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A STUDY OF ACID AND FERRUGINOUS MINE WATER
IN COAL MINING OPERATIONS

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ABSTRACT

The paper describes a bio-chemical investigation in the laboratory to identify various factors which promote the formation of acidic and ferruginous mine water. Biochemical reactions responsible for bacterial oxidation of Iron pyrites are described. The acidic and ferruginous mine water are not only responsible for the corrosion of mine plant and equipment and formation of scales in the delivery pipe range, but also pollution of the mine surface environment, thus affecting the surface ecology. Control measures to mitigate the adverse effects of acid mine discharge include the protection of mining equipment and prevention of formation of acid and ferruginous water. Various control measures discussed in the paper are blending with alkaline or spring water, use of neutralising agents and bactericides, and various types of seals for preventing water and air coming into contact with pyrites in caved mine workings.

INTRODUCTION

Interest in the contaminated drainage from mining activities stems from historical times. The ancient Romans are reputed to have recovered iron and copper sulphate from areas where natural leaching was taking place [1 & 2]. In 1919 Powell and Parr [3] implicated bacteria as agents partly responsible for pyrite oxidation in coal. This was confirmed in 1947 [4] by the isolation of *Thiobacillus thiooxidans* in acid drainage waters of a West Virginia coal mine, contributing to the formation of sulphuric acid.

The particular bacteria involved in current sulphide leaching operations in acid solution less than pH 2.0 are the species *Thiobacillus thiooxidans* and *Thiobacillus ferrooxidans* [5]. *T. thiooxidans* having the ability to derive energy from the oxidation of inorganic sulphur while *T. ferrooxidans* can utilise both ferrous iron and/or inorganic sulphur. Although certain types of heterotrophic organisms can also bring about

the oxidation of sulphur compounds, these are unimportant because they utilise an organic substrate.

In fact, the effluents from the bacterial leaching of commercial sulphides are used in several situations, as a commercial scavenging process for the treatment of low grade mine wastes, too low in mineral values to be treated by conventional mineral concentrating processes. The increasing interest in the role of bacteria in the leaching of sulphide minerals, has arisen primarily from the environmental aspect in preventing pollution from sulphur emissions associated with conventional smelting operations and provides an alternative hydro-metallurgical route for the treatment of commercial sulphide minerals.

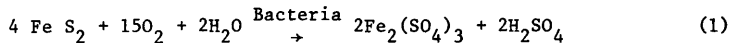
The detrimental presence of sulphur mainly in the form of finely disseminated pyrite has been traditionally recognised in the United Kingdom by the operation of a penalty clause agreement between the National Coal Board and the consumer. Sulphur is detrimental in coal as it contributes to the formation of acid and ferruginous mine water as well as giving rise to harmful air pollution and corrosion of boiler plant [6]. The increasing trend towards higher sulphur content of new reserves of coal, particularly coking coal coupled with increasing quantities of coal mining waste, (currently 66m tonnes/year) is the major source of solid waste. This poses the problem of natural leaching associated with coal mining activities.

BACTERIAL OXIDATION OF IRON PYRITE

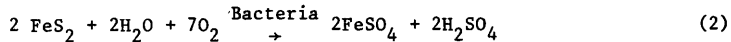
The study of the oxidation of pyrite in the presence of bacteria has been suggested to work by a 'direct' or 'indirect' mechanism [7]. The bacteria have also been implicated in an electro-chemical mechanism where an oxidise type enzyme increases the corrosive potential by catalysing a cathodic reaction at the mineral interface [6].

(i) Direct Mechanism

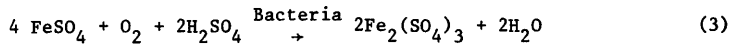
In the 'direct' mechanism the bacteria utilise the sulphur and/or ferrous ions or sulphide ions contained in the mineral for their energy source as expressed by equation (1).



Alternatively this reaction may proceed through two stages expressed by equations (2) and (3)



The ferrous iron produced being oxidised to the ferric state.



(ii) Indirect Mechanism

In the 'indirect' mechanism the ferric ions are considered to be the primary oxidant, oxidising the metal sulphide while in turn being reduced to the ferrous state. The bacteria oxidise the ferrous ions to the ferric state regenerating the primary solvent as expressed by equations (4) and (5).



Fig.1. 'Flyght' pump impellor after 10 days in acid water at pH 2.4.

(ii) Scaling

Experience with the use of asbestos cement and plastic pipes in acid mine water of pH 2.4 operating in a colliery working the Rhondda seam showed no effect of corrosion, beyond becoming coated with a reddish brown 'ochre' deposit. Fig.2 illustrates the iron encrustations formed on an asbestos cement pipe used for piping the acid water from a retaining barrier to the main sump reducing the effective diameter of the pipe from 175 mm to 75 mm in approximately one year and requiring expensive de-scaling operations.

(iii) River Pollution

Fig.3 illustrates the discharge of acid and ferruginous mine water from an old addit into the River Afan, S. Wales. It has been estimated that the amount of ferruginous water accounts for 8% (7% Alkaline pH 6.9 1.72 g/l sulphate and 1% Acid pH 2.9 1.25 g/l sulphate) of the total discharge in the United Kingdom from mining activities [12].

Although the acid mine drainage from an underground mine is exempt from treatment under the River and Pollution Acts [13] as it becomes neutralised, iron hydroxide precipitates out, causing discolouration and spoiling the inherent natural beauty of an unpolluted stream. The contamination caused by the precipitation of iron hydroxide is increased

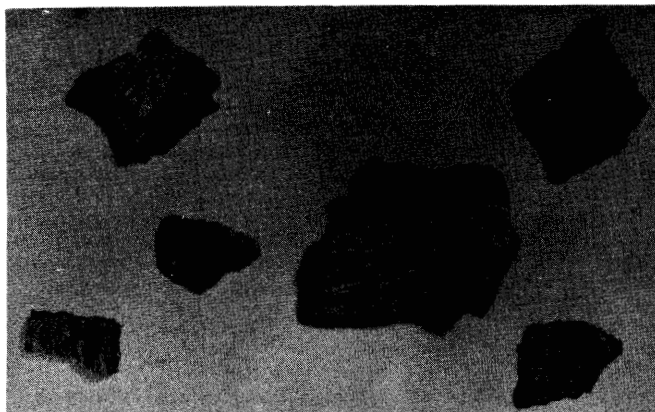


Fig.2. The thickness of iron encrustations formed on an asbestos cement pipe after pumping acid mine water



Fig.3. Drainage of acid and ferruginous mine water from an old addit Tonmawr, South Wales.

by the presence of neutral ferrous oxidising bacteria (*Crenothrix*, *heptothrix*, *Gallionella* etc.) which are large sheathed bacteria which oxidise ferrous salts and trap the precipitated iron hydroxide to form a slime blanket in the bed of a stream around the discharge point. This blanket of slime engulfs the plankton and micro-organisms forming the base of the food chain, consequently affecting the aquatic life of the river.

FACTORS INFLUENCING THE RATES OF PYRITE OXIDATION

As the workings in a mine which contain sufficient pyrite in the seams to form acid and ferruginous water are developed, the rate of discharge of effluent in the drainage will tend to increase. In the microbiological leaching of sulphide minerals, the bacteria utilise the dissolution products of sulphides as a substrate for providing energy for growth and cell functions as well as reproduction. The bio-chemical conditions for bacterial oxidation are more critical than for a mere chemical process, because the bacteria are living organisms and the micro-chemical environment is prerequisite to achieve optimum growth. The major factors influencing the biochemical environment and hence the production of undesirable effluent are briefly reviewed with reference to pyrite oxidation :-

(i) Control of air and of 'water make'

The micro-organisms involved in bacterial leaching are defined as aerobic, autotrophic bacteria and the presence, concentrations and mechanism of diffusion of oxygen and carbon dioxide are essential features in maintaining satisfactory leach rates. The oxygen supply serves as the ultimate electron acceptor in the oxidation process and the sole source of carbon for cell growth by the organism is obtained from the supply of carbon dioxide. In considering the importance of the diffusion of oxygen on leaching operations, it must be remembered that water saturated with oxygen at 20°C contains approximately 8 mg/l of oxygen. This is particularly important because in commercial dump leaching operation cyclic leaching processes are preferred over flooding technique, because oxygen transfer into aqueous solutions is limited by the surface area of the air-water interface [10].

(ii) Temperature - Radiation - pH

The optimum temperature for growth is within a temperature range of 30-35°C. However these bacteria are extremely versatile and have been reported to oxidise sulphides at temperatures as low as 4°C in Canada. A strain of thermophilic organism has also been developed which can function at temperatures up to 60°C [14]. Bacterial cultures are sensitive to ultra-violet light and exposure to this radiation will completely sterilise the bacteria, but they are not destroyed and are detrimental on electron transport and carbon dioxide fixation methods [15]. Bacterial leaching is currently carried out in acid solutions of pH < 3, this allows the metal cation to remain in solution and reduces the tendency of detrimental iron precipitation compounds to form. The bacteria have been reported to tolerate values of pH as low as 0.9 in the case of pyrite. Values of pH below 1.2 have suggested to be detrimental on the activity of the bacteria and resulting in elongation of the cell membrane [16].

(iii) Nutrient Requirement

The *Thiobacilli* used in leaching operations utilise an inorganic substrate to provide energy and in common with most living organisms require trace amounts of specific nutrients to enable the micro-organism to synthesis these compounds into cellule constituents. It is essential that these nutrients are available in the micro-environment to allow the cells to function properly and include :- nitrogen, sulphur, phosphorus, metallic elements and vitamins. In natural bacterial leaching operations most of the inorganic salts required for bacterial metabolism are associated with the sulphide minerals as contaminants and hence it may eliminate the necessity of supplementing the ore with added inorganic salts.

The ammonia-nitrogen and phosphate salts are found in practise to be the most critical [10]. Fig.4. illustrates the effect of varying potassium hydrogen orthophosphate from 0 to 3 g/l (normal '9k' medium after Silverman and Lundgren [17] contains 500 mg/l K_2HPO_4 for leaching

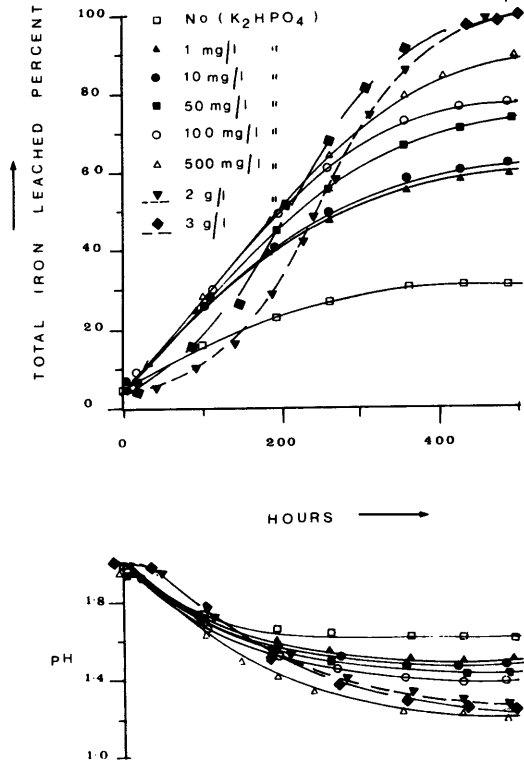


Fig.4. The effect of various additions of di-Potassium Hydrogen Orthophosphate (K_2HPO_4) on the bacterial leaching of pyrite. Pulp density 2%, temperature 35°C, Initial pH 2.0.

studies on ore concentrates). The result of the tests demonstrates that increasing the phosphate content by additives of K_2HPO_4 may be in some cases essential to achieve complete bacterial pyrite oxidation. It is unlikely that the bacteria would require an increase from 0.5 to 2.0 g/l K_2HPO_4 for the metabolic function of the cell and thus the phosphate may act as a buffering agent on the pH which may control the rate of iron extraction. Experimental studies on the oxidation of a sample of coal from the Amman Rider seam containing 5.61% pyrite indicated that sufficient inorganic nutrients are present as impurities in the coal matrix and for this particular coal sample additions of nutrients are unnecessary [10]. This has also been confirmed during the enhanced bacterial activity in a uranium mine that sufficient trace amounts of nutrients were present in the host rock.

(iv) Particle Size

This aspect is of particular importance in practical leaching situations, as the degree and limits of size distribution of pyrite in coal measures have considerable implication on the amount of acid mine waters produced. Many investigators studying bacterial leaching of sulphide minerals have demonstrated that in common with most heterogeneous chemical reactions that decreasing the particle size, which effectively increases the surface area results in a higher metal extraction, until some other factor becomes limiting [16].

To demonstrate the effect and limits of relatively coarse particles on the bacterial leaching of pyrite, the following size fractions were prepared by making synthetic mixtures from both a minus 300 mesh B.S. (- 53 μ m) screened undersize and oversize fractions, the composition of these mixtures are given in Table 1.

Table 1
Synthetic Size Fractions

| Size Fraction No. | Percentage minus 53 micron | Percentage plus 53 micron |
|-------------------|----------------------------|---------------------------|
| 1 | 100 | 0 |
| 2 | 75 | 25 |
| 3 | 50 | 50 |
| 4 | 25 | 75 |
| 5 | 12.5 | 87.5 |
| 6 | 0 | 100 |

Figs.5 and 6 illustrate the metal release obtained from these size fractions (tests being performed at 6% (w/v)) together with the corresponding bacterial growth result in μ g Nitrogen/ml for the respective experiments. The graphs clearly indicate that the presence of more than 25 percent of coarse particles at this pulp density have a pronounced detrimental effect on the leaching of pyrite. The nitrogen data from Fig.6 substantiates this fact and indicates that the presence of relatively large particles in the suspension produces degradation of the bacterial cell thus inhibiting the bacterial oxidation of pyrite. A similar series of tests were performed on the same size fractions

reducing the pulp density to 2% (w/v). In this case the respective size fractions were leached to completion and demonstrated that decreasing the pulp density from 6% to 2% (w/v) reduces the attrition of the bacterial culture. The result also demonstrates that particles ranging from 0 to 105 microns can be leached to completion providing the effect of bacterial attrition can be eliminated.

The results of the experiments varying particle size and also surface area per unit weight demonstrates that the oxidation of pyrite in the presence of bacteria, as measured by metal extraction, is related to surface area. The results clearly demonstrate however that the presence of relatively coarse particles are detrimental to bacterial growth in agitated systems. This however can be minimised by controlling the amount of coarse particles present in the sample to be leached and/or regulating the solid to liquid concentration [10]. In a static leaching system, such as a caved waste and/or mine waste dump containing pyrite, particle size is not important and it can be increased for leaching purposes. However, the leach rate would be considerably reduced because

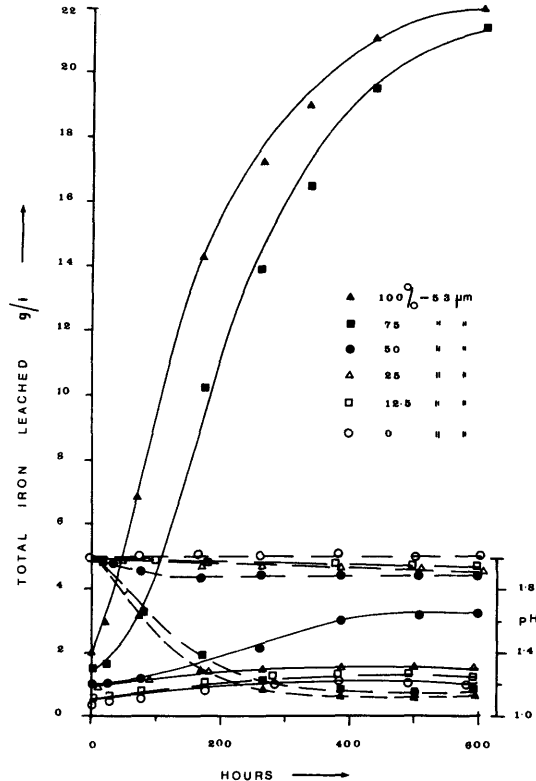


Fig.5. Bacterial leach tests performed on synthetic mixtures of Tharsis pyrite.
Pulp density 6%, temperature 35°C, initial pH 2.0.

of the decrease in surface area. The oxidation of pyrite will also be affected by weathering and strata collapse causing further increased exposure of pyrite in worked out areas and this will be influenced by the type of mining that is practised.

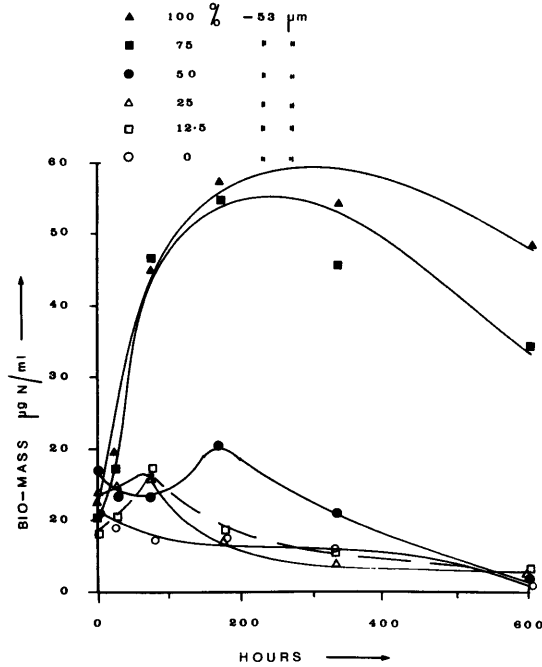


Fig.6. The bio-mass present during the leaching of synthetic mixtures of Tharsis pyrite at 6% pulp density.

(v) Mineralogical Factors

Many investigators involved in bacterial sulphide oxidation has observed that different specimens of normally the same mineral can react at appreciably different rates under the same conditions and this can be attributed to variations in mineralogy.

The gangue material associated with sulphide minerals can also influence bacterial leaching rates, particularly the presence of acid consumable material [6].

(vi) Precipitation Complexes

In commercial leaching processes a balance has to be found between the acid concentration to enable the metal cation to remain in solution and the optimum pH value to ensure that bacterial metabolism can proceed. Another important function of maintaining a low pH (> 3.0 pH) is to minimise the tendency of iron to precipitate and form compounds which

can, under favourable bio-chemical conditions, crystallise to form jarosite complexes [10]. These jarosite complexes ($K Fe_3(SO_4)_2(OH)_6$) have been implicated in preventing the complete leaching of various sulphide substrates. However, an experimental study on the oxidation of pyrite samples from different geological origins have shown conclusively that pyrite can be leached to completion in the presence of bacteria providing the pH was maintained in the pH range of 2.0 to 1.0. This result demonstrates that previous speculation on the formation of a protective reaction layer on the surface of sulphide particles which accounted for their incomplete oxidation (or toxicity of metal in solution) is invalid for iron pyrite [18].

CELL DEGRADATION AND ADAPTABILITY OF THE MICRO-ORGANISM ON SULPHIDE LEACHING

The actual role that bacteria play in the improved oxidation rate of pyrite is very difficult to elucidate. Fig.7 illustrates the effect of a leach test performed on a typical Tharsis pyrite at 6% (w/v) using inocula of bacterial cell fractions produced by disrupting the cells in a Hughes press to produce the following cell fractions :-

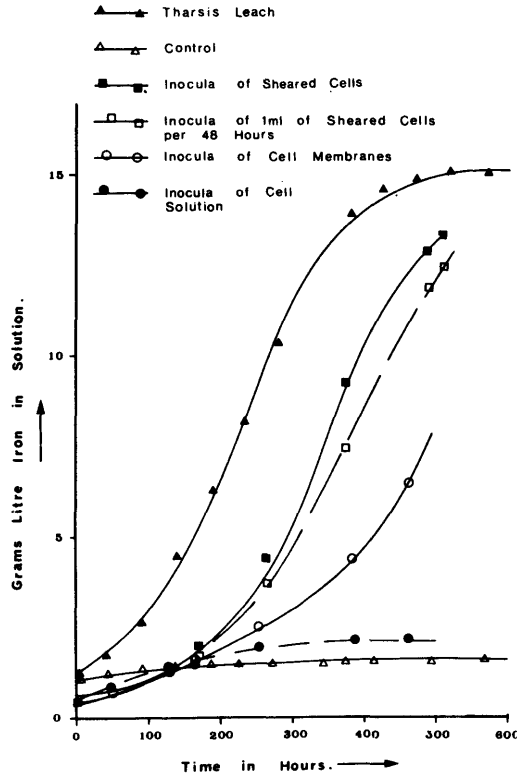


Fig.7. The effect of inocula of degraded cells in the leaching of Tharsis Pyrite. Pulp density 6%, temperature 35°C, Initial pH 2.0.

- (a) An inoculum of sheared cells (including all membrane and cell contents).
- (b) An inoculum of sheared cells filtered to remove cell membranes.
- (c) An inoculum of cell membranes filtered to remove cell contents.

The graph illustrates the effect of adding the various aliquots of sheared cells to the leach flask, together with another flask in which 1.0 ml of sheared cells was added every 48 hours. The graph also indicates that leaching took place in all flasks except the one containing only the cell contents. This emphasises that the inter cellular enzymes contained in the cell do not leach solely as an enzyme solution in the absence of the living cell or cell membrane. The rate of leaching in the flask is a function dependant on the survival rate of the bacterial cell, as the method of degradation has only a 60-70% death rate. Consequently the flask containing the most cell membranes would therefore produce the highest leach rate because of the larger percentage of living cells present.

Fig.8 indicates a '9k' Tharsis control (uninoculated flask) at 6% (w/v) which became contaminated (although care is taken to prevent contamination, particularly in the use of pH electrode). The '9k' leach curve indicates that only a contamination of the flask, presumably by a pH electrode was sufficient to inoculate the flask. The leach result was higher in this flask than the inoculated corresponding leach flask, and emphasises the adaptability of these micro-organisms to propagate in the right bio-chemical environment immaterial of the initial cell numbers. Experimental studies on the bacterial oxidation of pyrite on the importance of cell numbers also showed that varying the initial cell concentration from 1×10^5 cells to 1×10^{10} cells per ml per 1% (w/v) pulp density indicated similar metal release with only a difference in the lag phase of the typical logarithmic leach curves [18]. This confirms that varying the initial cell concentration by a factor of 10,000 produced very little difference in the leaching results obtained, emphasising that the bacteria will soon propagate providing the bio-chemical conditions are satisfied. Fig.8 also indicates the leach curve of Tharsis sample at 6% (w/v) using a leach liquor filtered to remove bacteria obtained from a leaching experiment using Sphalerite (ZnS) as a substrate.

The presence of the zinc concentrate in solution increases the chemical leach rate and indicates the presence of metals other than iron in solution may be an important parameter in influencing the leach rate.

BASIS FOR DESIGNING CONTROL MEASURES

- (1) The main factors which effect the kinetics of pyrite oxidation in the presence of bacteria have been outlined and are more critical than for a mere chemical process. In order to control the formation of acid mine water, priority must be given to measures that inhibit bacterial metabolism.
- (2) Experimentation on various sheared cells as inocula for bacterial pyrite oxidation revealed that the leach rate was a function of the degradation rate. This indicates that inter cellular enzymes contained in the cell do not leach solely as an enzyme solution in the absence of

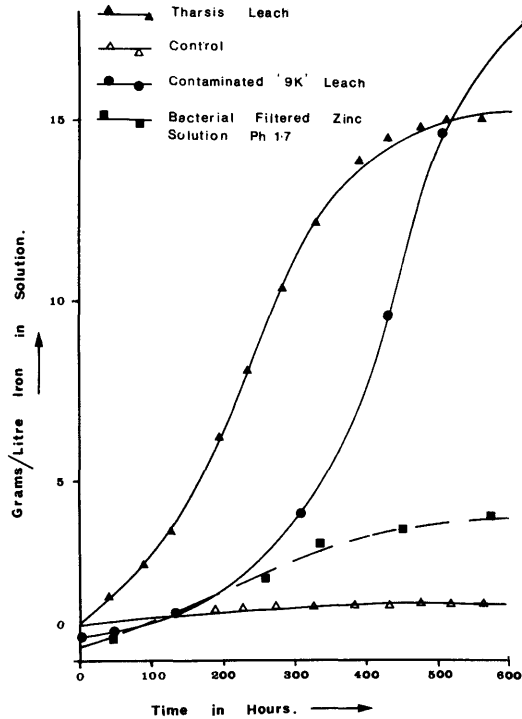


Fig.8. The effect of bacterial contamination and zinc leach solution in bacterial oxidation of Tharsis pyrite. Pulp density 6%, temperature 35°C, Initial pH 2.0.

the living cell or cell membrane. It has also been shown that the presence of trace elements such as zinc in solution may be beneficial to the oxidation of pyrite.

(3) Varying the initial cell concentration by a factor of 10,000 during the bacterial leaching of pyrite produced very little difference in the metal release and in fact in a flask which became contaminated produced comparable leach results with a longer lag time. This emphasises that once the right bio-chemical environment is established propagation of the micro-organism will be difficult to control.

(4) The other important factors which must be controlled are the presence of air and water, which in mining situations are inherent features, consequently difficult to control.

CONTROL MEASURES FOR ACID AND FERRUGINOUS MINE WATER

(i) Protection of Mining Equipment

Although various methods are available to protect conventional steel pumping equipment by the use of alternative materials, or methods of protection, such as, stainless steel, plastic, fibre glass, asbestos

cement and bitumen coating etc. This results in an increase of capital cost and maintenance of pumping equipment because of the restrictions on application of certain alternative materials with regard to pipe design (depth of mine).

These restrictions would apply to the use of non-metallic piping equipment because of problems of static electricity and flammability and would require special exemption. Also these materials would be limited in working pressure and consequently would restrict their application at certain working depths. Stainless steel could be used but in certain situations (long outbyes), costs would be prohibitive. Other measures would include the coating of pipes with bitumen. However, in practice unless a continuous and uniform coating of bitumen is achieved the corrosive water would penetrate behind the coating, particularly at the joints making protection measures ineffective.

From experience of pumps operating in acid water (pH 2.9) a conventional turbine pump was redesigned by the manufactures using stainless steel for the following parts :-

- (a) Casing, end covers, impellers, shaft; - 18/8 stainless steel.
- (b) Wearing parts i.e. neck rings, bushes, balance values; - 2/20 stainless steel.

Although comparable life spans of pumps are difficult to predict, from experience the average service life of the pump was increased from 2 months to 3 years by using stainless steel with a comparable increase in cost of approximately 500% [19].

The corrosive effect of acid water is not limited only to pumping equipment but extends to any metallic object, particularly rope haulages and track. The range of problems encountered are the reduced life span of ropes to catastrophic failure of ropes resulting in runaway trains.

(ii) Control Measures for Acid Mine Drainage

Primarily the type of techniques that would be applicable to specific mining situation will depend whether a mine is working or abandoned, with regard to the control of mine effluent discharge.

(a) Sump blending, mine design and flooding techniques

A practical method which has been used in mining situations when acid mine drainage from worked out parts of the mine was blended with alkaline water from current working districts (that is, not yet effected by the oxidation of pyrite) at specially designed sumps. Fig.9 illustrates the sump used for blending purposes and the design allows the precipitation of iron sludge. In this case water from worked out districts at pH 2.7 and pH 2.8 were blended with water at pH 7.9 from present working faces together with surface drainage water at pH 8.1 from the drift sump, before being pumped to the surface for discharge in a fibre glass pipe [19].

The advantages of blending the contaminated mine water are as follows :-

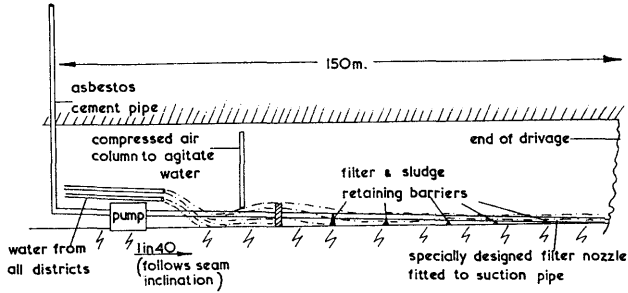


Fig.9..Sump system design for blending purposes - section view.

- o Increasing the pH and thereby reducing the corrosive effect of the water on pipe columns and pumps
- o Reduces the amount of iron encrustations in the pumping equipment by allowing some precipitation in the sump and reducing the maintenance cost from descaling operations
- o Reduces the amount of iron salts discharged into water courses.

Where seams are dipping then the mine design should be adopted to maximise this factor by driving all roadways to the rise and enabling longwall retreat to be practised up dip. This allows the goaf containing pyrite in the collapsed waste to be flooded and set up a sump for the following reasons :-

- o Enabling the goaf to act as a natural sump for blending and precipitation of iron salts.
- o Although pumping from a mine is operated principally for safety reasons to enable production to commence, unless the mine can be kept as dry as possible by continuous pumping then experience from dump leaching operation would be to allow the waste to flood as a control measure [10]. This minimises the problem of an inundation from the mine water "make".

(b) Spring water and well pumping systems

This technique could be applied particularly, in the case of an aquifer supplying domestic water contaminated by water from an overlying abandoned flooded mining complex containing acid mine water with high concentration of heavy metals. The system would necessitate the collection of acid mine water from the discharge of springs together with an integrated well pumping system into the mine workings. The collected water would then be treated by a lime neutralisation precipitation plant. A proposed system for the control of 87 l/sec of mine effluent from an abandoned lead zinc complex of Picher District, Oklahoma covering 186 km² using the above technique has been estimated to cost \$3.7 million for construction and \$0.56 million/year for operation and maintenance [20].

(c) Neutralising agents

The most effective methods for the treatment of acid mine drainage is to

neutralise the effluent with alkali reagents, the most common types being :- limestone, lime, magnesia, ammonia, sodium carbonate and sodium hydroxide. The most practical options are the use of lime or limestone and have been used in several commercial situations. The other alkaline reagents will neutralise but if they contain sodium, potassium or ammonia, which are costly and yield salts which are also pollutants. Ammonia and potassium agents would further be unacceptable because of their fertilising properties, and would result in vegetation growth clogging up settling lagoons and culverts used in this process [19,21].

The principle purpose of the neutralising plant for the treatment of acid waters are to perform the following requirements :-

- o Raise the pH value of the mine drainage to between 6 to 9 in order to neutralise and also precipitate metal ions
- o To produce a mine discharge to comply with statutory legislation with regard to pH, heavy metal concentration and suspended solids etc.
- o To produce a precipitate with reasonable sedimentation and dewatering properties and which could be disposed of at reasonable cost.

Table 2 summarises the most cost effective methods together with their merits.

Table 2
Cost Effective Methods of Acid Mine Drainage Control

| Neutralising agent | Method | Merits |
|--|--|---|
| Lime (CaO) - more effective when slaked with water to form hydrated lime Ca(OH) ₂ | Either added dry or in liquid form to mine discharge in agitated, aerated mixer to form iron colloidal sediment. Dewatered by thickener or settling lagoons. | <ul style="list-style-type: none"> o Cost (factor of 5 greater than limestone) o More effective for lower pH values containing ferrous iron o Compaction and disposal of sludge can cause problems o Gypsum scale on plant equipment |
| Limestone CaCO ₃ | Similar to above method, however requires additional oxidation to complete neutralisation process | <ul style="list-style-type: none"> o Cheap. Limestone chips tend to coat with ferric hydroxide and calcium sulphate o Abrasion problems with pipe columns from slurry mixes o Longer retention and reactivity time o Satisfactory for weak acid water containing mostly ferric iron o Less sludge and compacts more easily |
| Combined limestone/ lime method | Combination of above | <ul style="list-style-type: none"> o Initial equipment construction cost high o Less sludge produced o Retention time decreased |

(d) Bactericides

The application of stone dust using limestone and gypsum etc. primarily to comply with the prevention of coal dust explosion will also help to neutralise any flows of acid mine drainage. Bactericides (such as mercuric chloride, phenol, dioxin and antibiotic etc.) could also be incorporated into the stone dust and/or pump packs now used for roadway stability as a method of abatement [6,10]. The use of bactericides in laboratory experiments for sterile controls have been shown to be successful although, in certain circumstances bacterial adaptation may take place. Information of their use in practical application is limited [10].

The use of an anionic surfactant of sodium lauryl sulphate incorporated into rubber pellets have been tried successfully in small field tests and have been reported to give a 50 to 95% reduction in acidity in waste tip operations [22,23,24]. The principle of the pellet is to release surfactants into infiltrating rainwater to inhibit the bacterial activity until the waste dumps or surface mine sites can be restored by land reclamation and vegetation. The technique of rubber pellets however, is dependant on the permeability of the overburden in abatement.

The use of similar pellets either incorporated with surfactants or bactericides could also be incorporated in the drainage channels in underground mining situations and may be an encouraging method particularly with regard to the reduction of the corrosive effect on pumping equipment.

(e) Seals

(i) Pneumatic seals

The principle is to restrict the movement of the ventilation into abandoned workings. The seals can be constructed from rendered brick, masonry, concrete blocks and grouted aggregate seals. Provision should be made for the flow of water through an air trap if the seal cannot withstand hydraulic pressure. The ventilation system in some mines prevents the use of pneumatic seals because working parts of the mine are only accessible from abandoned working. Although, where possible, pneumatic seals (primarily used to prevent leakages which can be as high as 50%) should be constructed for abatement purposes for the control of oxygen.

(ii) Hydraulic seals

The procedure would be to seal off areas of active decomposition of pyrite in worked out areas by the construction of seals at the exit of these districts. The design and position of the seals should assure sufficient strength in the bed rock and the seal itself to withstand water and ground pressure. It may be necessary to grout or rock bolt the bulkheads to assure stability and to prevent leaking. The seals can be constructed of compacted clay, masonry walls, brick, concrete blocks, monolithic concrete and grout curtain (that is, to grout overlying permeable strata to prevent inflow of water from the strata into mine workings) and some of the types are illustrated in Fig.10 [19, 25]. In the case of where concrete is used in the construction, then the cement should be sulphate resistant.

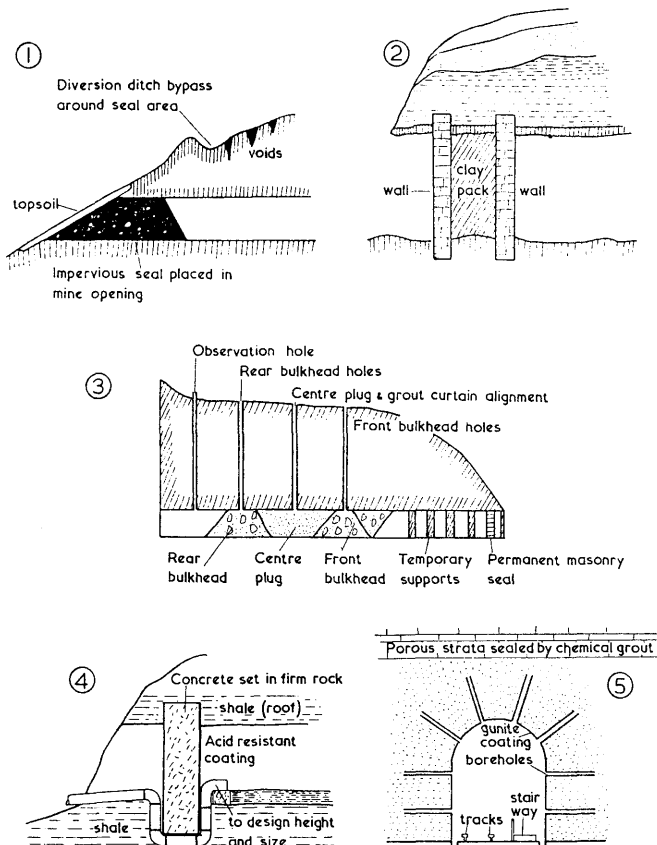


Fig.10. A selection of hydraulic seals.

1. Clay plug seal
2. Double wall, clay pack seal
3. Double bulkhead seal
4. Concrete seal with controlled flow
5. Grout 'curtain' seal

Although considerable technical difficulties would be encountered in the construction of these seals, the precise location of these seals would depend on two factors; legal responsibilities with regard to preventing an inundation and contamination of present working districts.

It is therefore unlikely that hydraulic sealing will provide an attractive solution in working mines, but would be more suitable to abandoned mining situations.

Miscellaneous Techniques

(i) Freezing - The process involves the partial freezing of acid mine water, thus concentrating the impurities in the unfrozen water. The method involves filtration of suspended solids (to prevent contamination of ice) freezing and separation of unfrozen water containing impurities and melting ice to produce purified water, resulting in an impurity reduction of 85 to 90% [19]. The major disadvantage is the cost of freezing mine water in relation to quantities drained.

(ii) Reverse Osmosis - This technique will involve concentrating dilute discharge of acid mine waters by diffusion through a semi-permeable membrane. The merits of the system is that providing there is a pressure differential it requires no pumping and consequently no power requirements. However membrane life would depend on the amount of totally dissolved solid removed. The disadvantages would be the cost of treatment of water particularly as in some cases some mines pump in excess of 5 million litres per day.

Various other techniques such as carbon absorption method, ion exchange, electrodialysis and ozonation have been evaluated for technical feasibility, but at present these techniques are not considered to be commercially viable.

CONCLUSIONS

Probably the most effective method of controlling acid mine formation in the future from proposed and existing mines will be accomplished by improvements in mine design. These measures should be aimed primarily at air and water ingress into the mine (however, ventilation is an inherent feature of mining activities) together with bacterial inhibitors. Depending on the seam formation (that is, geological strata formation, dip etc.) these may take the following form or combinations :-

(i) The increasing use of pump packing techniques for longwall systems primarily for strata control will also restrict air and water ingress by its inherent sealing properties and also the pack material could be incorporated with bactericides.

(ii) Design of mine layouts to allow all districts to work to the rise giving gravitational drainage into the goaf which acts as precipitation lagoon and sump.

(iii) Use of impregnated pellets containing bactericides and deposited in the goaf and/or drainage channels.

(iv) Use of dewatering system using pumped walls or grout curtains to minimise water make into the mine.

(v) Effective sealing on completion of mining activities.

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