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MANAGEMENT OF ACID MINE DRAINAGE (AMD) IN INDIAN COAL MINES

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ABSTRACT

Mining practices, present and past, contribute towards environmental degradation affecting the ecosystems and human health. The unscientific coal mining in the tertiary North Eastern Region (NER) Indian coal mines poses a serious threat to the environment. Dumping of waste rocks including mine rejects generated during mining adds to the problem by aqueous weathering and discharge of acidic effluents.

The coal mining in Meghalaya causes large-scale destruction and degradation of the environment. Coal extraction in the state is done by primitive sub-surface mining methods commonly known as 'rat hole' mining. The indiscriminate and unscientific mining, absence of post mining treatment and management of mined areas are making the fragile ecosystems more vulnerable to environmental degradation and leading to land use changes. The main problems in Meghalaya are the production of Acid Mine Drainage (AMD) in nearby areas by continuous leaching of acidic waste from the coal mining sectors. An Environmental Management Plan (EMP), has been developed for management of AMD in high sulphur coalmines by simulation of AMD from weathered coals and mine rejects. Sequential alkalinity producing (SAP) coupled with biological processes found effective in controlling AMD and reducing TDS, Conductivity, SO_4 and toxic elements. In this paper, the state of art for AMD and the processes suitable for the management of AMD are discussed.

Keywords: *AMD, EMP, Acid generating processes, State of Art for AMD.*

INTRODUCTION

Coal and metal mining disturb large volumes of geological materials and are exposed to the environment. The exposure to air and water, the sulfide minerals commonly associated with coals and metal deposits are oxidized and hydrolyzed resulting in Acid Mine Drainage (AMD) formation. AMD is a low pH, sulphate rich water with high amounts of acidity. The acidity is comprised of mineral acidity (Fe, Al, Mn and other metals depending upon the geological deposit) and also hydrogen ion concentrations. The pyrites present in coal and overburden (OB) materials are leached to form low pH drainage water originating largely due to metabolic activity of *Thiobacillus ferooxidans*. These microbes are acidophillic and capable of surviving in low pH and catalyze the pyrite oxidation. It obtains its energy by the oxidation of either iron or sulphur. Chemical or biological pyrite oxidation by molecular oxygen or Fe (III) ions is described by the following reactions:

The commonly accepted reactions are:

$$2FeS_2+7O_2+2H_2O \rightarrow 2Fe^{+2} +4SO_4^{-2} +4H^+ \quad \ldots (1)$$

$$4Fe^{+2} +O_2 + 4H^+ \rightarrow 4Fe^{+3} + 2\ H_20 \quad \ldots (2)$$

$$4Fe^{+3} +12\ H_2O \rightarrow 4Fe(OH)_3 + 12\ H^+ \quad \ldots (3)$$

$$FeS_2 + I4Fe^{+3} + 8H_2O \rightarrow 15\ Fe^{+2} + 2SO_4^{-2} +16\ H^+ \quad \ldots (4)$$

Oxidation of pyrites (FeS_2) and the factors affecting its rate have been studied extensively because of their importance in environmental quality and mineral recovery. This oxidation resulting in formation of AMD, is a significant environmental hazard, faced by large numbers of coal mining industries all over the world. The acid mine water readily flows into the surface water bodies lowering the pH of water and affects the aquatic lives. A reduction of pH has the potential to mobilize the release of potentially hazardous elements such as Pb, Cd, Hg, Fe, Cu, Zn, Ni, Co, etc, and essentially be removed from the water system to sediment making them bio available. The cumulative effects of such effluent discharge pose an instant threat to the biota and ecological balance. Acidic drainage has been recognized as a worldwide environmental liability for the mining industries. Therefore, recognition of the problem around the world has led to several R & D programmes. A substantial deposit of high sulphur sub-bituminous coals, mostly of tertiary origin is existent in Northeast (NE) India. The problem has also been well felt by these coal mining industries where no adequate measures are taken for its management. Some of the AMD affected sites in the state of Meghalaya are the coalmines found in Bapung, Sutunga, Lumshunong, Mondiati, Jarain, Cherrapunji, Lyngkyrdem, Laitrengew etc where coal extraction is carried out.

The mechanism of formation of AMD in NER coal mines

In the initial step, the reaction of pyrite with water takes place to produce ferrous sulphate acidity. Subsequently, the second step involves conversion of ferrous to ferric iron. The third step involves hydrolysis of Fe^{+3} iron with water to form the solid ferric hydroxide (ferrihydrite) and the release of acidity. The third reaction is pH dependent. Under acidic conditions of less than about pH 3.5, the solid mineral does not form and ferric iron remains in solution. At higher pH values, a precipitate forms. The fourth step involves oxidation of additional pyrite by ferric iron. The ferric iron is generated by the initial oxidation reactions in steps 1 and 2. This cyclic propagation of acid generation takes place very rapidly and continues until the supply of ferric iron in pyrite is exhausted. Oxygen is not required for the fourth reaction to occur. The overall pyrite reaction series is among the most acid producing of all weathering processes. Degradation of water quality in surface and ground waters in contact with acid producing mine tailings / piles is the major environmental problem associated with AMD. The pH of water is lowered due to introduction of sulphuric acid as a result of mineral weathering. Depending upon the composition of the mine overburden, the pollutants released into surface and ground waters can typically include the heavy metal ions, viz. iron, zinc, aluminium, manganese, cobalt, nickel, copper, arsenic, selenium, cadmium and lead. Acidic drainage from age-old abandoned and active coal mines, liquid run offs from the overburden and stockpiles of coal cause environmental degradation. The acid drainage has a devastating impact on people's life and economy. The impact in some localities is so severe that it threatens the very existence of plant and animal life. The pollutants from the coalmines have destroyed the quality of soil. The soil in these coal-bearing areas is highly acidic (pH often found as low as 2.42 in the dumping sites and 2.56 in nearby paddy fields) and is unsuitable for cultivation. Thus the agriculture productivity, the main source of rural economy in the areas nearby the mining sites, is dwindling year by year and the people are gradually giving up such activity. Apart from lowering of agricultural output, the mining has also caused acute scarcity of animal fodder.

As such, it is imperatively desirable to understand or to take short or long term systematic studies on the nature and effects of natural run off from the coal mines and coal-based industries. A systematic study on its genesis, monitoring of water quality and development of technology to control AMD, will have a bearing on the economy, agriculture, plant, animal and aquatic lives and the associated environment around.

Sub-bituminous Indian coals of Tertiary age are prone to acid mine drainage formation.[1–4] These coals have different characteristics in comparison to other Indian coals. The characteristics of these coals are of low ash and high S content. The mining of these coals generate a large volume of reject materials. The rejects and coals dumped near the pit opening are exposed to the environment. Pyrite present in these materials is oxidized and hydrolyzed resulting in the formation of acid mine drainage, acidic, sulfate–rich drainage water. The continuous leaching of mine wastes and aqueous discharge from the mining sites in the state of Meghalaya is a major environmental concern.

The AMD problem in these Indian coal mines has not been adequately studied so far, however some studies report the occurrence of the problem in north-east Indian coal mines.[1–3, 5–7] For effective site specific management of the AMD and the associated release of toxic elements, laboratory simulation studies for coals and mine rejects are essential. The leaching studies leading to low pH effluents reveal information on weathering rates, and values of acid production and aqueous leaching of metals. The present investigation reports characterization of Meghalaya coals and simulation in the scaled up units and subsequent treatment options for acidic effluents generated. The study will help in formulation of a site specific management action plan for the high sulphur coal mines in India.

Prevention/mitigation of AMD

Research on acid prevention and mitigation has been focused on three main areas:

1. Chemical inhibition of acid generating reactions
2. Inhibition of microbial activity in catalyzing formation of acid,
3. Physical or geotechnical treatments to minimize water contact and leaching.

Chemical methods

Alkaline Addition

A highly alkaline environment can be created by employing trenches loaded with alkaline material, usually a combination of soluble sodium carbonate and crushed limestone.

Alkaline Agents

The benefits of adding lime and other alkaline agents have long been recognized in mitigating acid drainage. However, the complex chemistry of spoil materials has given varying levels of effectiveness in alkaline addition studies. Direct mixing and contact with pyritic materials appears most effective but an optimum lime to pyrite ratio remains unknown.

Phosphate

The application of rock phosphate is another technique under study as a pyrite oxidation inhibitor[8–9] by which iron will combine with phosphates to form insoluble iron phosphate compounds and inhibits Fe+2 oxidation thereby effectively reducing acid generation.

Coatings and sealants

Other research activities are focussed on the surface chemistry of pyrite and development of various types of sealers, coatings and inhibitors to halt acid production.

Biological agents/bactericides

The catalytic role of bacteria in pyrite oxidation may be inhibited by application of many compounds like bactericides and the anionic surfactants. Sodium lauryl sulfate and alkyl benzene sulfonate are considered to be the most reliable inhibitors. Bactericides are generally water soluble and will leach from the spoil; however, the time required for leaching of bactericides is uncertain. It is also unclear whether the sulfur and iron oxidizing bacteria will repopulate the spoil and catalyze the acid-producing reactions when the bactericide is depleted.

Physical or geochemical treatments

Controlled placement

Controlled placement (special handling) is a preventative measure involving the placement of pyritic or alkaline material during mining to minimize or neutralize the formation of AMD. Placement of pyritic material encompasses either an attempt to exclude oxygen, usually by complete submergence below the water table; or an attempt to isolate the material from water contact to avoid leaching of acid salts. Placement of alkaline materials has a twofold role, they are

1. Inhibition of the acid-forming reactions by maintaining neutral to alkaline pH; and
2. Neutralization of any acid formed.

Submergence

Submergence relies on several physico-chemical phenomena for success. Oxygen diffuses very slowly and has limited solubility in water. For this approach to succeed, a stagnant or no flow condition and relatively thick saturated zone appears critical. Stagnant flow conditions leading to the development of anoxic (oxygen free) conditions and a saturated thickness on the order of several tens of feet appear to effectively curtail oxygen diffusion. This approach is most successful in large mines in flat terrain where ground-water gradients are low, the saturated zone is thick, and aquifers are of large areal extent. Hammack and Watzlaf[10] concluded that a water cover to maintain oxygen below a partial pressure of one percent is necessary to inhibit pyrite oxidation.

Submergence or flooding is also applied to prevent AMD from underground mines. Key considerations include:

- Whether the mine is located above or below drainage.
- The ability of mine seals and outcrop barriers to prevent seepage.
- Potential for mine seals and outcrop barriers to fail under hydraulic pressure.

In general, flooding to prevent AMD is believed to be more successful in below drainage mines. It is assumed that complete flooding eliminates oxygen and halts or severely curtails acid generation, the mine pool is stable and little or no discharge occurs.

Isolation above the water table

Placement of pyritic material above a water table is an attempt to isolate the material from contact with water, and preclude leaching of acid weathering products. Compaction and capping with clay or other materials may also be employed to reduce permeability. In practice, it has proven very difficult to completely isolate spoil materials from water contact; however, the clay caps and other flow barriers are prone to leakage and damage.

Encapsulation/physical barriers

Techniques to isolate or encapsulate pyritic material include the use of fly-ash, cements, bentonite, and other clays; these are a few of the materials studied as sealants and flow barriers by Skousen and others.[11] Successful application of these methods in the field is heavily dependent on good engineering and construction practices and site conditions. Other investigations have attempted borehole injection to isolate buried pyritic material.

Water management

Water management strategies both during and after mining are another option for reducing acid generation, which can be achieved by

- Diversions of surface drainage away from pyritic material or through alkaline material.
- Rough grading of mine rejects to prevent ponding and subsequent infiltration.
- Prompt removal of pit water can lessen the amount and severity of acid generated.
- Isolation of acidic water from non-contaminated sources to reduce the quantity of water requiring treatment.
- Construction of drainage systems to route water away from contact with acid forming material.

Special handling (controlled placement), alkaline placement and water management strategies alone or in combination can substantially reduce or mitigate generation of acid drainage. Optimal strategies are site-specific and a function of geology, topography, hydrology, mining method and cost effectiveness.

Mine-spoil hydrology

Mine spoil hydrology also plays a crucial role in determining drainage quality. But so far no universal effective technologies are practised.

EXPERIMENTAL

Management of AMD in Meghalaya

The physico-chemical analysis of freshly collected coal samples (from Bapung and Sutunga coal deposits) are shown in the Table 1, has been used for simulation studies in a pilot plant (500 kg/batch). The air-dried samples were ground to 0.211 mm before use. Proximate (TGA 701, Leco, USA), and sulphur (SD144, Leco, USA) analyzers were used for the proximate and sulphur analyses of the coal samples, respectively. The forms of sulphur have been analyzed by standard wet chemical methods.

For treatment of Acid Mine Drainage from coalmines of Meghalaya, a sequential alkalinity producing (SAP) process has been developed as herein described. The key factors for Acid Mine Drainage generation in these high sulphur coalmines responsible are coals collected in the pithead and accompanying geologic materials (mine tailings) dumped in the mine site while excavation.

Table 1: Physico-chemical characteristics of raw Meghalaya coals used for simulation study (as received, %)

Proximate Analysis	MB	MS
Moisture	1.5	2.9
Ash	11.5	20.0
Volatile matter	40.5	35.6
Fixed Carbon	46.5	41.5
Total Sulphur	4.23	3.46
Pyretic Sulphur	0.26	0.15
Sulphate sulphur	0.43	0.29
Organic sulphur	3.54	2.90

The coals, coal fines, and accompanying geological materials, after geo-chemical tests have been found to be acid producing in and around the mine sites, where they are dumped. To evolve an effective methodology for treatment of Acid Mine Drainage, a combination of alkalinity producing system coupled with biological processes have been tried in a scaled up unit. The results of coal as a raw material used for simulation are given in this paper.

RESULTS AND DISCUSSION

A pilot plant (500 kg/batch) for simulation of AMD from coal has been operated in two batches for consistency. Leaching has bee carried in ambient conditions until complete oxidation of pyrites present, seen by precipitation of Fe^{3+} ions. A sufficient residence time is given for almost complete precipitation of Fe^{3+} ions and physico-chemical parameters were measured. After settling, the clear water from top discharged into three oxidation tanks, after which, the whole volume of acidic drainage is transferred from to the alkaline chamber containing crushed limestone and kept for a sufficient residence time to increase the pH. Once the pH has increased, the water from the alkaline chamber was slowly released to the wetland chamber containing biomass and aquatic plants. The acidity of the simulated water was found to be similar to those from the mine sites.

Biomass treatment

After a residence period of 4 days in the alkaline chamber, the total volume of water at a pH of more than 5 has been transferred to the biomass chamber consisting of organic compost and aquatic plants. The physico-chemical parameters of the water samples collected from the biomass chamber were studied at different intervals of time to reach a pH suitable for surface disposal.

During the course of treatment, the acidity was found to be reduced along with reduction of conductivity, TDS and sulphates. The biomass material (aquatic plants) used for treatment showed absorption of toxic metals. The analysis of aquatic plants before and after showed reduction in toxic element contents in effluent water.

CONCLUSION

The coals, coal fines, and mine rejects of Meghalaya coal mines are acid producing materials. For effective treatment, a combination sequential alkali producing system coupled with biological processes are found effective. However, for effective site specific management of AMD, the following four interrelated studies are essential:

- Systematic evaluation of the spatial variability of deleterious materials in coal and coal-bearing strata.
- The study of kinetics of pyrite (FeS_2) oxidation and the formation of acid drainage from coal mines to improve the prediction of mine-drainage water quality.
- Development of protocol/systems to assess the potential for drainage from active abandoned mines.
- Development of methodologies for the remediation of waters discharged from coalmines with reduced coal-mine-drainage treatment costs and improving water quality.

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