ENVIRONMENTAL IMPACT OF COAL MINING ON WATER REGIME AND ITS MANAGEMENT

R. K. TIWARY
Central Mining Research Institute, Barwa Road, Dhanbad, Bihar, India
(e-mail: tiwaryrk_cmri@yahoo.com)*

(Received 16 March 1999; accepted 21 October 2000)

Abstract. Coal mining is one of the core industries that contribute to the economic development of a country but deteriorate the environment. Being the primary source of energy coal has become essential to meet the energy demand of a country. It is excavated by both opencast and underground mining methods and affects the environment, especially water resources, by discharging huge amounts of mine water. The mine water may be acidic or neutral depending upon the pyrite content in the coal as inorganic impurities. Acid mine drainage occurs in those mines in which sulphur content is found in the range of 1–5% in the form of Pyrite (FeS_2). It degrades the water quality of the region in terms of lowering the pH of the surrounding water resources and increasing the level of total suspended solids, total dissolved solids and some heavy metals. In non acidic mines, water quality shows high hardness, TSS and bacterial contaminants. The leachate water from overburden dump are found enriched in metal concentration especially Fe, Cu, Mn and Ni except in one of the clayey dumps. High values of hardness of mine water reduces it's utility in domestic purposes. The article illustrates the quality of acidic and non acidic mine water and leachate characteristics of opencast coal mining OB dumps. Pollutants such as TSS, TDS, oil and grease and heavy metal are found in the coal mining waste effluents. Management of these liquid waste at the primary level and secondary level have also been suggested to control the pollution level at the source.

Keywords: acid mine drainage, coal mining, environmental impact, leachate characteristics, management, water quality

1. Introduction

In the process of development, coal mining is a major industry, which is contributing inadvertently towards the pollution of the environment. But at the same time it also assures the energy supply which is indispensable for the development of a country. It is a major fuel used for generating electricity world wide. Coal provides around 27% of global primary energy need and generates about 36% of the world electricity. Coal is the major resource and most important primary source of energy in India, accounting for 0.8% of the total reserves of the world, 5.7% of the proven reserves and almost meets 67% of the total energy consumption of the country. Coal productions have increased by about seven times in the past 40 yr. In 1994 Indian coal reserves (proven) were estimated to be 68.0 billion tonnes against total 196.9 billion tonnes reserve. Of the total reserves, 63% are within a depth of 300 m, 27% within the depth range of 300–600 m and 10% are beyond 600 m. Since a

Water, Air, and Soil Pollution **132:** 185–199, 2001.

substantial percentage is within the 300 m depth, there is an increased share of opencast technology for coal extraction.

The bulk of the coal reserves are of non-cooking coal with high ash content (20–35%) and low calorific value leaving only 15% as cooking coal and 12% as superior grade cooking coal. 90% of the country's coal reserves are found in the central and eastern parts of the country.

Nearly 50 coal fields, ranging in size from a few square kilometers to greater than 1500 km^2, have been found in India. Most occur in peninsular India in the quadrant bounded by 78°E longitude and 24°N latitude. Within the basins the number of coal seams ranges from as few as two or three up to 44 with total minable intervals are 0.5 to 160 m with the rank of coals varying from sub-bituminous to bituminous rank.

Coal mining by both opencast and underground method affects the environment of the area (Dhar, 1993). In the process of mining huge amounts of water are discharged on surface to facilitate the mining operation. The discharged water often contains high load of TSS, TDS, hardness and heavy metals, which contaminate the surface and ground water (Tiwary and Dhar, 1994). Some times it is acidic in nature and pollutes the water regime (Tiwary *et al.*, 1997).

1.1. Sources of Water Pollution in Coal Mining Areas

1.1.1. *Drainage from Mining Sites Including Acid Mine Drainage and Mine Water*

Mine excavation usually have a water influx, either due to rainfall or to interception of ground water flows. This water is usually an unwanted feature of mining though it can sometimes be used for processing and dust suppression and rest may have to be pumped out. It can be contaminated by particulate matters, oil and grease, unburnt explosives and other chemicals. If the coal seems contain high amount of pyrities the mine water may be acidic and thus pollutes the nearby stream after being discharged.

1.1.2. *Sediment Runoff from Mining Site*

Runoff after rain can give rise to serious pollution problems. The disturbed land or active overburden dumps piled up near the mine is usually very susceptive to erosion and silting is thus a wide spread results. A variety of other pollutants may also be transported into water courses by runoff. Sometimes overburden dump material is piled up at the bank of the river and thus increases the suspended particulate load in the surface water.

1.1.3. *Oil and Fuel Spills/Workshop Effluents*

In the case of opencast mines large number of mining machinaries and vehicles are being used and thus every mine has its own workshop. Workshop effluents contain high amounts of oil and grease which are released during washing of the machinaries. Sometimes spillage of oil and other toxic reagents do occur in these areas which ultimately affect the water regime.

1.1.4. *Leaching of Pollutants from OB Dumps*

In OB dumps some rainfall is likely to permeate into them and may dissolve some toxic metals from the heap and may contaminate the water course. The problem becomes more complicated when the dump contains pyritic waste.

1.1.5. *Sewage Effluent from Site*

The water used by the mining community in domestic and sanitary purpose also becomes a source of pollution if not treated properly before discharge. It may be contaminated with detergents, suspended solids and organic matters.

1.2. MAJOR POLLUTANTS

Mine water discharged form underground and open cast mines generally contain high level of TSS, TDS, heavy metal, hardness, sulphate, oil and grease and nitrate and pollute the water regime if it is discharged without proper treatment.

Depending upon speciation and concentration, heavy metals can be lethal to aquatic animals and prevent their reproduction or enter the food chain by accumulating in fish tissue. Toxicity can be acute or chronic due to exposure usually greater than one year.

The toxicity of heavy metals in fresh water is not only dependent on metal concentration, but also on other factors such as pH, water hardness, occurrences of other non toxic metals and adsorbing or complexing agents. Heavy metal pollution is often associated with acid mine drainage. Impact of coal mining and coal based industrial activities on water quality of the Damodar river with special reference to heavy metals are described elsewhere (Tiwary *et al.*, 1994). Mine water often contains high level of total dissolved solids in the range of 200–860 mg L^{-1} and may have negative effects on river water quality. The dissolved cations include calcium, magnesium, sodium and potassium; the major anions are sulphate, chloride, fluoride, nitrate, bicarbonate and carbonate. Thiosulphate and sulphuric minerals may create environmental problems through their oxidation to acid in receiving waters. They originate from the dissolution of pyritic sulphur in the underground mines and their concentrations are generally found high in mine water and increases the hardness of water and therefore reduces it's utility in drinking purposes.

Nitrate ions are originated from explosives, which are used to blast the coal in the mines. It is found in pit water or waste rock from spilled or undetonated explosives or by leaching under wet blast condition. Nitrogen ion factors for explosives are normally between 1 to 6% nitrate account for about 85% of total nitrogen released in mine drainage while ammonia accounts for rest (Sobolewsky, 1998).

Mine water discharged from underground mines also contained high hardness due to presence of sulphate and chlorides and makes it unsuitable for drinking and even bathing purposes.

Oil and grease is found in the mine water and work shop effluent. The main source of oil and grease is workshop effluents, which include the washing of heavy machinery of opencast mines. Oil can form a thin film on the water surface and may interfere with the reoxygenation of the water. It can coat the gills of fish and feathers of birds and proves to be dangerous for aquatic ecosystems.

Suspended solid is also found in mine water discharge. Depending upon the nature and concentration, suspended solids may interfere with the self-purification capacity of water by diminishing light penetration and hence photosynthesis reactions. In extreme cases, silt deposition can lead to flooding and interfere with other biological activities. In case of coal mining TSS normally contains high amount of fine coal particles and makes surface water blackish and reduces aesthetic values of receiving water bodies.

1.3. Occurrences of Acid Mine Drainage (AMD)

One of the major causes of water contamination is acid generation from the oxidation of sulphur-bearing minerals like pyrities in coal mines. This occurs only when the minerals react with water and oxygen in the presence of thiobacillus bacteria to produce sulphuric acid and iron hydroxide or iron sulphate. The low values of pH result in further dissolution of minerals and the release of toxic metals and other constituents into waterways. This can occur on the surface of pyritic waste dumps and stockpiles. In case of underground mines, groundwater infiltrates into the mine and comes into the contact of pyritic coal and thus form AMD. In the case of open cast mines groundwater, rainwater and associated runoff into the pit may be acidic in nature.

Acid leachate may have two-fold adverse effects upon aquatic biota; the lower pH may harm aquatic organism and the elevated heavy metals may have toxic effects upon aquatic life, wild life and surrounding vegetation.

The reaction mechanism of acid generation is expressed as (Singer and Stumm, 1970)

$$FeS_2 + 3.5O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^2 + 2H^+$$

$$Fe^{2+} + 0.25O_2 + H^+ \xrightarrow{\text{Bacteria}} Fe^{3+} + 0.5H_2O$$

$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 + 3H^+$$

$$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \,.$$

Common characteristics of AMD include high acidity with pH values as low as 2.0. High sulphate concentration and high metal loading typically including iron and manganese are the common feature of the AMD (Tiwary *et al.*, 1997). The most obvious effects of AMD is the formation of a yellow-orange precipitate, usually called yellowboy, that coats the bottom of stream and obstructs the biological activities.

AMD may be devastating in terms of the quality of surface and subsurface water and extend their impact to the surrounding areas. Acidity and high metal concentration are toxic to aquatic life, wild life and vegetation. Sedimentation of metal precipitates adversely affects the visual aesthetics of the water as well as the water chemistry and aquatic life.

1.4. Disposal of Mine Wastes and Impact on Water Regime

The majority of mine wastes are in the form of OB materials, waste rock and tailing from the ore treatment process as solid waste and workshop effluent, mine water and runoff water as liquid effluents. Large volume of these can present typical problems on their disposal in regards to pollution hazards, land sterilization and quality of water resources.

Disposal of mine wastes in general and tailing in particular has the potential to affect the environment in a variety of ways. These include:

- Displacement of existing land use.
- Removal by clearing or burial of natural habitats.
- Dispersal of sediments into the drainage system and/or the sea, either as discharge overflows from tailing impoundments, spillage or by erosion of overburden dumps or tailing impoundments.
- Release of dissolved substance including heavy metals and other toxic substances to rivers; estuaries and the sea either as direct discharge, seepage or overflow from OB dumps.
- Contamination of groundwater by seepage from OB dumps.
- Dust dispersal from dried surface or tailing impoundments.
- Alteration of riverine system causing floods in the plain areas.
- Lowering of ground water table in the mining area due to exhaustive pumping of mine water.

2. Materials and Methods

Water samples were collected from different mines of major Indian coal fields. Study area is shown in Figure 1. In this study, acidic mines and non-acidic mines were selected for the physico-chemical characterization of waste effluent. Water sample was collected in pre acid washed polythene bottles and preserved for further analysis. Preservation and analysis were done by following standard methods (Greenberg *et al.*, 1992). Inductively coupled plasma spectrometer (GBC XM Integra), Oxitop BOD Analyzer (EMERK) and COD reactor (HACH) were used for the analysis of heavy metals, BOD and COD, respectively. Leachate water sampling was done in rainy season when the rate of water infiltration through overburden material is maximal. Three types of dumps were selected for this study

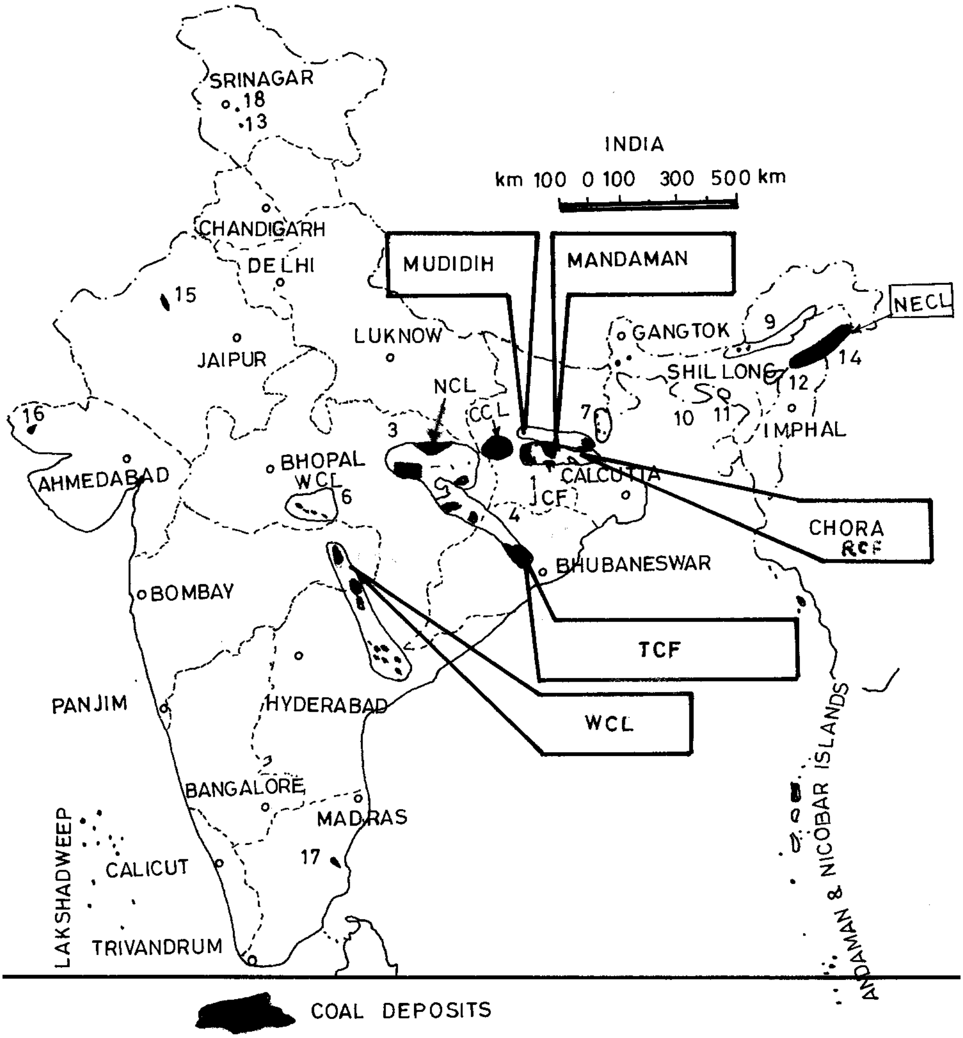

Figure 1. Location map of study sites.

depending upon the quality of overburden material. Water from the top layer and bottom layer were collected and analyzed in terms of Fe, Cu, Ni and Mn with other parameters like pH, temp. and conductivity using HACH conductivity, pH and temperature meters.

TABLE I

Physico-chemical characteristics of acid mine drainage of Indian coal mines

S.N	Parameters	Location		
		Western Coalfields (WCL)	Northern Coalfields (NCL)	Northern–Eastern Coalfields (NECL)
1	pH	2.8–6.0	1.53–6.65	2.85–4.30
2	SO_4	400.0–1948.9	498.0–1678.0	591.7–881.0
3	TSS	150.0–200.0	11.0–167.0	32.40–225.0
4	TDS	700.0–3300.0	380.0–2324.0	825.0–1012.0
5	BOD	0.8–2.5	1.20–3.60	1.5–4.5
6	Fe	2.0–51.03	32.70–84.30	2.86–50.79
7	Mn	0.030–3.062	0.02–0.40	0.03–2.60
8	Cu	0.001–0.037	0.001–0.020	0.001–0.015

All parameters are expressed in mg L^{-1} except pH.

3. Results and Discussion

3.1. AMD PROBLEMS IN INDIAN MINING CONDITIONS

Ecological disruption due to acid mine drainage is one of the most persistent pollution problem in some of the Indian Coalfields, particularly in the lower Gondawana coal of Barakar formation and tertiary coal of Assam. The problem no doubt is mostly confined to a localized zone at the source, but may extend to distance if the acid mine water is allowed to get discharged into the main water stream. The coal mines face a serious pollution problem due to acid mine drainage in India are Baragolai (ECL); Churcha and West Chirimiri (SECL), Ambara and Rakhikol (WCL); Gorbi (NCL). Water samples from WCL, NCL and Assam Coalfields, which are prime source of AMD generation, have been analyzed and results are presented in Table I.

In WCL, few mines investigated are having acid mine drainage problems. pH varies from 2.81 to 6.03 being minimal in the Chandamata colliery. Sulphate content in this water varies from 400–1948 mg L^{-1}, which is very high. The concentration of iron is found varying between 2.00 to 51.03 mg L^{-1}. The acidic water problems are also found in Northern Coalfields (NCL), which is fast developing as a major coal mining area of the country. Effluent from the mine of this coalfield have shown a pH in the range of 1.53–6.65. Other parameters like SO_4, TDS and Fe have been found in the range of 418 to 1678 mg L^{-1}, 380 to 2324 mg L^{-1} and 32.7 to 84.3 mg L^{-1}, respectively. The Tertiary coal of North–Eastern Coalfields (NECL) have been found to contain as high as 8% sulphur with varying percentage of pyrite, sulphate, organic and free sulphur. The overburden dumps around the mines of this coalfields are highly acidic having pH of even 2.65. Since rainfalls in this area are large, acid drainage is of serious environmental concern. Water contaminated with acid mine drainage have been found showing pH in the range of 2.85–4.30. Concentration of SO_4, TDS and Fe in the water has been found in the range of 591–881 mg L^{-1}, 825–1012 mg L^{-1} and 2.86–50.79 mg L^{-1}.

3.2. Mine water quality in non acidic coalfields of India

Mine water quality of Jharia Coalfields, Raniganj Coalfields, Central Coalfields Ltd. and Talcher Coalfields have been studied as representative of the non acidic mines. One special peculiarity of these coalfields are that mine water do not have acid mine drainage problems as coal deposits are not associated with pyrite bands and sulphur content in the coal are scanty. Organic sulphur compounds like mercaptans (RSH), sulphide, thioethers or other aromatic system do not exceed more than 1% (Rawat, 1982). Mine water quality of these coalfields is analyzed and results are presented in Table II. Results show that the pH of mine water vary between 6.50–9.22. Lowest and highest pH values are observed in the Jharia coalfield representing the coking coal producing area. Level of total suspended solids are also noticed to be in higher range in JCF as compared to other coalfield. Values of TDS are found in higher side and varies between 136–860 mg L^{-1} being maximum in RCF.

The concentration of sulphate is found in the range of 10.2 to 401 mg L^{-1} being maximum in Jharia Coalfields. SO_4 in excess of 200 mg L^{-1} may have laxative effect while the presence of H_2S may be toxic. Increase in the level of TDS and SO_4 is the root cause of high hardness of mine water, which is found in the range of 68–711.4 mg L^{-1}. JCF faces acute problem of hardness of water that reduces its utility in different purposes. Iron concentration in mine water are found in the range of 1.30–3.10, 0.28–4.20, 0.25–1.77 and 0.13–0.29 mg L^{-1} for JCF, RCF, CCL and TCF, respectively which are not too high due to less pyrite content in the coal.

Bacterial contamination takes place inside the mine and during the discharge. The presence of coliform is measured in the form of most probable number and found varying between 12–2400. Sometimes it increases by the seepage of domestic wastes into the mines due to improper drainage system. Level of oil and grease is found considerably low in all the coalfields but found maximum in RCF ranging between 0.08 and 4.78 mg L^{-1}. Level of biological oxygen demand varies between 0.4 and 120.0 mg L^{-1} being maximum in the RCF. It may be high due to interception with domestic waste. Level of Chemical Oxygen Demand are also found in higher side due to the presence of coal particles in the mine water as suspended solids. The presence of BOD and COD show that mine water is contaminated with organic pollutants.

Concentration of other toxic metals like As and Hg are found to be below detection limit. Whereas anions like fluoride and chloride are found in considerable

TABLE II

Physico-chemical characteristics of mine water

S.N.	Parameter	JCF	RCF	CCL	TCF
1	pH	6.50–9.22	6.98–8.99	6.70–7.30	6.80–7.10
2	Temp.	26.00–31.90	25.50–32.00	26.00–34.00	24.00–34.00
3	TSS	240.60–1180.00	10.00–182.00	10.00–528.00	136.00–352.00
4	TDS	459.00–796.00	348.00–860.00	200.00–670.00	136.00–278.00
5	Oil and grease	0.03–0.05	0.08–4.78	0.10–1.20	0.001
6	BOD	0.60–33.42	4.00–120.00	0.40–4.60	1.30–5.90
7	COD	21.05–235.20	9.00–340.00	18.00–53.00	13.40–46.30
8	As	0.001	0.001	0.001	0.001
9	Hg	0.001	0.001	0.001	0.001
10	Fe	1.30–3.10	0.28–4.20	0.25–1.77	0.13–0.29
11	CN	0.001	0.001	0.001	0.001
12	Cl	24.50–1009.00	27.00–73.00	20.00–69.00	15.60–44.70
13	F	0.10–1.50	0.28–1.30	0.60–1.40	0.50–1.30
14	SO_4	206.00–401.00	14.00–379.40	25.00–185.00	10.20–25.80
15	Hardness	600.50–711.40	68.00–324.00	260.00–570.00	171.00–276.00
16	Nitrate	40.80–58.00	12.00–41.00	0.11–4.60	2.80–15.30
17	Coliform (MPN 100 m L^{-1})	17.00–2400.00	920.00–1600.00	12.00–1400.00	22.00–61.00

All parameters are expressed in mg L^{-1} except pH.
JRF – Jharia Coalfield; RCF – Raniganj Coalfield; CCL – Central Coalfield; TCF – Talcher Coalfield.

amount which is obvious from higher TDS. Chloride varies from 15.6 to 1009 mg L^{-1} and found maximum in JCF. The concentration of cyanide is found to be below detection limit of 0.001 mg L^{-1}. Mine water is generally discharged in the nearby water streams and thereby deteriorates the water quality in terms of TSS, TDS and BOD and reduces its aesthetic values. Total suspended solids are found in the range of 75–1180 mg L^{-1} and further create environmental implications by getting deposited at the bed of the river and finally obstructing the biological activities.

3.3. Overburden dump leachate water quality

Leachate water from three types of opencast mine overburden dumps is characterized and the results are presented in the Table III. The result shows that the level of Fe, Cu, Ni and Mn were found more in the leachate water than that of top water. And this leaching behaviour of these metals affect the ground water quality because no precautions at the initial level have been taken to protect the ground water zone beneath the overburden dumps at the experimental site. It may also contaminate the ground water sources in nearby areas. The leaching of Iron has been found in

TABLE III

Quality of leachate water from coal OB dumps

S.N.	Mine site	Parameters						
		pH	Temp. (°C)	Conductivity (μs cm^{-1})	Fe (mg L^{-1})	Cu (mg L^{-1})	Ni (mg L^{-1})	Mn (mg L^{-1})
1	Mandman (Top water)	7.23	30.50	0.200	1.504	0.007	0.001	0.300
2	Mandman (Leachate water)	8.00	31.50	0.230	8.250	0.060	0.050	0.300
3	Chora (Top water)	7.55	33.00	0.034	4.210	0.034	0.019	0.230
4	Chora (Leachate water)	7.13	32.00	0.028	3.740	0.340	0.634	0.240
5	Modidih (Top water)	8.50	31.00	0.725	0.349	0.010	0.080	0.015
6	Modidih (Leachate water)	8.50	32.30	0.651	36.300	0.060	0.108	0.750

increasing trend in the OB dumps of Mandman and Modidih whereas in case of Chora dump it was not observed. It may be due to the fact that dump material at the Chora dump contains large amount of soil and therefore adsorption of iron may be taking place at the neutral pH ranging from 7.13 to 7.55. But the leaching of Cu, Ni and Mn have been noticed in the lower column of water of the same dump.

4. Management of Mining Waste Disposal

4.1. Initial level management

Many factors need to be considered while selecting sites for surface disposal of mine waste. Planing during the preliminary design stage of any mine development should consider following issues:

- existing land use.
- where to site dumps in relation to topography, drainage systems, water bodies and residential areas, so as to minimize dump instability, water pollution (surface and ground water) dust problems and adverse visual impacts;
- location and direction of the groundwater flow which can influence the migration of contaminants;
- allowing sufficient area around dumps for bunding or trenches to contain acid water runoff or for the placement of dams to collect seepage, runoff and sediments;
- prevailing wind direction and strength as dump materials may cause dust and noise problems downwind;
- distance of disposal sites from the mining area or processing facilities as this may adversely affect the economics of the disposal operations;
- placement of sub-economic grade materials for possible future reprocessing when either technology or commodity prices permit.

4.2. Secondary level management

The placement of waste on steep slopes should be avoided so as to reduce the risk of landscape and dam failure, particularly in the area of high rainfall and areas prone to landslides, earthquakes and tremors.

Dumps should be shaped during the dumping stage so that slopes are gentle enough (15–20° or 27–36%) to reduce erosion and to allow vegetation to be established. This will also reduce the negative visual impact of unsightly waste rock. Shaping at this initial stage will also reduce the need to reshape at a later stage and so avoid costly earthworks and ‘double handling’. The proper angle of slope will certainly reduce soil erosion and TSS load in the nearby aquatic system.

Others parameters like AMD, oil and grease removal of dissolved solids, suspended solids in the waste discharge may be minimized by adopting following method:

4.2.1. *Oil Pollution Control*

In the process of oil pollution control following steps should be considered

– Proper bunding of oil storage and workshop areas .
– Efficient oil/water separator equipment in the site drainage system.
– Areas to be bunded to prevent oil from escaping.
– Waste oils should be collected for recycling or proper disposal.
– Oil contaminated soils should be removed for proper disposal and treatment (such as bioremediation).
– Waste effluent should be stored in the series of settling tank provided with proper aeration system i.e. mechanical oil separator.

4.2.2. *Acid Mine Drainage Control*

4.2.2.1. *By Burying the Wastes Under Water.* Since availability of oxygen and moisture are the key factors for oxidation of pyrite and release of acid, the best method appears to be to create an anaerobic surrounding which can be achieved by keeping the tailings under water for the control of acid generation and is successfully experimented in Solbec mine, Canada (Amyot *et al*., 1997). After a series of experiments pH was found to near neutral and the anomalous concentration of iron, zinc and copper reduced. The trend is supported by a decrease in the oxidizing microbial population, the cessation of their oxidizing activity and the most notably the appearance of sulphate reducing bacteria. These bacteria contribute to the inverse oxidation process by reducing sulphate ions to sulphide ions, which reprecipitate the metals present in the more stable form of metal sulphides.

- Pre-treatment of tailing or waste rock to remove exclusively sulphide minerals;
- Segregation from non-sulphate bearing rock;
- Relocation of waste rock.

Significant optimization parameters in waste rock remediation are, the placement of the acid generating rock in the mine pit below the ground water table and the depth of atmosphere oxygen penetration in the waste rock above the ground water table (Jakubick *et al*., 1997).

4.2.2.2. *Covering and Sealing with a Layer of Clay/Soil.* Covering and sealing of the tailing material with clay also inhibit the acid formation process (Bunnet *et al*., 1988). Apart from the high cost involved in laying clay cover it is rather difficult to always procure the precious soil for covering of the mine spoils in India if not preserved earlier at the beginning of the mining.

- Additives to control pH (lime, limestone, NaOH).

Limestone ($CaCO_3$) inhibits the oxidation of iron disulphides and the subsequent acid production only if the application rate high enough to rain the pH of the system up to 6.7 (Nairn *et al.*, 1992, personal communication). However, this process results in the formation of iron precipitate that stick to the limestone, blocking the activities. Some other acid ameliorant like fly ash and blast furnace slag rich in Al_2O_3, SiO_2, CaO and MgO can also be effective (Thakur *et al.*, 1992) to reduce the AMD generation. To limit the contaminant release from the dumping site, the material is sometimes being amended with free lime (CaO) or portlarolite and placed below the future water table. The process is reported to be quite effective (Hockley *et al.*, 1997) with relocation of the waste dump.

4.2.3. *Total Suspended Solids*

High amount of TSS in mine water and workshop effluent may be removed by allowing the discharged water into a series of settling tanks. To check runoff water from OB dumps, a garland drainage should be constructed around the spoil heaps. Proper coagulant may be added to get settled the coarse materials in the garland drainage itself.

4.2.4. *Removal of Dissolved Solids and Hardness*

The concentration of dissolved solids and hardness may be minimized by adopting following methods:

- evaporation of water in large shallow retention ponds;
- conventional ion exchange process;
- membrane filtration; and
- removal of cations using cation exchange resin and removal of anions in a multistage process.

5. Conclusion

The study revealed that some of the coalfields of India like WCL, NCL and NECL are having acid mine drainage problem. Mine water quality of some of the mines of these coal fields is found to be acidic and also contains high amount of sulfate, TDS and heavy metals such as Fe and Mn. The pH of mine water is found in the range of 1.53 to 6.65 and may be polluting the nearby water regime. In non acidic coalfields like JCF, RCF, CCL and TCF, the level of TSS, sulfate, TDS and heavy metals were found in comparatively low concentrations. Hardness problem dominates in non-acidic coalfields which reduces the utility of mine water in domestic and other meaningful purposes. Leachate water characteristics of OB dump revealed that metal concentration increases in the leachate water as compared to the top water. Leachate behaviour reflects that the phenomenon depends upon the type of material of the dump. In the case of dump containing substantial amount of sub soil, iron gets precipitated and resultant leachate contains reduced level of iron.

Two tier management system have been suggested to minimize the visual and physico-chemical impact of mine waste water on surrounding water regime, one at the initial level and another at the execution level. Initial level management includes the steps taken at the planning stage which considers the existing land use pattern, drainage system, water bodies and ground water flow in the selection of the dumping sites to avoid impact on ground and surface water quality. Secondary level management includes the protectionary measures taken during the excavation process to minimize soil erosion, acid mine drainage control and the reduction of TSS, oil and grease, TDS and hardness. Soil erosion may be reduced by giving 15–20° slope of the dumps, which not only minimizes the soil erosion but also allow vegetation to be established. Acid mine drainage control may be achieved by burrying the waste under water, segregation of sulphate bearing rocks, covering with clay and addition of some neutralizer like lime, lime stone and relocation of waste dumps with addition of ameliorant like lime, flyash and alkaline slag, alkaline sources like cement kiln dust or paper mill waste. Provision of settling tanks at the discharge points also reduces the level of TSS, oil and grease and TDS. Garland drainage around the spoil heaps is very much helpful in reducing the TSS level in runoff water.

Acknowledgement

Author is greatly thankful to the colleagues of Environmental Management Group of Central Mining Research institute who rendered their help in the collection, analysis of water samples and preparation of the manuscript.

References

Amyot, G. and Vezina, S.: 1997, ‘Flooding as a Reclamation Solution to an Acidic Tailing Pond, the Solbec Case’, Proceedings of the Fourth International Conference on Acid Rock Drainage, Vancouver, B.C., Canada, 31st May – 6th June 1997, Vol. II, pp. 681–696.

Bennet, J. W., Harries, J. R. and Ritchie, I. M.: 1988, ‘Rehabilitation of Waste Rock dumps at Rum – Jungle Mine Site’, USBM, IC 9198, Vol. I, 104–108.

Clescerial, L. S., Greenberg, A. E. and Eatan, A. D.: 1998, Standard Methods for Examination of Water and Waste Water, 20th ed., APHA, AWWA, Publication, Washington D.C., pp. 3.37–3.38.

Dhar, B. B.: 1993, ‘Environmental Scenario in Indian Mining Industry’, in Chaudhary and Shiv Kumar (eds.), *Environmental Management, Geo Water and Engineering Aspects*, Balkema Rotterdam, pp. 615–619.

Hockley, D., Paul, M., Chapman, J., Jahn, S. and Weise, W.: 1997, 'Relocation of waste rock to the Lichtenberg pit near Ronneburg, Germany', Proceedings of the Fourth International Conference on Acid Rock Drainage, Vancouver, B.C. Canada, 31st May – 6th June 1997, Vol. III, pp. 1267–1283.

Jakubick, A. T., Gatzweiler, R., Mager, D. and Robertson, A. MacG.: 1997, 'The Wismut Waste Rock Pile Remediation Program of the Ronneburg Mining District, Germany', Proceedings of the Fourth International Conference on Acid Rock Drainage, Vancouver, B. C. Canada, 31st May – 6th June 1997, Vol. III, pp. 1285–1301.

Kleinmann, R. L. P., Crerar, D. A. and Pacelli, R. R.: 1981, *J. of Mining Engg.* **33**, 300.

Rawat, N. S.: 1982, 'Sulfur Occurrences in Coal and Its Relationship to Acid Formation', *J. of Metal and Minerals*, Sept. XXI, 10.

Singer, P. C. and Stumm, W.: 1970, *Science* **167**, 12–34.

Sobolewski, A.: 1998, *J. of Mining Environmental Management*, July, pp. 21.

Tiwary, R. K. and Dhar, B. B.: 1994, *Mine Water and Environment* **13**, 1.

Tiwary, R. K., Dhar, B. B. and Jamal, A.: 1997, 'Acid Mine Drainage Occurrences and Its Control in Indian Coal Mines', in Dhar and Bhaumik (eds.), Proceedings of the 27th International Conference of Safety in Mines Research Institute, New Delhi, India, February 1997, pp. 1253–1259.

Tiwary, R. K. and Dhar, B. B.: 1994, *International J. of Surface Mining, Reclamation and Environment* **8**, 111.

Thakur, D. N., Tewary, B. K., Kumar, B. and Singh, R. K.: 1992, 'Reclamation of Pyritic Dumps using Phosphatic Wastes as an Ameliorant: A Case Study', in R. K. Singhal (ed.), *Environmental Issues and Waste Management in Energy and Minerals Production*, Balkema Rotterdam, ISBN 9054100796, pp. 831–846.