*	*	*	*	*	800	810
Alumina	898	8.2	71	0.8	38	0	80	13	24	*	359	2.6
Total solids	18,300	12,200	1,920	2,040	560	680	6,100	5,500	*	*	9,080	5,830
pH	2.6	7.6	2.6	7.1	3.2	6.8	3.2	7.4	3.2	7.0	2.78	7.57

* = not determined

<u>AERATOR DESIGN DATA</u>

Item	Marianna bore hole	Young & Son gravity discharge	Morea Strip Pit	Loomis bore hole	Scrubgrass Creek	Warwick bore hole
Flow rate, MG/D	0.240	0.180	4.00	5.76	4.15	0.600
Number of Units	1	1	1	1	-	1
Volume/unit-ft^3	680	525	11,250	16,400	N	1,690
Surface Area/unit-ft^2	68	53	750	1,090	O	169
Dimensions/ unit-ft	8.25x8.25x10	7.25x7.25x10	30x25x15	33x33x15	N	13x13x10
Detention time-minutes	31	31.5	30	31	E	30
Turbine Aerators/unit	1	1	1	1	-	1

TABLE 3

THICKENER DESIGN DATA

Item	Marianna bore hole	Young & Son gravity discharge	Morea Strip Pit	Loomis bore hole	Scrubgrass Creek	Warwick bore hole
Flow Rate MG/D	0.240	0.180	4.00	5.76	4.15	0.600
Dry Sludge, T/D	12.5	0.69	2.17	21.6		16.5
Number of Units	1	1	2	3	N	1
Volume/unit, ft^3	16,000	7,370	130,000	78,700	O	44,400
Dimensions (diam XSWD)/ Unit, ft	45 x 10	25 x 15	105 x 15	100 x 10	N E	75 x 10
Detention time, hours	12	7.35	11.7	7.35		13.30*
Overflow rate, gal/ft^2/day	150	366	230	244		135*
Solids loading, ft^2/T/day	128	713	8,020	1,090		269*
Surface area/ unit, ft^2	1,600	492	8,670	7,870		4,440

*(exclusive of filtrate cycle)

TABLE 4

DRUM FILTER DESIGN DATA

Item	Marianna bore hole	Young & Son gravity discharge	Morea Strip Pit	Loomis bore hole	Scrubgrass Creek	Warwick bore hole
Flow Rate, MG/D	0.240	0.180	4.00	5.76	4.15	0.600
Feed Sludge Solids % by wt.	4.0	1.5	1.2	0.9		4.98
Dry Sludge, T/day	12.5	0.69	2.17	21.6	N	16.5
Volume Sludge, G/D	73,500	11,000	43,000	575,000 (3)	O	79,500
Number of units	2 (1)	1 (1)	2 (1)	5 (2)	N	1
Area/unit, ft^2	456	558	760	760	E	760
Dimensions(DiamxL)/ Unit, ft.	12 x 12	10 x 18	12 x 20	12 x 20		12 x 20
Hydraulic loading gal /ft^2/hr.	11.5	2.82	4.06	6.32		15.0 (2)
Solids loading, lbs/ft^2/hr.	3.9	0.36	0.41	0.66		6.21 (2)
Cake dry solids % by wt.	26	15.1	11.8	25.0		27.4 (2)
Cake, T/day	48	4.54	18.5	121		60.2

(1) Based upon 7 hr/day operation, 7 days/week

(2) Based upon 24 hr/day operation, 7 days/week

(3) To this feed sludge is added 8.65 T/day of gypsum as a sludge conditioner, based on 1 T gypsum / 1 T Fe^{+2}

TABLE 5

ACID MINE DRAINAGE
TREATMENT PLANT CAPITAL EXPENDITURES

Item	Marianna bore hole	Young & Son gravity discharge	Morea Strip Pit	Loomis bore hole	Scrubgrass Creek	Warwick bore hole
Flow Rate, MG/D	0.240	0.180	4.00	5.76	4.15	0.60
Water storage and transportation facilities	$22,800	$15,300	42,500	8,000	None	17,000
Control-Filter						
Building	223,000	160,000	275,500	614,000	8,600	144,000
Aeration	6,000	6,200	18,400	34,000	None	9,200
Thickening	45,000	26,600	254,000	342,000	None	84,000
Sludge Holding	9,500	2,500	7,500	9,000	None	10,000
Piping and Site Preparation	40,900	19,300	59,500	87,000	1,250	35,500
Total Capital Cost	$347,200	$229,900	$657,400	$1,094,000	$ 9,850	$282,700

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TABLE 6

ANNUAL OPERATING COSTS

Item	Marianna bore hole	Young & Son gravity discharge	Morea Strip Pit	Loomis bore hole	Scrubgrass Creek	Warwick bore hole
Flow Rate, MG/D	0.240	0.180	4.00	5.76	4.15	0.600
Amortization	$ 25,550 (1)	$16,900 (1)	48,371 (1)	80,500 (1)	2,275 (2)	22.000 (1)
Labor and Supervision	36,500	20,000	42,500	108,000	730	43,000
Power	4,700	3,200	8,700	100,000	87	15,000
Chemicals(lime)	22,000	2,300	20,000	152,000	7,045	29,000
Maintenance	6,500	5,000	7,000	35,000	99	8,500
Total Annual Operating Costs	$ 95,250	$47,400	$126,571	$475,500	$10,236	$117,500

(1) 20 years amortization @ 4% interest

(2) 5 year amortization @ 5% interest

TABLE 7

TOTAL ANNUAL UNIT COSTS

Item	Marianna bore hole	Young & Son gravity discharge	Morea Strip Pit	Loomis bore hole	Scrubgrass Creek	Warwick bore hole
Flow Rate, MG/D	0.240	0.180	4.00	5.76	4.15	0.600
Cost per 1,000 gal., treated	$1.09	$0.72	$0.087	$0.226	$0.0068	$0.537
Coal Marketed-tons/D	5,000	40	none	none	none	5,000
Cost per ton of coal	$0.052	$3.25	none	none	none	0.095
Cost per ton of dry solids	$27,780	$333,000	$302,600	$50,700	none	$ 17,133
Cost per ton of iron	$425,500	$1,362,000	$6,780,000	$126,700	$ 428,260	$158,640
Cost per ton of acid	$ 85,000	$ 397,000	$ 207,200	$ 81,400	$ 6,610	$ 90,319

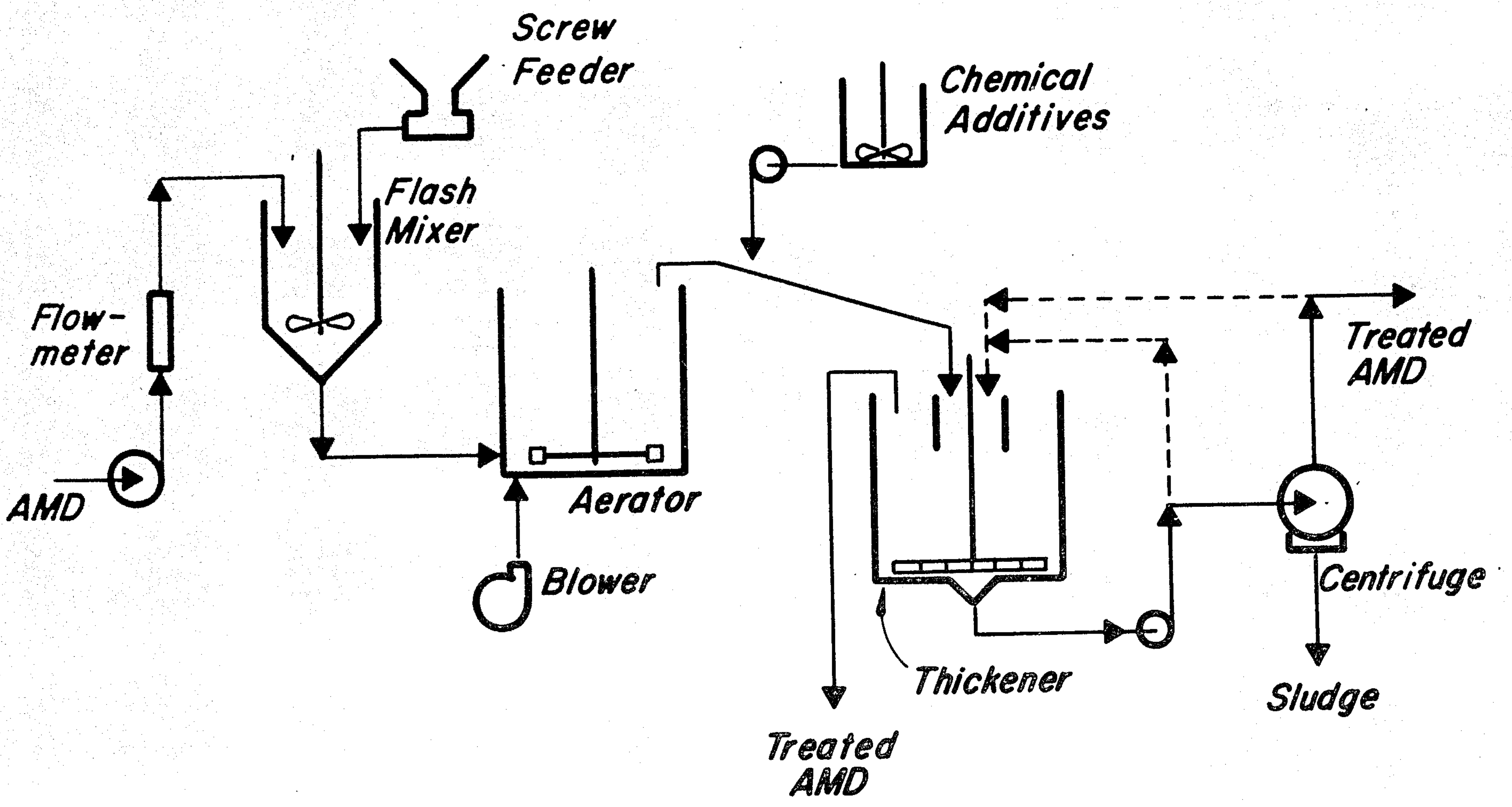

FIGURE 1- FLOWSHEET FOR AMD PILOT PLANT
"OPERATION YELLOWBOY-DESIGN AND ECONOMICS OF A LIME
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by H. B. CHARMBURY, DAVID R. MANEVAL, and LUCIEN GIRARD III

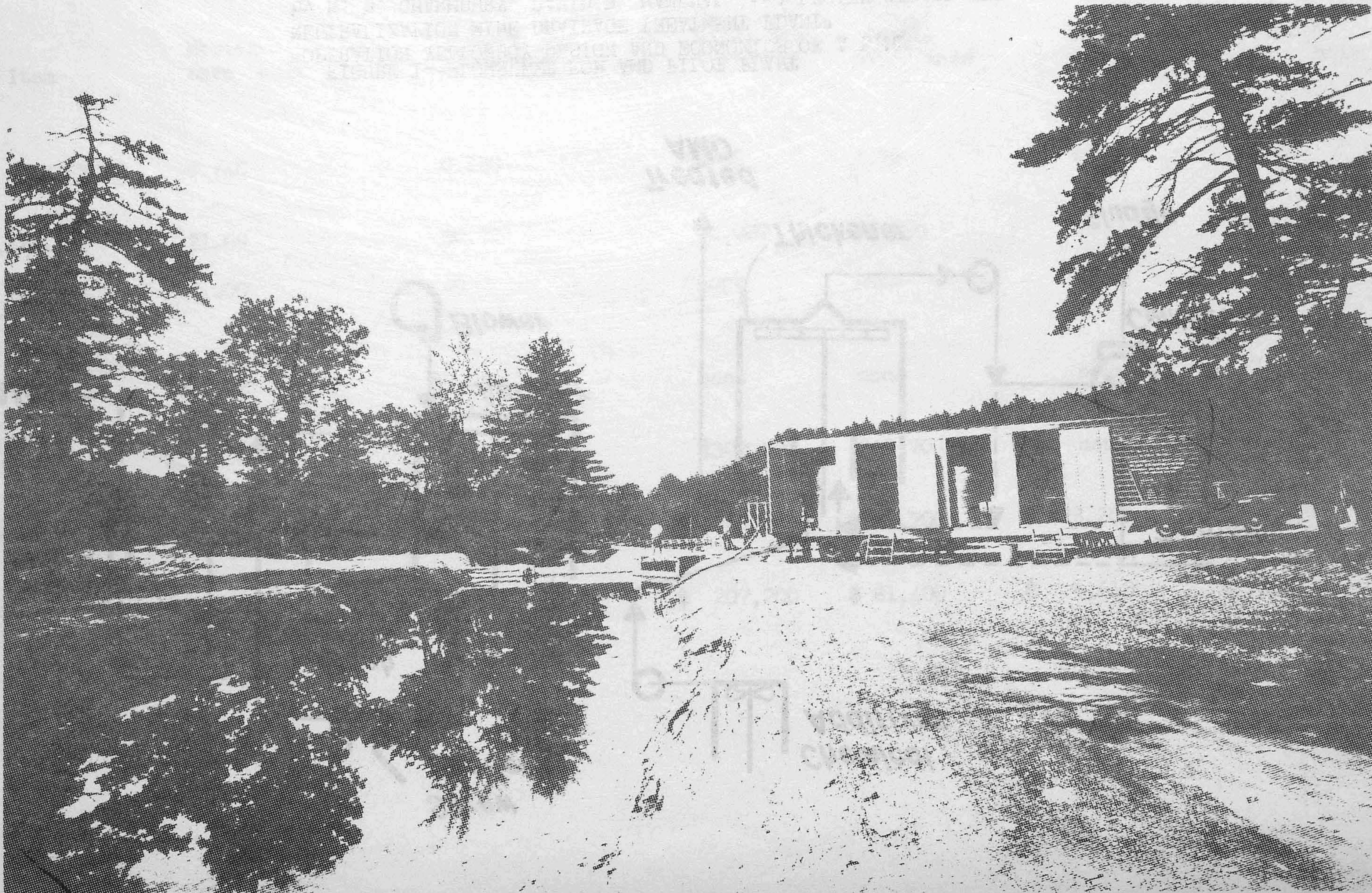

Figure 2. PILOT PLANT OPERATING AT THE MOREA STRIP PIT "OPERATION YELLOWBOY-DESIGN AND ECONOMICS OF A LIME NEUTRALIZATION MINE DRAINAGE TREATMENT PLANT"

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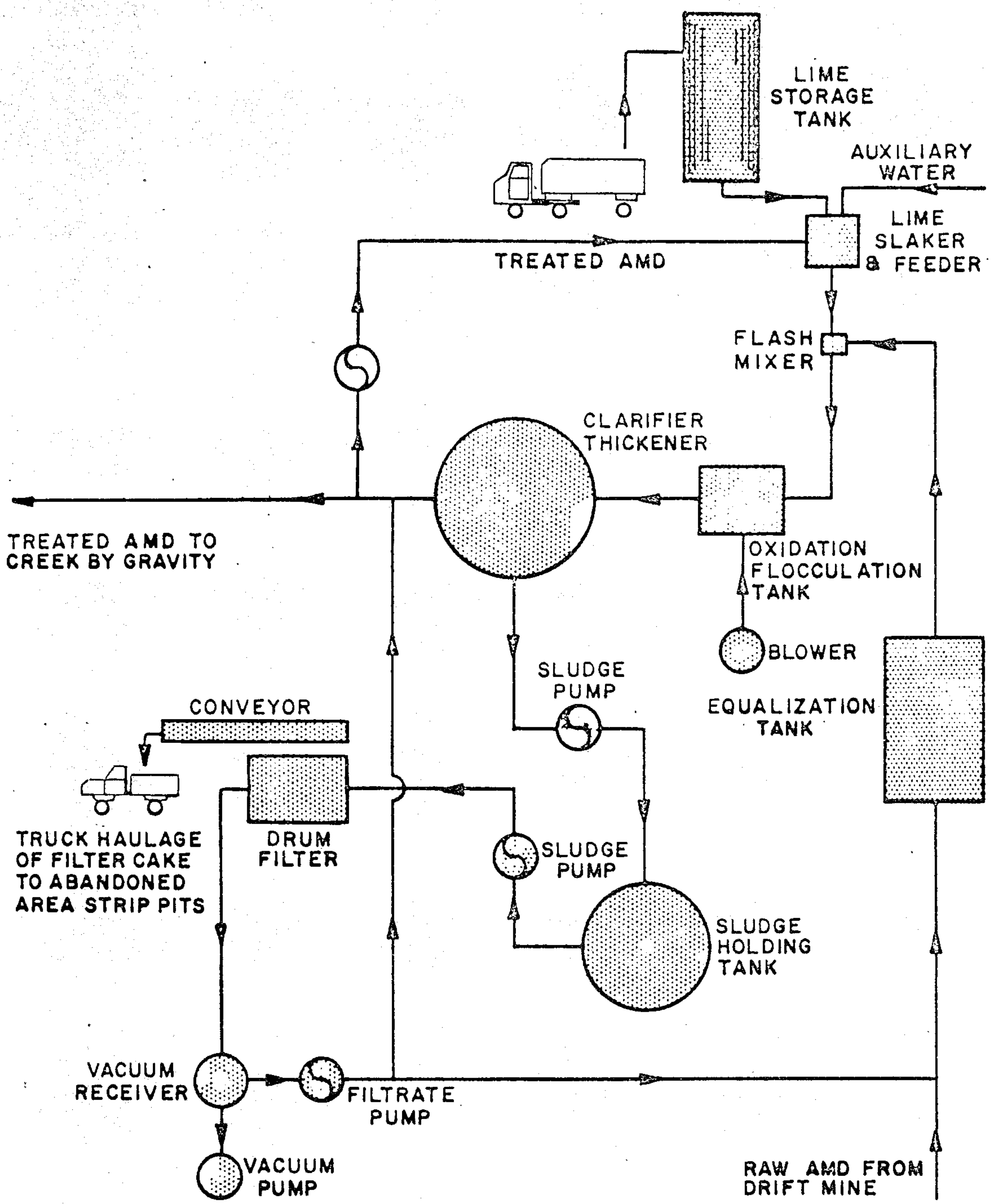

Figure 3

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF MINES AND MINERAL INDUSTRIES

SCHEMATIC DIAGRAM
OF AMD TREATMENT PROCESS

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