Coal Mine Drainage Treatment

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INTRODUCTION

There has been a great deal of publicity, legislative activity, control action, and just plain talk in recent years about Acid Mine Drainage as a major factor in stream pollution. Pennsylvania enacted in 1965 Act No. 194 which classified mine drainage as an industrial waste and made drainage subject to its Clean Streams Law. Article 900 of the Rules and Regulations of the Pennsylvania Sanitary Water Board, set up to implement this law, spells out the limitations for mine drainage, requiring all discharges to be alkaline with a pH in the range of 6.0 to 9.0 and a maximum of seven mg/l of iron. This law and its accompanying regulation is the first really comprehensive attempt to control mine drainage, and will serve as a model for those in other states.

To understand the problems of the treatment of acid mine drainage, we must first have some idea of what it is and where it comes from. Acid mine water is a natural phenomenon resulting from the exposure of sulfur and iron-bearing materials to processes of erosion and weathering. When coal is mined, sulfur and iron-bearing materials, largely pyrites, associated with the coal are exposed to the air. Oxygen in the air reacts with the pyrites in remaining coal layers and the adjacent strata, and the pyrite oxidizes to soluble forms. This oxidation is not a simple process, but an extremely complex series of reactions, accelerated by the presence of moisture and even by bacterial action. Ground water seeps and flows through the various soil strata. The initial oxidation is followed by secondary oxidation, neutralization, and hydrolysis reactions, dependent on the exact nature of the strata, character of the water, extent of aeration, and length of contact. The end product of these complex reactions tends to fill the underground area. When it flows into active mine workings, it must necessarily be removed, generally by pumping it to the surface; treatment of this drainage from active mines is the subject of this paper.

Because of the complex nature of the reactions in which mine drainage is formed, the differences in the nature and character of the strata overlying the mines, and the different drainage conditions in different mine areas, there is no one "typical" mine drainage discharge. Rather, each discharge point from each mine represents a unique problem, and a variety of approaches is required to eliminate pollution from mine drainage. This variety will be illustrated by a consideration of the drainage from five different discharge points at three of J and L's coal mining operations. Table I illustrates these five drainage sources -- giving the flows and critical analyses of each.

Thompson Borehole at Vesta No. 5 Mine was the first stream we chose for study. Its location was convenient, its flow moderate. It has a moderately high

TABLE I

MINE DRAINAGE

Source	Flow gpd	pH	Fe mg/l	Acidity mg/l
Thompson..........	150,000	3.5	120	500
Bercik	1,500,000	6.5	20	-100
No. 1 Air Shaft	700,000	2.8	700	1500
No. 3 Air Shaft	100,000	7.5	2	-400
11 Face 17 Butt	100,000	6.7	12	-200

acidity and moderate iron content. It flows into a small branch creek where, before treatment was started, it destroyed the appearance of the stream with a yellow deposit and eliminated all aquatic life.

Bercik Borehole of Vesta No. 4 Mine represents a completely different drainage condition. Flow is very high, about 1,000 gpm. The water is alkaline, in contrast to "acid" mine drainage, but its iron content rather high. The problem here is that as the drainage undergoes aeration, the soluble ferrous iron is oxidized to insoluble ferric iron with the precipitation of "yellowboy" for several miles downstream.

No. 1 Air Shaft Borehole at Shannopin Mine is our worst single source of pollution. This large discharge, 700,000 gpd, is extremely acid and contains a very high dissolved iron content. This discharge flows into a moderate sized creek depositing a heavy bed of yellowboy and making the entire stream quite unattractive.

No. 3 Air Shaft Borehole at Shannopin Mine again represents a completely different situation. This is a large flow of mine drainage, but it is not pollution. It does, however, represent an interesting approach to pollution.

Finally, the drainage from the borehole designated as 11 Face/17 Butt in Vesta No. 4 is a marginal situation. The water is alkaline but the iron content is just over the regulation limit. This discharge is typical of many minor discharges, causing no real pollution and yet a source of worry to the operator.

TREATMENT METHODS

The Thompson Borehole was the first drainage we treated. Experimental work in the laboratory and pilot plant work on a 100 to 300 gpm unit indicated that hydrated lime would adequately neutralize the acid and precipitate the iron in stable "ferric" form without aeration. Treatment of the 150,000 gpd flow resulted in formation of about 4,000 gpd of wet sludge. The terrain near this borehole was such that no suitable spot could be found for long-range accumulation of this sludge. Several miles away, however, an unused borehole led into an abandoned section of our Vesta No. 6 Mine which was well below water table, offering a vast area for sludge disposal. After thorough inspection by the State Department of Mines and Mineral Industries, we were given permission to pour the sludge into this area. On the basis of this work the treatment plant (Figures 1 through 4) was installed.

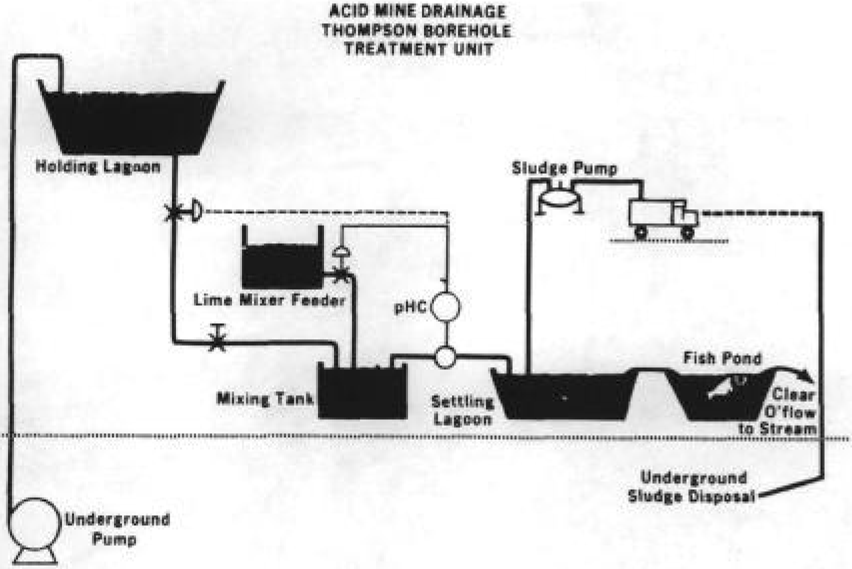

Figure 1 - Acid mine drainage treatment unit at Thompson Borehole.

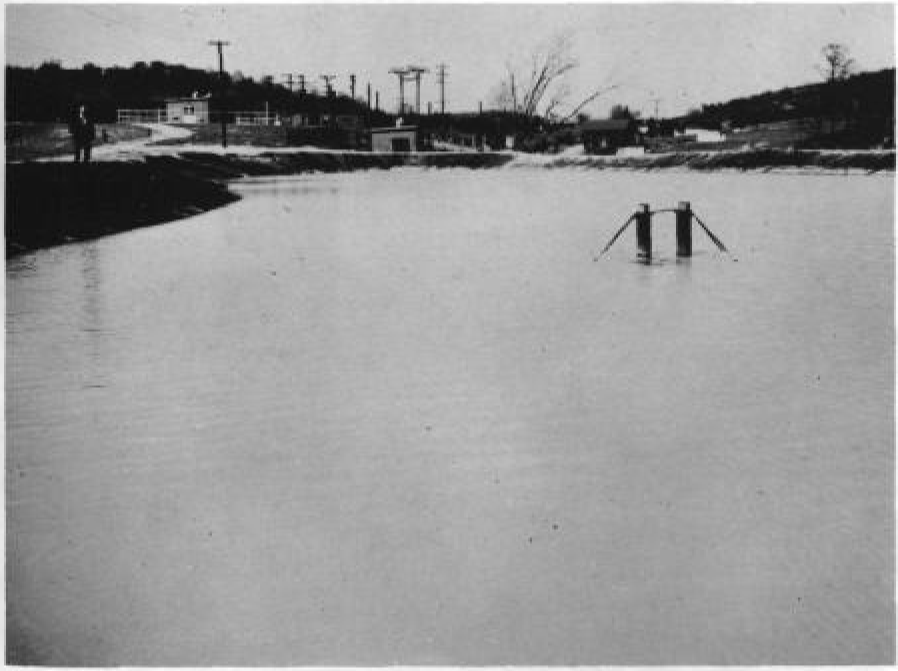

Figure 2 - 750,000 gal holding basin at Thompson Borehole treatment unit. Standpipes in center of basin control flow to neutralization unit.

Figure 3 - Lime feeder and mixing tank at Thompson treatment unit. Note pH electrode in overflow line.

Figure 4 - Overall view of Thompson Borehole treatment unit. Holding lagoon at right, neutralization in building, settling lagoon with sludge pumps at left and fish pond in foreground.

Since the flow from the mine is variable, drainage is pumped to a 750,000 gal holding basin to assure a steady flow of rather constant composition to the neutralization unit. Flow from the holding lagoon through the system is by gravity. Feed to the neutralization unit, manually set at about 110 gpm, is introduced to a mixing tank. Here a lime slurry is added from the lime mixer at a controlled rate. The mixed acid water and lime slurry pass through the baffled tank to an overflow pipe. A pH electrode installed in the overflow pipe controls the rate of flow from the lime mixer and records the pH continuously, maintaining the discharge at pH eight. The pH control has a high and low limit switch controlling an air operated valve in the feed line. This stops completely the operation of the plant if pH goes out of control, preventing untreated drainage from reaching the lagoon.

From the overflow pipe, the treated drainage enters the 90,000 gal settling lagoon, where the sludge settles out. The clean overflow, alkaline and essentially free of iron, flows to the receiving stream. The settled sludge, at about six per cent solids by weight, is periodically pumped from the lagoon into trucks and hauled to the borehole leading to the abandoned section of Vesta No. 6 Mine.

Analyses of feed and overflow are shown in Table II. The ranges show both the variability of the discharge and the uniformity of the treated stream. Table III shows a typical analysis of the sludge; the complex chemistry of this material is an indication of the complexity of the reactions which occur in the formation of mine drainage. Although our working analyses are only for acidity and iron content, there are many other elements present, resulting from the variety of material present and reactions taking place.

TABLE II

THOMPSON SHAFT BOREHOLE TREATMENT EFFICIENCY

Flow 150,000 Gals/Day

	Feed	Effluent
pH	3.5 - 5.5	7.6 - 8.4
Acidity, mg/l	200 - 700	-70 to -100
Fe, mg/l	70 - 195	0 - 11

TABLE III

THOMPSON SHAFT BOREHOLE SLUDGE ANALYSIS

Calcium Sulfate	$CaSO_4$	40%
Magnesium Sulfate	$MgSO_4$	5%
Free Lime	CaO	3%
Magnesia	MgO	1%
Ferric Oxide	Fe_2O_3	15%
Manganese Oxide	Mn_2O_3	4%
Silica	SiO_2	20%
Aluminum Oxide	Al_2O_3	12%

This treatment plant has been operated successfully for over one year. During this time, the change in the receiving stream has been remarkable. Yellow deposits on banks and bottom have disappeared, and aquatic life has returned right up to the discharge point.

At the Bercik Borehole, there was no problem of neutralization. The extremely large flow (1,000 gpm) drainage was alkaline and clear as it came from the borehole and fed the stream. Natural aeration then caused the iron to oxidize and precipitate on stream bottom and banks. The problem here was simply to provide adequate contact with air and sufficient time for oxidation and precipitation to occur before this drainage entered the stream. The remote location of this borehole and its inaccessibility for maintenance work, however, required that a very simple installation be made. The location of the borehole was propitious for installation of a system of lagoons providing adequate surface for oxygen absorption and adequate retention time for oxidation and settling of the iron. From the drainage discharge, a simple baffled aerator was installed to start aeration (Figure 5). The lagoon system is shown in Figures 6 and 7. Three lagoons with volumes of 240,000, 140,000, and 660,000 cu ft giving a total holding time of five days, make up this system. Effectiveness of this system is shown in Table IV, which shows analyses of both feed and discharge at two widely different times, showing the effect of seasonal temperature variation on the operation of the system.

It is anticipated that 800,000 cu ft of sludge will be produced over the 10-year life of the property, so that even at the end of this operation, holding time will be one day, adequate for complete oxidation and settling.

No. 1 Air Shaft of Shannopin Mine is our most severe drainage problem. Table V shows the analysis and variation in this stream. Figure 8 shows the entry

Figure 5 - Aeration trough at Bercik Borehole treatment plant, showing vigorous agitation in gravity flow.

Figure 6 - First holding lagoon at Bercik Borehole, with discharge pipes and aerator in background.

Figure 7 - Third holding lagoon at Bercik Borehole, with first two lagoons in background.

TABLE IV

BERCIK BOREHOLE TREATMENT EFFICIENCY

Flow 1,500,000 Gals/Day

	December		February	
	Borehole	Effluent	Borehole	Effluent
pH	6.6	7.2	6.8	7.9
Acidity, mg/l	-280	-275	-300	-290
Fe, mg/l	44	1.2	46	4.5

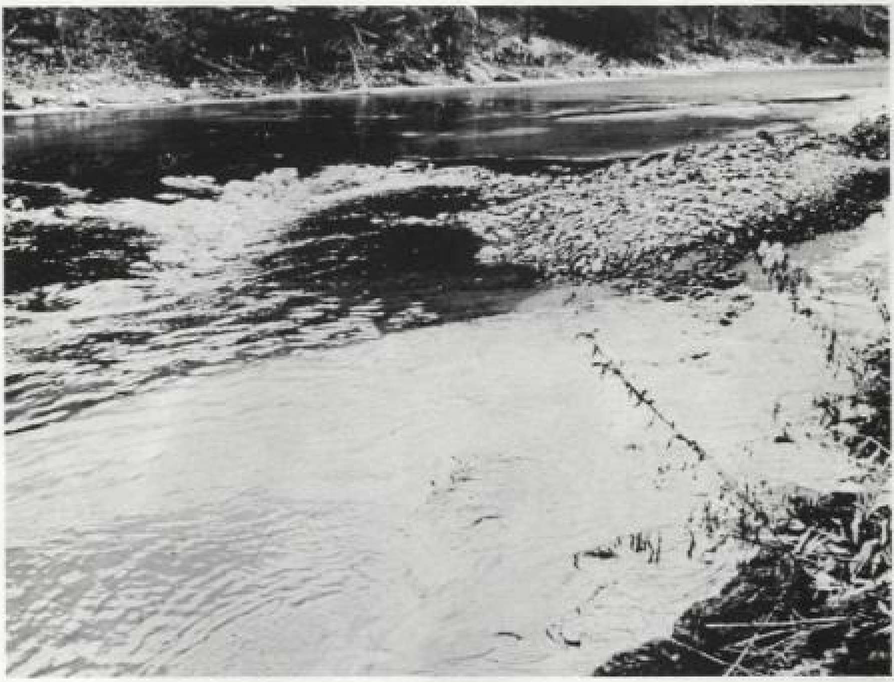

Figure 8 - Entry of discharge from borehole at Shannopin No. 1 air shaft into Dunkard Creek, indicating extent of pollution.

of this drainage into Dunkard Creek and illustrates the magnitude of the problem. Again laboratory and pilot plant studies were carried out to indicate the proper course of action. In this case, neutralization alone did not prove adequate; because of the extremely high ferrous iron content of this drainage, aeration is required to form a stable ferric iron precipitate. Tests showed that aeration prior to neutralization was not effective, as the iron will not oxidize readily in the acid medium. Aeration following neutralization, however, did a satisfactory job of oxidation. Calculation of sludge volume from neutralization of this drainage showed that a tremendous volume of sludge would be produced -- 40,000 gpd. Handling of this volume of material would appear to present a prohibitive expense; nor was there a suitable underground area nearby for disposal. Thus, permanent lagoon storage appeared most feasible at this operation.

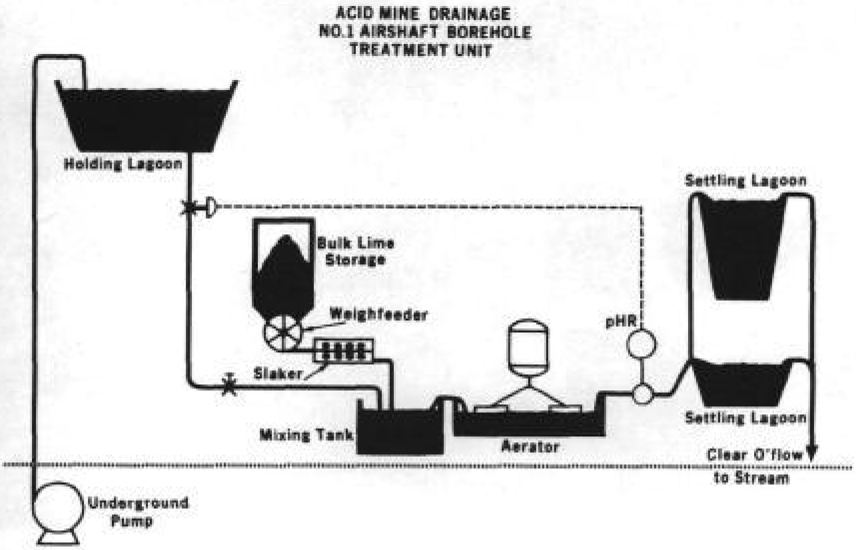

Figure 9 - Acid mine drainage treatment unit at No. 1 airshaft borehole.

On the basis of this testwork and analysis, the treatment plant shown in Figure 9 was designed. The process flowscheme is relatively simple. The drainage is again pumped to a holding lagoon, from which it flows by gravity to a neutralizing tank where it mixes with milk of lime. The milk of lime is made by slaking quicklime with water in a separate slaker unit. Neutralized water is then aerated in a specially designed tank by means of a surface aerator. Neutralized water then flows to one of two settling lagoons, used alternately. Retention time in the lagoons will be a minimum of 24 hrs. In order to provide maximum compaction of sludge, the out-of-service lagoon will be drained and the sludge permitted to dry and compact.

The relative simplicity of this flowscheme belies the true complexity of this installation. The sheer magnitude of the flow and its high mineral content have made this a major job. These photographs of the construction show what was involved. The borehole is located in a narrow valley. In order to provide area for the holding and settling lagoons it was necessary first to run two eight-in. pipelines 2600 ft to an area suitable for a lagoon (Figure 10). Because of the magnitude and variability of the flow it was necessary to provide a 1,500,000 gal holding lagoon (Figure 11). Pilot operations confirmed calculations that sludge production would be 40,000 gpd. Since permanent impoundment of the sludge appeared most feasible, over 10,000,000 cu ft of settling lagoon was necessary. To achieve this volume, the massive earthworking and mining operations indicated in Figures 12 and 13 were carried out. The one lagoon is the last open cut from a strip mine 1,000 ft x 80 ft x 50 ft deep. The second took advantage of the natural slope of the ground and utilized dikes to provide an area 600 x 800 ft with depth varying from zero to 60 ft, averaging about 20 ft.

This plant differs from that at Thompson Shaft in several ways. Quicklime is used instead of the more easily handled hydrate. This is strictly an economic

Figure 10 - Pipes from borehole to holding lagoon (left) and from holding lagoon to treatment unit at Shannopin No. 1 air shaft.

Figure 11 - Aerial view of treatment facility at Shannopin No. 1 air shaft, showing holding lagoon (top), mine pit lagoon (middle) and diked lagoon (bottom).

Figure 12 - Strip pit 1000 x 80 x 50 feet deep to serve as holding lagoon at Shannopin No. 1 air shaft treatment plant.

Figure 13 - Earthwork for diked lagoon to provide settling at Shannopin No. 1 air shaft treatment unit.

decision; the much greater lime requirement, five to six tons per day instead of about 700 lbs per day at Thompson, justified the investment in bulk handling equipment and the slaker. pH control will be manual instead of automatic because the long holding time in the lagoon will provide a more uniform composition to the unit. (Provisions have been included for later addition of automatic control should the recorded pH indicate this is needed). The pH recorder will shut down the plant, however, should the pH go beyond the 6.0 to 9.0 control limits. Mechanical aeration was proved necessary here where testwork at Thompson showed it was not needed. Although we can report over a year's successful operation at Thompson, construction is only now nearing completion at Shannopin No. 1 Air Shaft. It will be in operation by July 1, 1967.

TABLE V

SHANNOPIN NO. 1 AIR SHAFT DRAINAGE ANALYSES

Flow 700,000 Gals/Day

	Average	High	Low
pH	2.5	3.0	2.4
Acidity, mg/l	1500	2650	1250
Fe, mg/l	700	800	450

The borehole at No. 3 Air Shaft of Shannopin Mine represents a completely different approach to pollution control. The previously discussed discharges represent efforts to correct existing pollution. The No. 3 Air Shaft Borehole was installed at a later date when the pollution caused by mine drainage had been recognized as a problem. Considerable study had been done on the mechanics of acid drainage formation, and a series of practices developed to minimize pollution potential. In designing and laying out a new section of the mine with its necessary drainage system, these recommended practices were followed closely. In this effort we were guided and assisted by Dr. S. A. Braley, who spent many years working on this problem at Mellon Institute. The practices are listed below:

1) Surface water and ground water are diverted where practical to prevent the entry of, or reduce the flow of, water into and through workings.

2) Water is not allowed to accumulate in working areas. Sumps are dug in low spots and kept pumped out, thereby keeping the water from the acid-forming pyrites on the face. Numerous pickups are employed for each pump.

3) Wherever possible, pipes, instead of ditches, are provided to conduct water by gravity. This keeps exposure to acid-forming material on the bottom to a minimum.

4) Gathering or main sumps are provided in the mine by driving separate sump entries or by digging up the bottom. This practice does not permit water to accumulate in the local low gob areas with large acid-producing surface areas exposed to the water. These large sumps also provide reservoir capacity and prevent surges of mine water from entering a stream.

5) Discharges into streams are regulated, insofar as practical, to equalize daily accumulation throughout a 24-hr period.

TABLE VI

SHANNOPIN NO. 3 AIR SHAFT DRAINAGE ANALYSES

Flow 100, 000 Gals/Day

	Average	High	Low
pH	7.2	7.4	7.0
Acidity, mg/l	-400	-700	-300
Fe, mg/l	1	2	0

The results of this strict adherence to good drainage practice are shown in Table VI. This demonstrates that, in some circumstances, pollution from mine drainage can be eliminated by proper planning and mine design, when this control is made part of original planning.

One more discharge of interest is that from the borehole identified as 11 Face/ 17 Butt at Vesta No. 4 Mine. This discharge has been pumped at a rate of 100, 000 gpd for over 20 years. Its average analysis over the past year is shown in Table VII.

TABLE VII

11 FACE/17 BUTT BOREHOLE DISCHARGE DURING 1966

Flow 100, 000 Gals/Day

	Average	High	Low
pH	6.7	7.8	5.7
			(1 sample below 6.0)
Acidity, mg/l	-202	-90	-331
Fe, mg/l	12	19	4

This borehole discharge is a major part of a small stream; in dry weather it is the only flow in this stream. Practically no discoloration is evident in the stream bed, as shown in Figure 14. Analyses of the water 3, 000 ft downstream from the discharge shows a maximum of one mg/l of iron. Minnows and chubs abound in the stream (Figure 15), even when the entire flow is from this borehole. Cattle water from the stream regularly. Treatment could be done only by diversion which would cut off a reasonably attractive and useful stream. Thus, even though the discharge does not fully meet the requirements of the State Regulations, which limit iron content to 7.0 mg/l, we feel that it causes no pollution, and have requested from the State permission to continue the discharge as an exception to regulation limits.

Figure 14 - Clear discharge from 11 Face/17 Butt Borehole at Vesta No. 4 mine. Note clear stream bed.

Figure 15 - Fish netted in stream just below 11 Face/17 Butt Borehole, demonstrating water is suitable for aquatic life.

SUMMARY

This discussion hopefully has given some idea of the complexity and variability of the problems of mine drainage control. Because of the geological and chemical factors involved in the formation of mine drainage, no two mines and no two drainage sources are exactly the same. In some cases proper mine engineering has resulted in drainage which causes no pollution. In many others, pollution exists to varying extents. Selection of a treatment scheme where pollution exists is very much a problem of the individual drainage, its volume, characteristics, and location. What succeeds for one operator certainly will not work for all. Jones and Laughlin is perhaps fortunate in that our problems have proven amenable to solution. By the middle of 1968, we believe that we will have most of them solved.