Mine Drainage
Part 1: Abatement, Disposal, Treatment

INTRODUCTION

A number of active research projects concerning mine drainage have been undertaken over the years treating various aspects of mine drainage problems and the findings published. Despite this, Pennsylvania and many other states still are plagued with mine drainage which pollutes many rivers and ground water reservoirs. This indicates that either our research efforts, although of value, have been insufficient in scope or the solutions found have not been put into operation through broad management programs. If the former is correct and problems still remain to be solved, then the initiation of new research, demonstration projects, and administrative implementation of existing solutions to these problems is justified. In short, fresh approaches should be welcome, for it is obvious that no one solution will apply in all cases to the problem at hand, or if it does, it may not be the most economical.

It is not even realistic to assume that we should now cease mining coal as a solution to mine drainage problems, since we have the legacy of the past mistake and an immediate and long term need for the coal industry. Radioactive wastes accompanying atomic power generation and the more taxing problem of safely disposing of these wastes for thousands of years to come should sober our thinking in regard to the role of coal today and in the immediate future.

While the mining industry has concerned itself with mine drainage in the past, recent legislation in Pennsylvania has accentuated the problem. Reclassifying “acid” mine drainage as an industrial waste and prohibiting its disposal into any stream, clean or polluted, were the two basic changes in the new Clean Streams Bill that caused a reappraisal of an old and perplexing problem. With millions of gallons of mine water containing ferrous sulfate and ferric hydroxide being discharged annually in amounts of acidity varying from 50 to 20,000 ppm, research has been accelerated in an attempt to obtain a solution to the problem.

Iron disulfide, FeS₂, associated with the enclosing rock strata as well as being present in the coal seam itself, undergoes chemical change in the presence of air and water, resulting in the formation of “acid water”.

\[
\begin{align*}
2\text{FeS}_2 + 2\text{H}_2\text{O} + 7\text{O}_2 & \rightarrow 2\text{FeSO}_4 + 2\text{H}_2\text{SO}_4 \\
4\text{FeSO}_4 + \text{H}_2\text{SO}_4 + \text{O}_2 & \rightarrow 2\text{Fe}_2(\text{SO}_4)_3 + 2\text{H}_2\text{O} \\
\text{Fe}_3(\text{SO}_4)_2 + 6\text{H}_2\text{O} & \rightarrow 2\text{Fe}(\text{OH})_3 + 3\text{H}_2\text{SO}_4
\end{align*}
\]

There is no typical “acid” mine water, and it is a more complex solution than the above equations would indicate. Not only does the ferrous to ferric iron ratio vary, but pH is not a true indicator of total acidity. Additional ions such as silica, aluminum, manganese, calcium and magnesium are present, as well as autotrophic bacteria, which are thought to accelerate the formation of acid.

While coal associated iron disulfide usually is isolated from oxygen and water in its natural environment in the earth, deep-mining the coal seam removes support from the overlying strata and induces caving, while strip-mining physically disrupts the strata. An influx of water and air, together with the exposure of additional acid-
looks more to the future, although there are some immediate benefits possible from the manipulation of ground and surface waters.

**Immediate Abatement**

Contaminated mine water formation can be reduced by utilizing mining systems that will minimize the amount of water inflow into the mine, or by arranging some mining in such a manner that the inflow can be removed from the mine as quickly as possible. In all probability both of these approaches could be employed simultaneously for a given mining system.

Partial extraction to avoid caving to water-bearing strata would minimize the inflow of water. In addition, it would permit better collection and control of the water to divert it from the mine, for one of the major problems associated with caving techniques is that there is no control of the drainage patterns once the abandoned workings become inaccessible.

However, the economic and conservation aspects of partial mining must be weighed against any potential water benefits. Furthermore, the hazards of possible mine fires through spontaneous combustion must be considered. In many coal fields, the systematic pulling of pillars with controlled caving is the only way that excessive rock pressures are relieved and the excavations maintained. It is interesting to note that recent legislation in Pennsylvania with respect to mine water and subsidence might be driving the mine operator to partial extraction as a short-term solution. For long-term benefits to the Commonwealth, this may only be the most expedient answer and not the most satisfactory one.

There are other novel aspects to the abatement program that might prove to be far more satisfactory, although at present they are largely in the “thinking” stage. For instance, it has been suggested that a chemical that will coat the sulfides and thus inhibit acid formation be placed in the ground water in a mining area. The availability of such a chemical, its possible side effects, must carefully be explored. Further, more must be known about hydrology to achieve the most effective chemical dispersion.

Another abatement possibility would be an attempt to intercept ground water in a mining area before it enters the mine. In Britain experimental attempts are being made to drain overlying strata prior to caving. No doubt considerably more can be done with abatement techniques, but much research is necessary.

**Disposal Method**

**Established Methods**

Subsurface disposal involves removing unwanted materials from their original environment and placing them in isolated subterranean zones. Permanent removal of undesired liquid water generally is accomplished by using injection wells to transport the material to the disposal horizon.

The petroleum industry first employed subsurface disposal in the early part of the twentieth century to dispose of oil field brines. During the past ten years other industries have adopted this method to dispose of manufactured wastes, and injection wells are presently being used in the drug, chemical, steel, and paper manufacturing industries. Radioactive material from nuclear plants also is being injected into disposal wells.

Injection wells are drilled from the surface to a geologic formation previously selected as the disposal zone. They are drilled and completed in the same manner as gas and petroleum wells, and waste travels down the well through a non-corrosive injection tube. Subsurface facilities associated with injection wells consist of a waste gathering and storage system, filtering equipment, and one or more pumps. Multibarrelled displacement pumps are generally used for this purpose. The rate at which a disposal well can accept fluid depends upon the fluid properties, rock properties, the size of the well and the pressure gradient in the system. Pumps provide the pressure necessary to push the waste into the disposal zone. The necessary injection pressure may be calculated from the following relationship:

\[ P_i = P_r - P_s + P_f \]

where \( P_i \) = Injection pressure from pump, \( P_r \) = Well bottom formation pressure, \( P_s \) = Pressure of fluid column in well, \( P_f \) = Friction loss in injection tube.

Formation pressure \( (P_f) \) cannot be measured until the well has reached the disposal zone, and even then, an accurate measurement is not always possible. An estimate can be made by multiplying the well depth by the geologic pressure gradient. The generally accepted pressure gradient is one pound per square inch pressure per foot of depth. The fluid column pressure \( (P_s) \) can be calculated from the well depth and the fluid density. Friction loss \( (P_f) \) can be calculated from well depth, injection tube material and size, and the flow rate. Flow rate into the disposal formation is usually not directly proportional to injection pressure. At higher pressures, incremental pressure increases result in a proportionately greater flow rate.

If it becomes desirable to increase flow rate for a given pressure, the formation properties may be altered. Several methods of well stimulation are practiced in the petroleum industry to achieve a more efficient well. During the past ten years hydraulic fracturing, well perforating, and acidizing. Hydraulic fracturing is the most popular of these methods.

**Geologic Factors**

The main factor to be considered when contemplating the establishment of a disposal well is the presence of the proper geologic formations. The disposal formation must have a large enough storage capacity to contain the total volume of fluid that will be injected during the life of the well. The capacity depends upon the area and thickness of the formation and upon the effective porosity of the formation. A disposal formation should also be surrounded by relatively impermeable rocks to prevent migration of the waste away from the disposal zone. The disposal zone itself, however, should be very permeable to allow rapid flow of the waste away from the well with a minimum expenditure of pumping energy. Finally, a potential disposal zone should not contain usable ground water or any economic fuel or mineral deposit that could be contaminated by the waste.

**Waste Characteristics**

The experience of companies using injection wells has shown that wastes which are to be
injected into porous beds ideally should have the following properties:

1. A pH less than the formation water
2. No suspended solids
3. Low viscosity
4. Low metal content
5. High specific gravity
6. No self-polymerizing materials
7. No dissolved gases
8. No bacteria

The waste should also be chemically stable and compatible with the formation rock and fluids. The main concern in injecting wastes into a porous formation is the possibility of plugging the disposal zone. Recovery of a plugged well is expensive and time consuming.

Exploratory Efforts — Experimental Well

Acid mine water, while having a low pH and viscosity and containing no self-polymerizing materials, does not meet the stated criteria. Of particular concern are the presence of suspended solids, bacteria, dissolved gases, and concentrations of iron. Polluted mine water is not chemically stable and its compatibility with the formation will not be known until samples of the rock and connate water are available. It was felt that these problems, although difficult, were not insurmountable and could be solved.

The bituminous coal fields of central and western Pennsylvania lie in a region of well-stratified sedimentary rock. Principle rock types are sandstones, limestones, shales, siltstones, and claystones, all varying in areal extent and thickness. Shales, siltstones, and claystones are very impermeable rocks and, therefore, are generally ruled out. The two remaining rock types, if occurring in large enough bodies, can be considered potential disposal reservoirs.

Many sandstone beds are quite thick, underlie large areas, and often have high porosity and permeability values. Fluid flow through a sandstone brings the liquid into intimate contact with the rock, causing a maximum amount of contact between waste and the formation. The sandstones in question are largely silica, a comparatively non-reactive substance.

Limestones generally exhibit lower permeability and porosity than sandstones and are often clogged by ground water, thus forming a series of subterranean channels. Fluid flow in these channels is similar to that in an irregular system of pipes, and although formation to fluid contact is minimal, the extent of the fluid migration is difficult to determine. Limestone is calcium carbonate, a more reactive compound than silicic dioode.

General geologic structural information is available for many of the larger rock units in central and western Pennsylvania, while detailed lithologic information is very limited, with cores being unavailable. However, in this area extensive drilling has been conducted for gas and oil, and drillers' logs are available. While it was realized that these do not always have the desired accuracy, it was thought that sufficient information might be available for a feasibility study. Considering all the information available, it seemed that the "salt sands", the Homewood and Connoquenessing sandstones, were an excellent potential disposal zone for the part of the Commonwealth where they are brine saturated. These formations were chosen because:

1. Many polluted mine water discharge points are present.
2. No producible amounts of natural gas or any other petroleum product have been found.
3. The salt sand formation was reported to be a mineralized brine under nearly hydrostatic pressure.
4. Drillers' logs of wells indicate high porosity and permeability values.
5. Drillers' logs also indicate adequate formation thickness over a large area.
6. The "salt sands" are vertically bordered by impermeable shales.
7. The shallow depth of these formations (about 1500 feet) would not require the use of excessive pumping pressures.

This feasibility study is contained in a Special Research Report (SR-52) to the Commonwealth Coal Research Board.

An area in southwestern Pennsylvania was selected as a site for actual drilling of an injection well. Water from an existing mine well was available for this full scale test. Subsurface contour maps prepared for the area indicated that the "salt sands" were approximately 130 feet thick at the proposed well site and were covered by about 1400 feet of overburden. The exact site was located so that the well would penetrate the center of a large pillar in the mine, while all surface facilities were considered adequate.

Well Development

The well was cable-tool drilled to a depth of 1302 feet, caliper and formation density logs were run, and a seven-inch casing was set and cemented in place.© Diamond core drilling (2⅜ in.) then proceeded from the 1302 foot level to 1588 feet, and the interval was then reamed to a diameter of 6⅛ inches. The cores revealed that only an 80-foot thickness of salt sands existed compared to the expected 130 feet. Furthermore, the caliper log revealed that the interval from 1342 to 1351 feet, occupied by two beds of claystone, had spalled considerably. Visual examinations of the cores revealed that the salt sands were not as high in quality as had been expected with many shale striations. Analyses of cores for porosity revealed that these values were much lower than had been expected. Geologically, the disposal zone was not nearly as favorable as drillers' logs had suggested.

Well Testing

Despite the minor disappointments of low porosity values and thinness of sandstone units, a fresh water testing program was conducted. Fresh water was injected into the entire uncased interval of the well. Over 48,000 gallons of water entered the well at flow rates ranging from 100 to 220 gpm. Pumping pressures for these rates were considerably higher than expected, ranging from 1500 to 1940 psi.

Therefore, a decision was made to hydraulically fracture the uncased part of the well following this initial injection test in an effort to lower pumping pressures. The well was fractured, open hole, using approximately 30,000 gallons of fresh water and 34,000 pounds of 20-40 mesh sand. Fracture pressure was 1600 psi for a flow of 1500 gpm. The well was allowed to back flow following this treatment.

Radioactive beads were injected with the "frac" sand. A radioactive log run on the well following the fracture treatment indicated that a horizontal fracture had occurred at a depth of 1508 feet.

Following this, another fresh water injection test was performed. A total of 15,942 gallons was injected during a 1½ hour period. The pumping rate was 150 gpm and the pressure ranged from 1750 to 1800 psi. The well was allowed to back flow following this test. The water was initially clear, but later be-
came cloudy. Upon close inspection it became apparent that this cloudiness was caused by suspended silty particles. This phenomenon raised the possibility that these particles were clogging the sand face.

Attempts to bail down the well revealed that frequent bridging, or plugging, of the hole was occurring below the 1350 level. Claystone from the spalled zone, indicated by the caliper log, was identified as the cause, but results of efforts to cement off the spalled zone were inconclusive. A third injection test that followed involved a total of 46,200 gallons of fresh water pumped at rates from 105 to 250 gpm with pressures from 1800 to 2000 psi. Very little pressure fluctuation was observed for the various flow rates used in this test.

It was decided that perhaps more selective hydraulic fracturing of a narrower and more promising zone might prove fruitful. Since the cores revealed that the interval from 1480 to 1520 feet was the most permeable and porous, this zone was isolated, hydraulically notched and fractured. Unfortunately, a vertical fracture bridged the packer which was used at the top of the zone for isolation. This fracture orientation allowed the injected water to enter the formation, bypass the packer, re-enter the well bore above the packer and flow to the surface. Two attempts were made to reset the packer at a higher elevation in an effort to isolate the entire fracture, but both were unsuccessful. Irregularities in the well bore prevented the moving of the packer to a higher elevation and the test was halted.

Further work on the well ceased following this test; it was covered with a vented cap and allowed to remain full of water. The decision to halt the work was brought about by the conclusion of all parties involved that any further well stimulation would be futile and that a pumping pressure of nearly 2000 psi would be required to inject 150 gallons of acid mine water per minute into the well. The higher capital and operating costs at these high flow rates and pressures ruled out further development of this process at this time.

Summation of Test
The major disappointment in this investigation was the comparatively small amount of sandstone penetrated by the well and its poor hydrologic properties, and this factor undoubtedly affected the pumping pressures in the injection tests. In this instance, what was thought to be sufficient information in the initial phase of the investigation proved to be unreliable under test. In any undertaking of this type, decisions should be based on accurate information. If reliable geologic data are not available, a core-drilling program must first be performed at any proposed injection site.

Perhaps the most significant finding of this study was the discovery that it was possible to inject water into the salt sands at the rate necessary to dispose of the available discharge. However, insufficient water was pumped into these formations to determine the long-term effect of this practice. Also, the compatibility of mine water with connate water and the formation rock was not established during the abbreviated testing program.

Treatment
Mine drainage waters which escape from a mining operation, either an active deep mine, a stripping operation, or an abandoned operation of either type, have various levels of soluble pollution components as previously discussed. It must be stressed that the development of polluted mine drainage results from a natural phenomenon and that mining operations have increased the volume and level of pollution of these waters. Although the Clean Streams Act of 1965 classifies mine drainage as an industrial waste, no action is now required for drainage originating from abandoned mines. This area is under constant study and is certain to be important in the not too distant future. Thus, in terms of today's conservation movements and the fulfillment of existing legislation, it becomes essential to consider remedial processes. An annotated bibliography covering the various aspects of mine drainage has been developed and is currently being maintained. (8) (2)

One idea suggested as a remedial process would be to dilute the drainage waters to such an extent that they have negligible effect on subsequent receiving streams. Actually, this process now occurs daily in nature; however, the volumes are so great that adequate dilution sources are unavailable. The economic capability of developing an adequate collection system prior to dilution also seems unrealistic. In addition, such a process does not always eliminate the unsightly conditions which develop during collection.

The approach currently available is to treat these mine waters in such a fashion that the pollutants are removed from the waters or are rendered innocuous.

Water Quality
When one considers the treatment of any water, it is necessary to establish a product quality requirement. In Pennsylvania specifications have been established for active mining operations and are being developed for discharges resulting from coal preparation plant operations. These requirements include:

1. The pH must be in the range of 6 to 9.
2. The alkalinity must exceed the acidity as defined.
3. The iron content must not exceed 7 milligrams per liter.

Development of such criteria is most difficult. All natural streams contain various levels of soluble components which may limit their use for certain purposes. Metabolic and toxicity requirements are not fully established either for man, aquatic plants or animals. Industrial water requirements vary widely. The control of pathogenic organisms usually is not a factor. There are many uncertainties about the levels of mineral pollutants that may be acceptable in streams. For example, calcium sulfate, a very common pollutant and one that would exist in an essentially saturated condition in any mine drainage treatment waters in which lime has been used as a neutralizing agent, exists with considerable uncertainty as to its toxicity. Authorities differ regarding the effect of water containing calcium sulfate in that some consider the "toxicity" level to be in the neighborhood of 200 parts per million, while others feel that it can be as high as the saturation point which approaches 3,000 parts per million.

The development of a system of stream zoning which would define quality in terms of anticipated usage appears the most reasonable approach to a criterion. In the absence of a zoning system, criteria cannot be realistically established. The removal of all dissolved solids is a practical impossibility and probably an undesirable goal, since upon returning such waters to the streams they will again achieve a certain level of impurities from soluble constituents in strata through
which they pass. A vital consideration in development of quality requirements involves treatment costs. The higher the quality of product required, in general, the higher the treatment costs. The decision then must represent a policy which is indicative of the cost the sociological group is willing to pay for maintaining the given level of water purity. The Pennsylvania regulations appear to have been selected on a somewhat arbitrary basis, considering a level of water quality which will permit normal plant and aquatic life metabolism.

**Treatment Processes**

When considering the development of any treatment process, a thorough understanding of the characteristics of the pollutants is essential. The main pollutant of most coal mine drainage is ferrous iron which may exist in concentrations up to at least 5,000 parts per million. The acidity associated with mine water acts in most respects as free sulfuric acid, and by standard titration tests will range to values in excess of 10,000 parts per million CaCO₃. The acid response is believed to originate primarily from the "hydrolysis" of dissolved salts. The use of pH as an indicator of acidity is most misleading. It is at best a qualitative indicator, but should not be relied upon as significant in indicating the extent of pollution. Less frequently considered are other pollutants, usually in much lower concentrations. These include aluminum, magnesium, manganese, sodium, and chloride. A second type of mine drainage water which receives little attention, contains little or no acidity. In fact, it is commonly alkaline due to a bicarbonate content and can contain appreciable quantities of iron. The treatment of such waters involves completely different considerations although it should be less costly.

Another characteristic of mine drainage pollution which cannot be ignored is its instability in regard to changing concentration resulting from rainfall, caving conditions within mines, and the interception of long-abandoned deep mines with later strip operations. There is a constantly changing concentration of the pollutants. The cultivation of the oxidation of ferrous iron by oxygen originating from the air to form various insoluble iron compounds which coat the bottom of any receiving stream. There are many variable factors make the planning of any treatment process especially complex. In addition to the problems concerned specifically with the water, concepts of treatment become further complicated in selecting the location of a treatment facility. In many areas which develop mine drainage, the drainage will seep from several locations within a relatively small area, and since the coal measures in Pennsylvania cover such a large geographic area, a large number of receiving streams become involved. Thus, future decisions must establish whether small treatment plants or a centralized treatment plant following water collection should be employed. This overall problem is complicated by whether or not the treatment is to be carried out by an individual company, a governmental agency or an interagency authority. The gathering of the waters to deliver to a common destination can be very intricate, possibly requiring extensive pipeline and even pumping costs. In many of the active mining locations today it is necessary to remove water from the mine in fact, as was discussed earlier, improved mining practices would suggest prompt removal of any waters developed in the mine as rapidly as possible, again requiring water-gathering networks and pumping to the surface for treatment.

There is no question that processes and technology now exist which permit purification of these waters; however, their practical application within the existing industrial and social structures poses more difficult problems. As shown in Table 1, various water treatment approaches can be considered. Included in this listing are systems which dispose of the water rather than actually treat it. Some systems would be expected to be more adaptable to those waters where the level of pollution is relatively minor and can be controlled with the very minimum of treatment. There are huge volumes of water which could be so-classed. This discussion, as with most developments today, is more concerned with those waters containing higher levels of pollution.

The treatment of such waters falls into two main areas. Those cited in Class I essentially provide techniques which remove all constituents soluble in the water. The pollutants are rejected as a very high salt-content brine or, when carried to the ultimate disposal method of solid-fluid separation applied, are transported as a solid, transportable material. They may be utilized as a raw material, as a raw material, or as a finished product high in cholrides, although acid waters which are high in cholrides may tend to return them into solution. There is no known use for these slurdes. Obviously disposal methods for the brines from Class I processes are yet to be devised.

Table 1.

<table>
<thead>
<tr>
<th>Mine Drainage Water Treatment Methods</th>
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<tbody>
<tr>
<td>Class I: De-mineralizing Methods</td>
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<tr>
<td>a. Ion exchange</td>
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<tr>
<td>b. Reverse osmosis</td>
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<tr>
<td>c. Electro-dialysis</td>
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<tr>
<td>d. Electrotroping</td>
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<tr>
<td>e. Flash distillation</td>
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<tr>
<td>f. Freezing</td>
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<tr>
<td>Class II: Alkali Neutralization Methods</td>
</tr>
<tr>
<td>a. Hydrated or calcined lime</td>
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<tr>
<td>b. Limestone</td>
</tr>
<tr>
<td>c. Magnesium hydroxide</td>
</tr>
<tr>
<td>d. Dolomite</td>
</tr>
<tr>
<td>e. Potassium permanganate</td>
</tr>
<tr>
<td>f. Sodium hydroxide</td>
</tr>
<tr>
<td>g. Potassium hydroxide</td>
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<tr>
<td>h. Ammonium hydroxide</td>
</tr>
<tr>
<td>i. Sodium sulphide</td>
</tr>
<tr>
<td>j. Phosphate</td>
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<tr>
<td>Class III: Other Specific Chemical Processes</td>
</tr>
<tr>
<td>a. Solvent extraction</td>
</tr>
<tr>
<td>b. Ozone</td>
</tr>
<tr>
<td>c. Coal reaction</td>
</tr>
<tr>
<td>d. Solid adsorption</td>
</tr>
<tr>
<td>e. Anaerobic reconvension</td>
</tr>
<tr>
<td>f. Microbiological oxidation</td>
</tr>
<tr>
<td>g. Aeration</td>
</tr>
<tr>
<td>Class IV: Particulate Matter Control</td>
</tr>
<tr>
<td>a. Lagooning</td>
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<tr>
<td>b. Filter</td>
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<tr>
<td>Class V: Geological — Geochemical — Biological Methods</td>
</tr>
<tr>
<td>a. Deep well disposal</td>
</tr>
<tr>
<td>b. Water table management</td>
</tr>
<tr>
<td>c. Drainage field disposal</td>
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<tr>
<td>d. Field spray</td>
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<tr>
<td>e. Water management — lagooning</td>
</tr>
<tr>
<td>f. Aeration, flow control</td>
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<tr>
<td>g. Bacteriostic</td>
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<tr>
<td>h. Mine sealing</td>
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</tbody>
</table>

There is very little industrial experience from which operating concepts can be developed. In 1964 the Pennsylvania Coal Research Board initiated a research program which has considered many of the processes cited in Table 1. The results have been described and are available from that agency. In the past, essentially all treatment of mine waters that has occurred has been limited to the addition of small amounts of lime in those instances where the water has been used in coal beneficiation, with treatment being carried out as an anticorrosion measure rather than to develop a purified water product.

**Lime Treatment**

Currently there is a lime neutralization plant treating about 150,000 gallons of mine water a day in operation at the Jones and Laughlin Corporation Thompson Shaft Bore Hole No. 5 near Beallsville, Pennsylvania. This organization has been issued a permit to dispose of the sludge in abandoned underground mine workings. The plant includes a 750,000 gallon holding lagoon, a 150 gallon per minute neutralization unit and a 35 by 160 foot settling basin. The mine water is treated with lime to reach a pH between 8.0 and 8.5.

In the eastern part of Pennsylvania, the Blue Coal Company has been adding hydrated lime directly to waters pumped from their underground workings, with the treated water reporting to a large settling lagoon before discharge. The most complete engineering data that are available have resulted from a portable lime-treatment plant termed "Operation Yellowboy" developed by the Pennsylvania Department of Mines and Mineral 

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December 1966
These data cover studies made at locations throughout Pennsylvania and are comprehensive, including treatment costs ranging between $0.057 and $1.09 per 1000 gallons. Recent news reports and technical papers would suggest that most mining operators are contemplating some form of lime treatment as an approach to meeting the recently developed Pennsylvania water treatment requirements. In fact, the Manual and Guidelines developed by Pennsylvania state regulatory agencies are based upon lime treatment processing.

An aspect of alkali neutralization processes involving oxidation of the ferrous iron to the ferric state with oxygen is not fully understood in all its ramifications, as required in plant design and operation. Three parameters are effective in controlling this reaction, although others are undoubtedly involved: (1) pH-acidity of the system, (2) temperature, and (3) ion concentrations (FeII, FeIII, SO42-, dissolved oxygen, etc.). The oxidation rate is very slow at pH values below 3.8 and increases rapidly by factors of 10 to 1000 as the system becomes alkaline. An interesting phenomenon is observed in laboratory studies in alkaline systems which indicate an incubation period is required for oxidation. Possibly some intermediate complex is formed which thus involves several reactions to complete the cycle. Certainly the mechanism is more complex than would first be apparent, and cannot be wholly disassociated from the hydrolysis of ferrous and ferric sulfate. The temperature response is most important since mine waters are commonly discharged near 50°F, while most plants would visualize out-door operations with no planned temperature control. The design and operation implications of this variable have been discussed by Barthauer. The concentration effects have been given little consideration and are most important because of the widespread variation in the existing waters. There is reason to believe that certain species of autotrophic bacteria may play a role in these reactions. Other problems not fully detailed involve the composition, solubility properties and settling rates of the iron compounds formed in the alkaline systems.

Treatment with a Coal Product Three research studies aimed at the treatment of mine water have been in progress for the past two years in the Department of Mineral Preparation at Penn State. The first of these studies developed the concept of the potential use of coal to treat mine water, despite the association of pyrite with coal and the role pyrites play in the origin of mine drainage pollutants. There is some basis to anticipate that coal may improve water quality. Anthracite is successfully used as a filter medium; it may have characteristics of molecular sieves; sulfonated bituminous coals have ion exchange properties; and some coals will react with sulfuric acid under rather mild conditions. Analyses of water discharge from certain coal preparation plants which use make-up water from acid streams indicate improvements with regard to acidity and iron content. Preliminary laboratory studies indicated that if mine water is treated with coal, the pH increases and the acidity and iron content is reduced. Consequently, further studies were initiated to establish the mechanism of such an observed response to permit more practical development of the phenomenon.

This stream now has a very undesirable appearance due to the large iron deposits on its bed. These yellow deposits are now virtually insoluble in normal waters and will remain a problem for some time to come.

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This study established that coals will react with coal mine drainage to decrease acidity and remove iron. The acidity and iron can be reduced to negligible proportions. Calcium carbonate content by standard procedures.

The magnitude of the response of coal mine drainage to coal is dependent upon various coal properties including its composition, mining and processing history, and its particle size. It also varies with the coal-to-water ratio and reaction time. The most significant coal composition characteristic affecting this response is the available calcium carbonate content. Natural fine sizes of coal, which tend to be higher in mineral matter, are most reactive. The most reactive size fraction was minus 200 mesh, with the reaction decreasing as the particle size increased, although some reaction still occurred in sizes larger than 05 mesh. The neutralizing ability of coal increases as its concentra-
selected north of Cleafeld, Pennsylvania, employing water being discharged from abandoned deep mines. The plant will have a capacity between 500,000 and 1,000,000 gallons per day. The main concept of this study will be to develop a plant which will be highly versatile in terms of the basic unit operations involved, allowing extensive accumulation of data under variable operating conditions, including the variation in quality of the water, as well as variation in the flow over a year's period.

It is expected that the plant will be more highly instrumented than any plant proposed to date. The purpose will be primarily to collect data; however, it is considered that in practice instrumented plants will be highly desirable to provide adequate safeguards in maintaining the quality of the water discharged, as well as to minimize labor costs.

"Natural Treatment" The third study which has been developed is concerned with naturally-occurring, insitu processes of water management, such as mixing of several mine water streams, lagooning, aeration, control of stream flow by available elevation drop and flow through existing strata. It is conceived that combinations of such processes could be controlled to enhance iron mineral dropout and acidity reduction. Such a study is complex to design and carry out. The accumulation of significant data must of necessity be carried out over a long period of time. Our studies, which are modest, are of a preliminary nature. They were initiated in the field and have not been developed to the point where data could be accumulated more rapidly in the laboratory.

A detailed study was initiated in the New Liberty, Pennsylvania, area, where several streams of varying levels of pollution intersect prior to entering a larger stream which is called the Moshannon Creek. At various locations along these streams, flow measurements and water quality analyses have been carried out over a period of months and the data are being analyzed in an attempt to understand the naturally-occurring phenomena. These data show that both iron dropout and acidity reduction occur to a significant degree over relatively short distances and suggest that with proper control these natural occurrences could be enhanced. Potential impact of the preliminary data developed in these studies on the beneficiation of polluted waters, especially from abandoned mines, suggest encouragement for further, immediate and enhanced study. They have also posed a most intriguing technical question: in the laboratory or treatment plant air oxidation of ferrous iron proceeds very slowly in mine waters which are highly acidic; why then, do similar types of waters form heavy deposits of "yellowboy" in stream beds within relatively short distances after emerging from abandoned mines?

The concepts summarized in these paragraphs suggest that in the design and operation of treatment plants there are unexplained technological problems, and probably as these plants are constructed and begin operation many additional problems will develop, which at the present time are not anticipated.

Immediate and positive steps are to be taken to design and operate various types of treatment plants, especially in Pennsylvania, to meet the requirements of existing regulations. The magnitude of the problem that is facing the coal industry and water control agencies is still not fully realized, especially in terms of its economic and sociological implications.

Meeting of Ceramic Society Division

The full meeting of the Basic Science Division of the American Ceramic Society was held at University Park on October 23-25, 1966. The Basic Science Division was established some 15 years ago in order to provide an outlet for basic studies in the chemistry and physics of nonmetallic materials which did not fit into other divisions of the American Ceramic Society.

Dr. E. F. Osborn, vice president for research, and Professor F. A. Hummel, head of the department of ceramic science, were charter members of the division and partly responsible for its origin and subsequent growth.

Several members of the Penn State faculty were involved in the meeting, at which thirty-three scientific papers were presented on sintering, diffusion, recrystallization, crystal growth, microstructure, and mechanical properties of high-temperature nonmetallic materials. Professor Hummel is trustee of the Division and Dr. Rustum Roy of the Materials Research Laboratory is chairman-elect. Dr. Henry B. Kiechler, a graduate of the ceramic science department who is now affiliated with Linden Laboratories, presided as chairman.

Dr. Thomas F. Bates, on leave from his position as professor of mineralogy to serve as science advisor to the Secretary of the Interior, was the keynote speaker at the banquet held at the Nittany Lion Inn on Monday evening.

Other degrees supervised by E & MS faculty members:

Solid State Technology
JOSEPH FRANCIS BALASCIO, M.S.
Crystal Growth in High Pressure Liquid Ammonia

Geography
KATHRYN ANN GREGORY, M.Ed.
Faculty Attends Fall SME Meeting

Faculty members from three departments of the College presented papers at the fall meeting of the Society of Mining Engineers of A.I.M.E. in Tampa, Florida, from October 13 to 15. C. B. Manula, assistant professor of mining engineering, and Thomas J. O'Neil, development engineer with Ingersoll Rand Corp., presented a paper entitled "Computer Simulation of Materials Handling in Open-Pit Mining," which dealt primarily with a mathematical model to analyze truck haulage.

T. S. Spicer, professor of mineral preparation, and Charles G. Zink, vice president, Blue Coal Corporation, and an alumnus of the College, presented a paper on "The Industrial Uses of Anthracite." Mr. Zink was among the first group to receive degrees in mineral economics at this University. The paper called attention to the growing importance of industrial consumption to an industry which was once dominated by its domestic space heating market. Approximately half of the market for anthracite in this country is now in industrial power uses of diverse types, and it is also a natural source of carbon. Air pollution regulations should bring about renewed interest in this low sulphur, smokeless coal.

Three papers were presented by faculty and alumni in the session on "Economic Factors in Industrial Minerals." The session was of particular importance to the Department of Mineral Economics since three of the five speakers were present or former students of the department. Henry McCarl, who is completing work on his doctorate and is now with Vulcan Materials, discussed "Regional Economic Factors Influencing Consumption of Nonmetallic Mineral Construction Materials." His paper dealt largely with statistical methods for isolating significant variables. George Schenck, currently a doctoral candidate and instructor in mineral economics, talked about "New Dimensions in Overland Transportation," which covered recent improvements in rail, truck, pipeline, and conveyor movements. Alvin Kaufman, B. S. in mineral economics in 1950 and now with the U. S. Bureau of Mines, in his speech, "Population, Food, and Fertilizer," indicated that demand for fertilizer will rise rapidly enough to absorb most of the announced increases in production capacity.

Silver Anniversary Petroleum Meeting

The Twenty-fifth Technical Conference on Petroleum Production, coordinated by the department of petroleum and natural gas, was held at the J. Orvis Koller Conference Center on October 19-21, 1966.

At each meeting of this conference, which was first held in 1936, papers are presented which deal with both research and field studies on all phases of petroleum and natural gas production. In recent years strong emphasis has been placed on tertiary recovery methods.

Much of the research carried out at the University is directed toward the economic recovery of the Commonwealth's as yet unrecovered crude reserves. Industry has supported the research program since 1928 and this close association is an outstanding example of industry-university cooperation.

Those gathered at the Silver Anniversary dinner on Thursday, October 20, heard interesting aspects of the long history of this research association by J. P. ("Dick") Jones, President, Penn Grade Crude Oil Association, and Edward Steidle, Dean Emeritus of the College of Earth and Mineral Sciences. The principle dinner speaker was Chester H. Lauck, executive assistant to the Chairman of the Board of Continental Oil Company.

Mr. Lauck is an unusual combination of businessman and entertainer. Better known as "Lum" of the popular radio and movie team of "Lum and Abner," Mr. Lauck travels more than 130,000 miles annually for Conoco from coast to coast. Constantly on the "Conoco circuit," he has talked at countless business meetings and state and national conventions since joining the firm in 1955.

College News Notes

At the invitation of NATO, Larry Davis, instructor & research assistant in meteorology, participated in an Institute on the Dynamics of Clouds and Cloud Systems from July 3-9 at the Imperial College, London, England. Mr. Davis was also the associate director of an experimental weather modification program conducted in Flagstaff, Arizona, during July and August, 1966. The program was a cooperative effort which included several universities, institutes and private groups sponsored by the Bureau of Reclamation and National Science Foundation for the purpose of determining feasible methods of increasing summer rainfall.

W. Pariseau, assistant professor of mining engineering, and H. R. Hardy, Jr., assistant professor of mining engineering, attended the Eighth Symposium on Rock Mechanics on September 14-17 at the University of Minnesota, where Professor Hardy served as co-chairman of the session dealing with the brittleness of fracture rocks.

Reprints Available

Recent publications of the College of Earth & Mineral Sciences are listed below. Those desiring reprints should address their request to the senior author, 5, Mineral Industries Building, University Park, Pennsylvania, 16802.

Title and Author

Loadin and Transportation in Surface Mining. B. J. Kochanowsky and B. K. Singhal.


Reaction of Liquid Titanium with some Refractory Compounds. M. Garfinkle and H. M. Davis.

Environments of Marine Evaporite Deposition. R. F. Schmaltz.

Experimental Data for the System MgO-FeO-Fe2O3-CaSiO3-SiO2 and their Petrologic Implications. P. L. Roeder and E. F. Osborn.

Stability of Zircon in the Temperature Range 1180° to 1300°C. Erik Rosen and Arnulf Muan.


Formation of Gibbsite from Aging Hydroxy-Aluminum Solutions. Po Ho Hou.

Stability of MgAl2O4 at 1400°C as Derived from Equilibrium Measurements in CoAl2O4-MgAl2O4 Solid Solutions. E. Rosen and A. Muan.


Migrations and the Settlement of Mindanao. F. L. Wernstedt and P. D. Simkins.

Application of Statistical Technique in Power Study of Striping Shovels. A. Meekerjej and B. J. Kochanowsky.

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