DESIGN AND ECONOMICS OF AN ACID MINE DRAINAGE TREATMENT PLANT - "OPERATION YELLOWBOY"

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INTRODUCTION

With the passing of the Pennsylvania Clean Streams Law a technically sound and economically feasible process for the treatment of acid mine drainage (AMD) is desired. Water standards, set down by the Pennsylvania Sanitary Water Board, prohibit the discharge of mine water that has an iron concentration in excess of seven parts per million. The pH of the mine water discharge must be within a range of 6.0 to 9.0. These standards will require at least 80 percent of the mine discharges within the Commonwealth to resort to an acid mine drainage treatment process.

In an effort to alleviate the problem of acid mine drainage, the general assembly of the Commonwealth of Pennsylvania legislated Act 43A in June, 1964. This act allocated $100,000 for the payment of cost and expenses incurred in developing, constructing, staffing and operating a mobile pilot plant for the treatment of this vexing pollutant. This appropriation was allocated to the Coal Research Board of the Commonwealth's Department of Mines and Mineral Industries, who 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 the Dorr-Oliver program are to perform unit operations in a mobile pilot plant at various mine sites throughout the Commonwealth and obtain design and economic data that can be used to evaluate the process under examination.

A four phase research and development program was planned to carry out the objectives of the project.

Phase I - Feasibility Study and Site Selection.

Phase II - Pilot Plant Design and Fabrication.

Phase III - Operation.

Phase IV - Process Evaluation.

The program is currently in Phase III - Operation and to date six mine sites have been tested.

TREATMENT PROCESS

The process chosen for the treatment of the acid mine drainage is the lime-neutralization-aeration-dewatering process. Basically this is a four step process and involves the following steps:

Step 1. Neutralization

This entails the conversion of

a) sulfuric acid to calcium sulfate
$$Ca(OH)_2 + H_2SO_4 \longrightarrow CaSO_4 + 2H_2O$$
b) ferrous sulfate to ferrous hydroxide and calcium sulfate
$$Ca(OH)_2 + FeSO_4 \longrightarrow \underset{\text{green ppt.}}{Fe(OH)_2} + CaSO_4$$

Step 2. Aeration (oxidation)

The oxidation of ferrous hydroxide to ferric hydroxide

$$O_2 + 4Fe(OH)_2 + 2H_2O \longrightarrow 4Fe(OH)_3$$

Step 3. Clarification - Thickening

Step 4. Dewatering

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 converting 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 settles to the bottom of the thickener while the clear effluent overflows the thickener and is considered treated mine water. The thickened slurry is then pumped to a solid bowl centrifuge for additional dewatering. The centrate, depending on its quality, may be considered treated mine water or, if required it may be returned to the thickener for additional processing. The cake is considered process waste.

PILOT PLANT

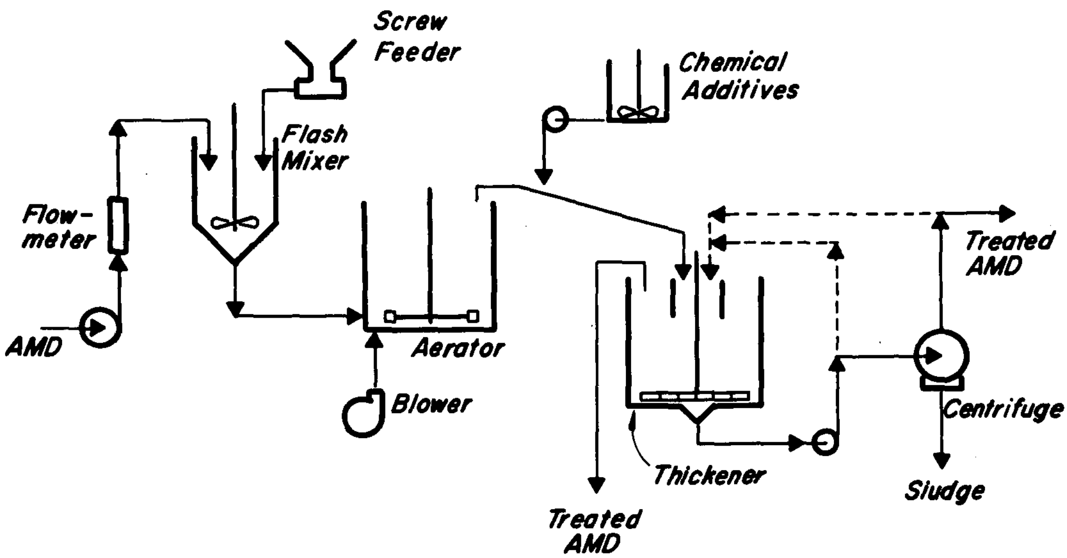
Information derived from Phases I and II led to the hydraulic design of a 50 gallon per minute pilot plant. The pilot plant was erected in a 40 foot long van type trailer that complied with the regulations for use on Pennsylvania roads without special permits. The mobile pilot plant was easily hauled from one site to the next. Figure 2 is a curb side view of the trailer while Figure 3 is a close-up of the pilot plant. The flow of mine water through the plant is from left to right. Pilot units shown in Figure 3 are the aerator, flocculent mixing tank, thickener, solid bowl centrifuge, and the pilot plant's power source - a 25 kw diesel generator.

A laboratory bench located in the forward section provides a work area for performing routine chemical analysis, settling tests, and leaf filtration tests.

TEST SITE

The first test site chosen for field operations by the Coal Research Board and that which forms the basis of the material reported in this paper is The Bethlehem Mines Corporation, Marianna Coal Mine No. 58, located at Marianna in Washington County This is an operating shaft mine in which 7000 tons per day of Pittsburgh coal is mined The coal is processed in a cleaning plant where 5000 TPD of clean coal is produced along with 2000 TPD of refuse. Mine water is collected in sumps within the mine and pumped to the surface four times a day at periods up to one hour per pumping. Reaching the surface the water flows by gravity through a conduit into Ten Mile Creek.

The acid mine water processed in the pilot plant was obtained from the Marianna Mine No. 58 bore hole prior to its flowing into Ten Mile Creek. Because of the intermittent pumping schedule a 24 ft. diameter by 4 ft. in height storage pool was filled with mine water each day from the morning pumping to serve as a supply for the duration of the pilot run. The influent was obtained by placing a hose into the storage pool and pumping with a self-priming pump into the flash mixer. The raw acid mine water was metered either by a flowmeter on the discharge side of the feed pump or by



FLOWSHEET FOR AMD TREATMENT

FIGURE 1

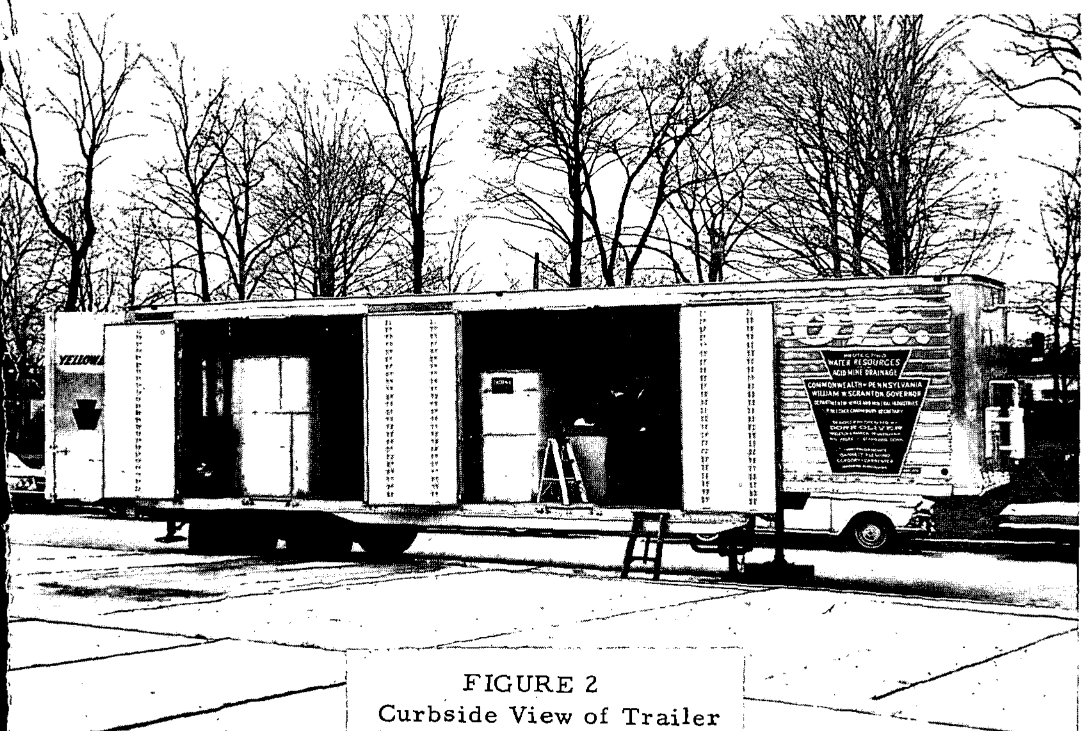


FIGURE 2
Curbside View of Trailer

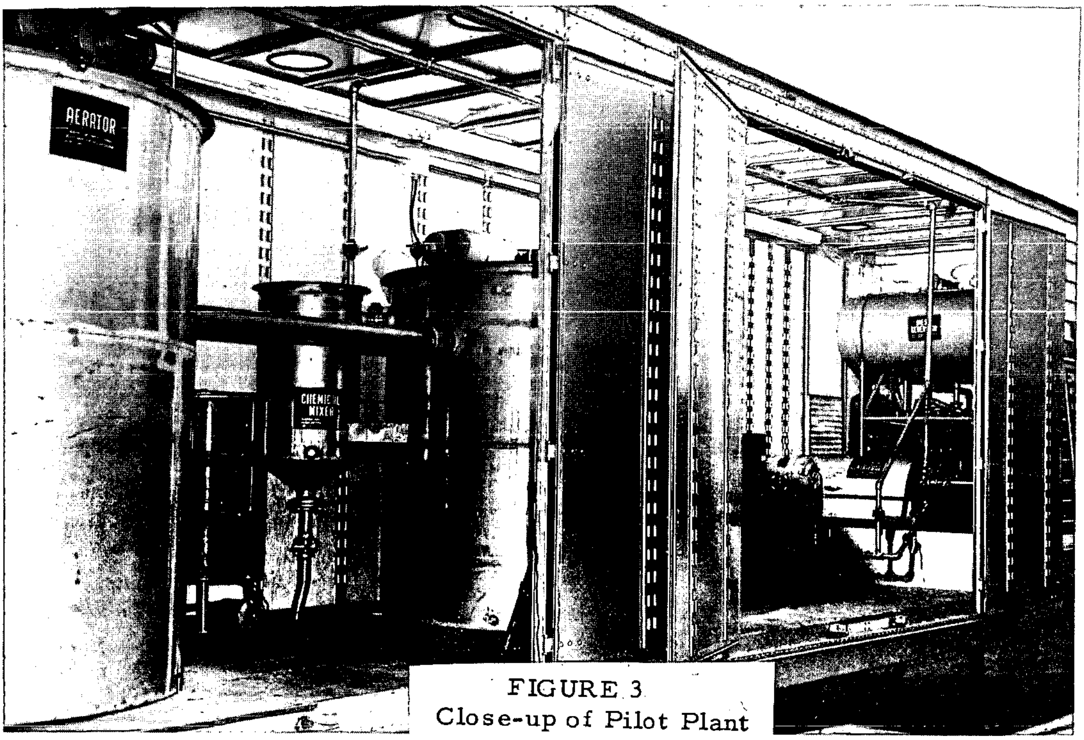


FIGURE 3
Close-up of Pilot Plant

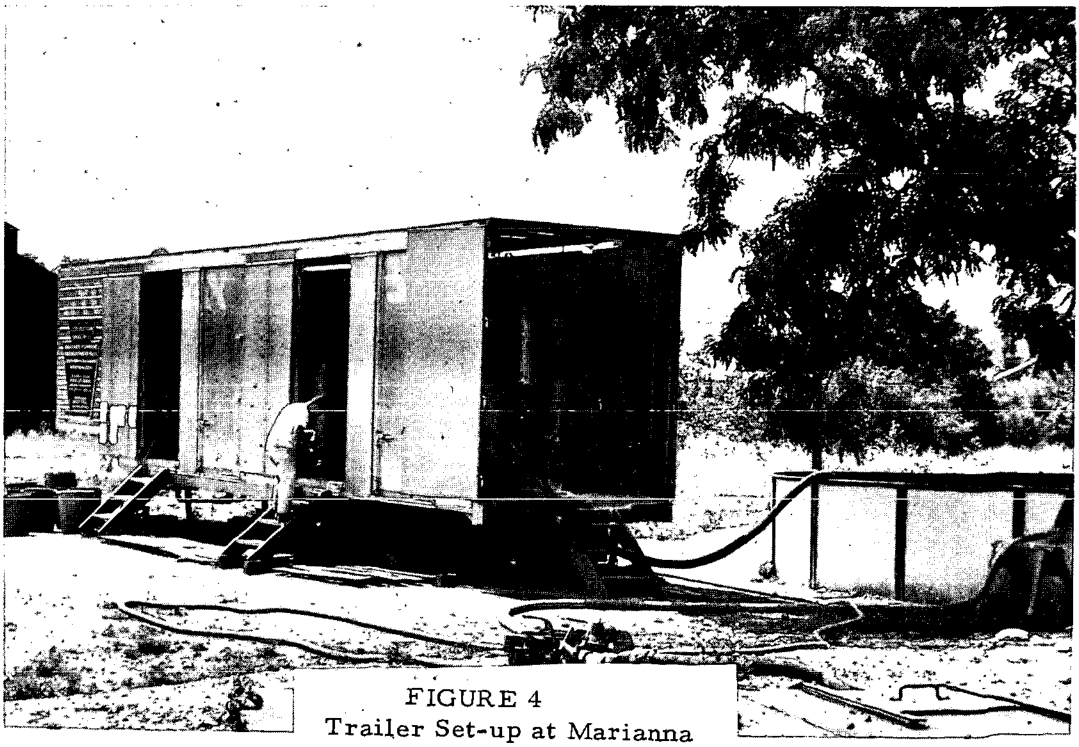


FIGURE 4
Trailer Set-up at Marianna

checking the volume per unit time of thickener overflow which accumulated in a 50 gal. head tank attached to the side of the thickener. After processing, the treated mine water was returned to a man hole where it was discharged into Ten Mile Creek. The resulting yellowbow sludge was accumulated in 20 gal. pails. Figure 4 is a photograph showing the set-up at this site.

PILOT PLANT OPERATION

The pilot plant operated at the Marianna Mine No. 58 during May and June of 1965. The first month's operation served as a shakedown period for the pilot plant and its operating crew. This period showed the inconsistency of the mine water chemical analysis in that the iron content and the acidity would fluctuate with each pumping cycle. The reason for this fluctuation, was that the mine water is first collected in sub-sumps and is then pumped to a main sump where it is pumped up the bore hole and per-mitted to flow to Ten Mile Creek. Acid forming conditions (pyrite, air, and water) varied within different areas of the mine resulting in different strengths of mine water. By using the storage pool, before feeding the acid mine drainage to the pilot plant, the fluctuations were kept to a minimum.

A Mason "N" hydrated lime was used for the neutralization of the mine water. The lime demand of the process proved to be just about Stoichiometric.

After it was felt that the "bugs" had been eliminated from the pilot plant units, a four day continuous test was conducted. This run was well monitored with sampling and laboratory analysis being run every three hours. During this period a close observation was kept on the various unit operations of the pilot plant and necessary design data was recorded.

A composite of the raw and treated acid mine water chemical analyses collected during this continuous test is reported in Table 1. The data demonstrates that the raw acid mine drainage was up-graded from a pH of 2.64 to a pH of 7.6. The total iron in the water which was 815 ppm was reduced to 5.8 ppm. Manganese, silica, and alumina were also reduced with the increase in pH. Silica and alumina had a beneficial effect on sedimentation in that they form large flocs upon reaching their solubility limit and aid the coagulation of the iron hydroxide.

DESIGN DATA

The scaled-up data used for the engineering design was generated during the shake-down period of the operation and confirmed during the continuous test run. Individual unit operations were investigated and the findings are as follows:

A. Flash Mixing

This investigation entailed feeding acid mine water to the flash mixer at different rates. Hydrated lime was mixed with the mine water and pH readings were taken of the neutralized mine water as it flowed on its way to the aerator. Detention times between one and seven minutes were investigated at a constant propeller speed of 350 rpm. During this investigation it was found that the detention time was always sufficient to ensure neutralization (pH>7). It should be noted that this test was made in May and June and the ambient temperatures at Marianna were in the neighborhood of 80°F. during the day. At colder temperatures longer detention times may be required.

B. Aeration

The pilot plant aerator produced 2 SCFM of air which is the equivalent of 16.9 g. of oxygen per minute. This air supply, assuming 100 percent efficiency, would oxidize 121 grams per minute of ferrous ion to ferric ion. At this aeration rate satisfactory oxidation always was achieved.

An intensified aeration study was not conducted at Marianna because it was difficult to maintain a uniform supply of ferrous ion to the aerator due to hydrolysis in the storage pool. It was also difficult to supply hydrated lime to obtain neutralization at high through-puts of mine water.

Aeration equipment was designed from basic process data without the need of field testing. The information required was:

1) Volume of water per minute

2) Oxygen uptake

3) Depth of aerator

4) Desired dissolved oxygen level

All this information was collected during the test runs.

C. Flocculation Tests

A bench study was conducted to determine flocculating agents that will improve the clarity and settling rates of the aerator overflow during sedimentation. Evaluation was made by comparing the physical behavior of the suspended solids in a freshly obtained sample of aerator overflow before and after the addition of a flocculent.

Reported in Table 2 are some of the favorable flocculents tested and their required dosages to produce a clear effluent. Nalcolyte 670 appeared to be the most prominent flocculent tested from the results of the bench scale tests. However, when Nalcolyte 670 was employed in actual pilot plant operation it did not perform adequately and Nalcolyte 672 was substituted and produced excellent results.

When a flocculent was used on the continuous test run the product water contained less than 1.5 ppm of iron as opposed to an average of 6 ppm in the non-flocculated product water.

It was also discovered during the bench test that some flocculents are apparently more pH sensitive than others which implies that pH control of plant operation must be held to precise control ranges if effective flocculation is to be maintained. It should also be noted that while flocculents increase settling rates they do not necessarily increase the solid concentrations of the thickener underflow. Centrifuge and bench filtration tests demonstrated that within a few hours after the floc had formed and settled it apparently went stale. The original floc formation, when disturbed by pumping, will break up and not reform again to its original well flocculated structure. Because of this effect no real additional benefits can be gained from flocculation in further dewatering steps.

D. Thickening Tests

Bench scale settling tests were performed and the results were checked in the pilot plant thickener during the shakedown period and continuous run. Summarized in Table 3 are the important design criteria that were determined from these tests.

Operation of the pilot thickener was designed so that the feed rate to the thickener would not exceed the unit area of 89 sq. ft. per ton per day. When this rate was followed no difficulty was encountered in maintaining overflow clarity substantiating the bench settling tests.

. Centrifuge Tests

Centrifuge tests were conducted using the Merco Z-1-L solid bowl which is an integral unit of the pilot plant. Feed slurry was pumped to the centrifuge from the settled thickener underflow by way of a positive displacement pump. Difficulty was experienced in obtaining and maintaining a clear centrate in the early stages of operation. The slurry is definitely plastic in nature. The unit was operated at solid bowl speeds ranging from 4,620 rpm up to 5,600 rpm with a scroll differential between 23 and 38 rpm's and contained a ring dam with a diameter of 6.5 inches. A ring dam influences the capture and the dryness of the products from the centrifuge. A small inside diameter ring dam causes the depth of the liquid in the bowl to increase, thus improving the capture and increasing the cake moisture. A large inside diameter ring decreases the depth of liquid in the bowl thus reducing the capture and decreasing cake moisture. When it became apparent that the larger ring dam was not producing the desired results a 5.9 inch ring dam was inserted. For the first few days of operation with the small ring dam and a lower bowl speed no effect on the centrate clarity was noticed. At this time a flocculating agent was added to the thickener underflow while it was being fed to the Z-1-L. This immediately cleared the centrate and for a period of time the unit was operated with flocculent until it was discovered that a flocculating agent did not have to be added continuously. A clear centrate was also attained by "slugging" the centrifuge with a flocculating agent whenever the centrate became cloudy. After a good iron hydroxide and gypsum beach had been built up within the unit it was no longer necessary to use flocculents to achieve good consistent clarity.

Although the centrifuge cake consistently averaged 30 percent solids or greater and the suspended solids recovery was approximately 100 percent the desired feed rate to the unit could not be achieved. Power costs also proved to be high. For this reason filters were chosen in place of centrifuges in the final design of the plant.

Filtration Tests

Laboratory filtration tests were conducted on samples of the thickener underflow using a 0.1 sq. ft. test filter leaf at cycles and conditions simulating those of drum and disc filters. For all the tests performed a filtercloth of Nylon 1016 material was used. This is a relatively tight cloth and the use of this cloth has proven superior to other cloths in an earlier laboratory testing program (Phase 1 of the Yellowboy Project. The results demonstrated that only a small benefit can be derived from the filtration of a thickener underflow that had been flocculated.

In all cases tested a quick drum cycle appears to provide the best filtration results. Although the cake thickness is only 1/16 of an inch, the tests demonstrated that a good roll discharge can be attained.

Presented in Table 4 are the important design data derived from the filter tests and used as the basis for filter scale-up.

.NT DESIGN

Design data generated during the pilot plant operation at Marianna has been used a basis for the scale-up to a full-size acid mine drainage treatment plant. This ıt has been designed to treat a flow of 240,000 gallons per day of mine water.

Presented in Figure 5 is a schematic diagram of the flowsheet recommended for ating all the acid mine water from the Marianna Mine No. 58 bore hole. Basically flowsheet is the same as that tested in the pilot plant with a few minor modificans to make it adaptable to this location. The raw mine water is pumped to a holding oon, which is already in existence, prior to entering the treatment plant. The pose for this is as follows:

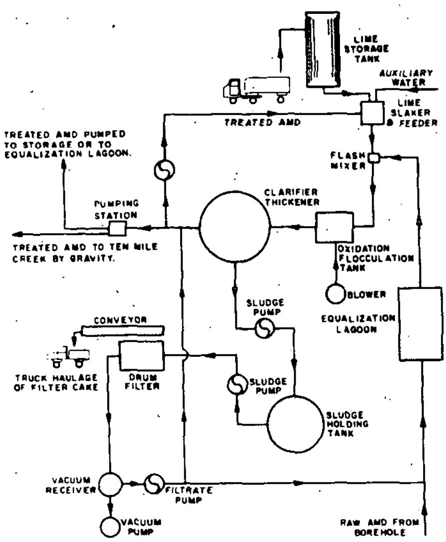


Figure 5

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF MINES AND MINERAL INDUSTRIES

SCHEMATIC DIAGRAM
OF AMD TREATMENT PROCESS

Bethlehem Steel Company Mine No. 58
Marianna, Pennsylvania

FIGURE 5

FIGURE 6

ACID MINE WATER
TREATMENT PLANT CAPITAL EXPENDITURES

Water Storage and Transportation Facilities	$ 22,800
Control-Filter Building	223,000
Aeration	6,000
Thickener	45,000
Sludge Holding	9,500
Piping and Site Preparation	40,900
Total Capital	$347,200

FIGURE 7

ANNUAL COSTS

Amortization (20 yrs @ 4.0%)	$25,550
Labor	36,500
Power	4,700
Chemicals (Lime)	22,000
Maintenance	6,500
Total Annual Costs	$95,250

1. A uniform flow will be maintained when pumping from the mine is intermittent.

2. It is anticipated that scaling will be a problem and shut-downs of the plant will be necessary from time to time. In order not to interfere with the pumping from the mine the lagoon will supply ample storage capacity.

3. Hydrolysis will take place resulting in less demand of aeration equipment during the treatment process.

The mine water in the holding lagoon flows by gravity to the treatment plant where is neutralized by the addition of milk of lime in a flash mixer and then aerated. ie slurry then flows to a thickener where the solids settle and the effluent, process oduct, flows to Ten Mile Creek. The settled solids are then filtered, with the filate being blended with the raw mine water or depending on quality, can also be rerned to Ten Mile Creek. The filter cake (25% solids) is trucked to a nearby site. ie holding lagoon is cleaned periodically by slurrying the settled solids and processing n the treatment plant.

OST EVALUATION

Different plans of operating the acid mine drainage treatment plant have been tudied and the economics are in favor of continuous treatment of the mine water through he thickening-clarification step. The filters are operated only one shift per day for even days a week.

The scale-up of the pilot plant data to treat a flow of 240,000 gallons per day 167 gpm) would require a capital expenditure of $347,200. This cost is exclusive of dditional treatment of sludge. Annual costs are $95,250. A breakdown of these costs s shown in Figures 6 and 7.

Based on treating 240,000 gallons per day and marketing 5000 tons of clean coal per ay (actually 7000 tons per day of coal is mined; after coal preparation 2000 tons reorts to refuse while 5000 tons is marketed) the annual unit costs are $0.052 per ton of lean coal marketed or $1.09 per 1000 gallons of acid mine water. These costs exclude xpenditures for additional sludge treatment.

ONCLUSION

It is in the scope of this report to present the technical feasibility and economic soundness of treating acid mine water at the Bethlehem Mines Corporation, Marinna Mine No. 58 by the lime-neutralization process. This investigation has produced he following conclusions:

1. Mine water can be treated to produce a product containing less than 6 ppm of iron and a neutral pH without flocculents.

2. With flocculents a product containing less than 2 ppm of iron can be produced at a neutral pH at increased costs.

3. Based on data derived from the pilot plant operation, 1000 gals. of acid mine drainage can be treated for $1.09. These costs do no include expenditures for additional sludge processing.

4. Scale formation will be an operating problem.

5. Manganese, alumina, and silica are also removed by lime neutralization resulting in a decrease in total hardness.

ACKNOWLEDGMENTS

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TABLE 1

COMPOSITE CHEMICAL ANALYSES of RAW AND TREATED AMD

	Raw AMD	Treated AMD
pH	2.64	7.6
Total Iron, ppm	815.0	5.8
Total Acidity, ppm as H_2SO_4	4040.0	-
Total Alkalinity, ppm as HCO_3	-	46.0

TABLE 2

FLOCCULENTS PRODUCING A CLEAR EFFLUENT

Flocculent	Dosage (#/Ton of Dry Solids)
Separan NP 10	0.6
Superfloc #84	1.0
Superfloc #16	0.5
Nalcolyte #670	0.4
Nalcolyte #672	0.6

TABLE 3

THICKENER DESIGN DATA

Unit Area, ft^2/T/day	89.0
Time in Compression, hrs	11.4
Capacity, #'s of Solid/ft^2/hr	0.93
Storage, #'s of Pulp/ft^2	192.1
Final Dilution, % Solids	6.7

TABLE 4

FILTER DESIGN DATA

Solids Loading, lbs of Dry Solids/ft^2/hr	10.4
Hydraulic Loading, gal/ft^2/hr	14.9
% Solids of Filter Cake	26.2