ABSTRCT

CHAPTER I

Introduction

First part of this chapter is the general introduction to open cast mining in Ledo colliery of Margherita, Assam; the different sections of this chapter provide the information about the major types/forms of coal found in Margherita, coal resources and its distribution in NER India, present scenario of coal utilization, geological settings of Ledo open cast mining area. The generation of Acid Mine Drainage (AMD) and its environmental consequences are included as the main text of this chapter.

The literatures about the amount of environmental impact of Ledo open cast coal mining and other Indian coal mining states along with different coal producing countries are included in this chapter.

The objectives of the present study and arrangement of the chapters are incorporated in the Chapter I

CHAPTER II

Methods and materials

This chapter provides the complete description of the study area, standard methods used for sample collection and respective analytical methods adopted in the course of research work. The representative coal, OB, soil, sediment and mine water/ water samples were collected during monsoon and non-monsoon seasons to show the variation of different physico-chemical parameters in both seasons. For detail characterization of the samples, a number of sophisticated instruments were used for different analytical procedure including X-Ray Diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), Raman spectroscopic analysis, Mössbauer spectroscopic analyses, sulphur analysis, field emission scanning electron microscopy -energy dispersed spectroscopic (FESEM-EDS), high resolution transmission electron microscopy- energy dispersed spectroscopic (HRTEM-EDS) analysis, atomic absorption spectroscopic (AAS) analysis etc. for coal, OB, soil and sediment. The analytical methods used for the water samples were ion-chromatographic analysis,

atomic absorption spectroscopic (AAS) analysis, and inductively coupled plasma optical emission spectrometry (ICP-OES) analysis.

CHAPTER III

Seasonal variability study of acid mine drainage formation in Ledo high-sulphur coal mine area

This chapter gives the possible information about the impact of seasonal variation in Ledo coal mining area on the formation of acid mine drainage (AMD). To study the variation of different physico chemical and chemical parameters of coal, OB, soil, sediment and the mine water/water samples, the samples were collected twice a year in monsoon and non-monsoon seasons by using standard methods. The analytical data obtained for physico chemical parameters of mine water show that the pH values for non-monsoon season (maximum value, 8.4) is higher than those collected in the monsoon season (minimum value, 3.3) because of the low rate of pyrite oxidation in the winter due to low temperature. In the present analysis it was found that the mine water samples (seepage 1 and 2) having highest value of EC (1.30-2.49 ms cm^{-1}) had the highest TDS value (1068-1339 ppm) in monsoon season. High TDS value of water is responsible for the increase in salinity and change in ionic composition of water. The sulphur content is higher in monsoon season than in non-monsoon season.

From ICP-OES analysis it is found that the concentration of metals like Al, Fe, Mn, Ni, and Pb is higher in the mine water during monsoon season over non-monsoon season. In non-monsoon season due to low rate of pyrite oxidation, leaching of a number of metals from coal or OB during non-monsoon season is not possible. The analytical data shows that major elements have concentration levels, higher than the permissible limit in most of the water samples collected during the monsoon season than for those collected during the non-monsoon season. From ion-chromatographic analysis of water samples in both seasons, it was found that the concentration of Mg^{2+} in the mine water samples was highest (29.29-282.60 ppm), Na^{+} and K^{+} ion has a moderate concentration (0.682-5.790 and 0.103-4.08 ppm) in the water samples of monsoon season. Again, this analysis revealed that the concentrations of Mg^{2+}, Ca^{2+}, K^{+}, and NH_4^{+} ions in the water samples collected in the non-monsoon season were below the detection limit or low in

most of the samples. The concentrations of different anions including SO_4^{2-}, Br^-, and Cl^- were found to be high in monsoon season but except SO_4^{2-} ion, the other anions have a concentration below the desirable limit in non-monsoon season.

From the polynuclear aromatic hydrocarbons (PAHs) experiments on mine water samples it is clear that the presence of a number of PAHs are responsible for toxic effects in different human cell and rat cells which were studied by using four cell lines including normal rat muscular cells (L6), human pancreatic carcinoma (MIAPaCa2), human lung carcinoma (A549) and human hepatocellular carcinoma (HepG2), which are widely accepted parameters for such studies. Thus, results of this study will be helpful to interpret the water quality in mine source and nearby water resources in monsoon and non-monsoon seasons. Moreover, this study helps in indicating the higher contaminant level of metals in water system in monsoon season than in non-monsoon season which may pose a threat to survive the flora and fauna.

CHAPTER IV

Physico-chemical and elemental analysis of laboratory aqueous leachates of high sulfur coal and Overburden from the Ledo colliery

This chapter deals with the aqueous leaching of coal and OB from Ledo coal mine and the characteristics of the leachates in terms of physico-chemical parameters. The physico-chemical parameters including pH, EC and TDS for the aqueous leachates were determined at different time periods and temperatures. The AMD generation and metal leaching processes from mine over burden (OB) dumped near the mining area occur in a parallel way. Thus, to know the AMD potential, the aqueous leaching experiment of a few coal and OB samples from the Ledo colliery of the Northeastern coalfield, Mergherita (India), at different time periods (1hour, 3hours, 5hours and 8hours) and at different temperatures(25º C, 45º C, 65º C, 90º C) were investigated. From the analysis of different physicochemical parameters of aqueous leachates, it was found that the pH of leachates decreased from 1 hr to 5 hr at room temperature whereas the EC values increased from 1hr to 5hr under same temperature. On the other hand the TDS values of leachates increase with leaching time as well as the temperature indicating high mobility of ions at high temperature.

From the study it was revealed that the concentrations of trace and hazardous elements like Na, Mg, Fe, Al, Si, Hg, Pb, Cd, Cr, Mn, As, Se considerably change with leaching time as well as with leaching temperature. Change in physical and chemical structures of the coal and OB results from leaching was studied by FESEM/ EDS analysis. The release of potentially hazardous elements (PHEs) from the raw coal and OB during leaching was detected by ICP-OES and Ion-Chromatographic analyses of leachates. The association and mode of association of different functional groups in minerals were studied by FTIR and XRD analytical techniques. The overall data of the study discussed in this chapter will be useful to relate the characteristics of aqueous leachates of coal and mine OB generated in the laboratory condition with that under natural weathering condition at mine area.

CHAPTER V

Environmental assessment and nano-mineralogical characterization of raw coal, overburden, and sediment from Ledo coal mining acid drainage area

This chapter provides the information about the nano-mineralogical characterization of coal, OB, and sediments of Ledo colliery has been carried out by electron beam techniques like FE-SEM and HR-TEM analysis to measure the different nano-minerals/nanoparticles present in coal, OB samples etc.

The chemical parameters of the coal, overburden, soil and sediments along with the coal mine drainage (CMD)/ acid mine drainage (AMD) were investigated in order to understand the overall environmental impact from high sulphur coal mining at northeastern coalfield (India). It was found that the total sulphur content of the coal is noticeably high compared to the overburden (OB) and soil. The volatile matter of the coal is sufficiently high against the high ash content of the soil and overburden. The water samples have a high electrical conductivity (EC) and high total dissolve solid (TDS). Lower values of pH, indicate the dissolution of minerals present in the coal as well as other minerals in the mine rejects/overburden. The chemical and nano-mineralogical composition of coal, soil and overburden samples was studied using a high resolution-transmission electron microscopy (HR-TEM), energy dispersive spectroscopy (EDS), selected-area diffraction (SAED), field emission-scanning

electron microscopy (FE-SEM)/EDS, X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), Raman and ion-chromatographic analysis, and Mössbauer spectroscopy. From different geochemical analyses it has been found that the mine water sample from Ledo colliery has the lowest pH value of 3.30, Tirap colliery samples have the highest electrical conductivity value of 5.40 ms cm^{-1}. Both Ledo and Tirap coals have total sulphur contents within the range 3-3.50%. The coal mine water from Tirap colliery (TW-15B) has high values of Mg^{2+} (450 ppm), and Br^{-} (227.17 ppm). XRD analysis revealed the presence of minerals including quartz and hematite in the coals. Mineral analysis of coal mine overburden (OB) indicates the presence both of pyrite and marcasite which was also confirmed in XRD and Mossbauer spectral analysis.

The ^{57}Fe Mössbauer spectra of coal, overburden and soil/sediment samples were measured in order to obtain information about the iron containing minerals present in them. Pyrite was found to be the only Fe-mineral present in coal, indicated by the 100% relative abundance. Although other Fe-minerals were found to be present in the overburden and soil and sediment of Ledo colliery like illite $(K,H_2O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2.(H_2O)]$, jarosite and marcasite, but the jarosite and iron sulphate are the oxidation products of pyrite. The high relative abundance of pyrite in the coal samples indicates the higher possibility of AMD formation. Both FTIR and Ion-chromatographic analyses indicated high concentrations of SO_4^{2-}. The nano-mineralogical analysis of coal and overburden revealed the presence of Si minerals like kaolinite $[Al_2Si_2O_5(OH)_4]$ with other minerals including sulphate minerals such as barite $[BaSO_4]$, jarosite $[KFe_3(SO_4)_2(OH)_6)]$, pickeringite $[MgAl_2(SO_4)_4.22(H_2O)]$ sulphide mineral galena [PbS], pyrite $[FeS_2]$; oxide mineral hematite $[Fe_2O_3]$, and organic matters which are combined with pyrite. HR-TEM analysis of the coal and mine overburden reveals the presence of nano-minerals containing potentially hazardous elements. Galena containing high concentrations of Pb, kaolinite having high concentrations of Al and Si can cause health implications. The presence of nano-minerals like nano-hematite in coal samples was revealed by HR-TEM technique. These nano-hematites with high surface area and reactivity are very environmentally sensitive. The nano-toxicity indicate that particle size and the different properties

linked to the particle size, have an effect on both the bioavailability and the subsequent level of toxicity to organisms including human being. The presented data of the minerals and ultra/nano-particles present shows their ability to control the mobility of hazardous elements, suggesting possible use in environmental management technology, including restoration of the delicate Indian coal mine areas.

CHAPTER VI

Remediation of mine waters/acid leachates by using nano-sized limestone

This chapter is concerned with the major problems created by acid mine drainage water to the environment of nearby areas and the possible remediation to minimize the effect of AMD. From previous research it was found that mine drainage may be contained for decades in the mine site and nearby areas. From our study, it was found that the effect of open cast coal mining in Ledo area spreads up to 5km distance from the mining source. Due to its long lasting effect of AMD, It is necessary to protect and recover the environment in the coal mining areas to ensure that the environment be protected from a spreading pollution problem. Most of the coals producing countries have taken different remediation procedures but such remediation processes are often not sufficient for controlling the degradation of the environmental quality in these mine sites. Nano particle-assisted remediation is a very new and emerging technique and recent research has done where zero valent Iron (ZVI) nano particles for the treatment of soil and water loaded with heavy metal rich AMD was used. Due to the small size, a large surface area and high mobility, nano ZVI can easily spread into the environment and its use can have a very adverse effect on the environment. Thus, the use of nano ZVI is not very eco-friendly. In the present study a new concept for a nano remediation process, by using laboratory based nano limestone treatment for AMD remediation has been used which may have less amount of environmental effect.

CHAPTER VII

Summary and recommendations

This chapter explains about the summary and recommendation of the present. This chapter brings out an overall summary from Chapter I to Chapter VII. The results found in all chapters are included in this chapter from which the environmental implications from coal mining activities can be highlighted. The AMD generated in Ledo coal mine is highly acidic in monsoon season having the lowest pH of 3.3. During monsoon season most of the physico-chemical characteristics were more focusing than in non-monsoon season. ICP-OES and Ion-Chromatographic analyses revealed that most of the heavy elements and ions present in mine water had concentrations more than desirable limit. This strong acidity of AMD creates a major threat to the environment due to high dissolution of PHEs thereby contaminating water bodies and land profile in habitat areas. The amount of impact of these elements depends on their mobility in AMD water. Subsequent dilution and interaction with different minerals mainly carbonate minerals increase the pH of AMD and there is the formation of a typical orange yellow precipitate of ferric hydroxide. The ferric hydroxide precipitated from AMD plays an important role in controlling the mobility of metals thereby scavenging and/or releasing elements under varying physicochemical conditions. From the study, it can also be concluded that although only pH is determinant factor for heavy metal dissolution, but these metals can leach out from coal and OB under normal weathering conditions. From the overall study of the work it was found that only pyrite is not responsible for mine drainage water, but some other sulphur bearing minerals like, barite, galena, pyrrhotite etc. are also equally responsible for the AMD formation. Also, the nanoremediation process using limestone which is available in a northeastern state Meghalaya is economically profitable and is easy to handle. All the results found in this study give a better picture of environmental condition of Ledo coal mining area of Makum coal field, Northeast India.

Madhulika Dutta
(PhD scholar)

Dr. Binoy K Saikia (Co-guide)
Dr. Durlov Saikia (Guide)