WASTEWATER CHARACTERISTICS, MANAGEMENT AND REUSE IN MINING & MINERAL PROCESSING INDUSTRIES

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Contents

Summary

This article focuses on the management of water and wastewater within a mining and mineral processing industry. The scope of mineral processing is restricted to the on-site activities. This article identifies the sources of wastewater generated from a typical mine site and then presents the typical characteristics of the wastewater produced from various sources. The wastewater characteristics presented are derived from several case studies conducted on coalmines in the Illawarra region of Australia. Subsequently, the article also identifies possible wastewater minimization, treatment, reuse and disposal options.

1. Introduction

Most industrial processes and mining in particular produce significant environmental pollution. As a result, there is a growing concern about the quality of the living environment. This calls for more innovative efforts to protect the environment. Now, the industries are expected to pro-actively reduce the amount of pollutants discharged into the environment. In addition, the environmental management is now regarded as an essential element of an organization's overall management plan as opposed to a stand-alone and sideline issue in the past. Towards this end traditional "End-of-pipe treatment" is grossly inadequate. In fact the end-of-pipe treatment only transfers the pollution from one form to the other. For example, control of air pollution results in the water pollution, which in turn results in the soil pollution and ultimately all the pollutants end up in the water body.

To counter the above shortcoming and to preserve the high quality of the environment new concept called Cleaner Production (CP), or Low or No Waste Technology (LNWT) is being introduced in many countries. CP refers to technology designed to prevent waste emission at the source itself. The philosophy behind this is "to produce better while polluting less" (Overcash, 1986). In practice this technology and its application go by many other names such as clean technology, waste minimization, pollution prevention, waste recycling, resource utilization, residue utilization, etc. (Martin, 1986). CP minimizes or totally eliminates the emission of pollutants to the environment. While investing little on the process, it is possible to save a lot of money on waste disposal and operation of the process. Often the capital return period is less than 5 years.

The mining industries have also caught up with the above principles of waste management. They are particularly concerned about the wastewater being generated at their facilities. Not many studies are found in the area of application of source reduction principles for the wastewater management in mining facilities. However, several studies (Singh et al., 1996; Sivakumar et al., 1994) have reported the application of wastewater recycle/reuse principles in order to achieve cleaner production goals in collieries. Singh et al. (1996) reported, for one of the mine in Illawarra region (Australia), that the fresh water consumption can be reduced by about 50% (from 1500 m^3/d to 740 m^3/d) with a corresponding saving in the cost of AU$0.245 million/yr. However, in this study the issues related to stormwater management were not considered. In a recent study, Dharmappa et al. (2000) reported a case study relating to the application of cleaner production principles to both wastewater and stormwater management. It was proposed to manage the wastewater through in-plant recycle/reuse and the stormwater through source reduction.

In accordance with the current trend in the wastewater management in the mining industries, this article aims to cover the following issues:

- Identification of sources and characteristics of wastewater from the mine site;
- Wastewater minimization;
- Treatment of wastewater;
- Wastewater recycle/reuse;
- Final disposal of wastewater.

It should be noted that the most of the data presented in this article are related to coal mining industries, which are located in and around Illawarra region of Australia.

2. Wastewater Sources and Characteristics

In any waste management application, the first step is the identification of sources of wastewater and characterization of the same. The main sources of wastewater from a mine site can be broadly classified into:

- Mine water;
- Process wastewater;
- Domestic wastewater;
- Surface run-off.

The most probable contaminants in the wastewater produced by a typical mining industry can be broadly classified into 5 categories and are listed in Table 1. Out of these 5 categories, biological pollutants essentially emanate from domestic and sanitation facilities within the amenity building and usually they should be connected to an urban sewer or a properly designed on-site waste disposal system. Radiological pollutants are very specific to uranium and related open cut mines. It is important to realize that "effective prevention of contamination at source" is the only solution available for managing radioactive wastewater.

Main categories	Sub categories

Physical	Suspended solids (SS) Turbidity Color Temperature Taste and odor
Chemical (organic)	Coal Oils & grease Soaps & detergents Rubber Dyes and phenolic compounds
Chemical (inorganic)	Heavy metals (Cr. Hg, Cu, Cd, Pb, Zn, Ni, etc. Acids Alkalis Cyanide Dissolved salts: - Cations: Mg, Ca, K, Na, Fe, Mn, etc. - Anions: Cl^-, SO_4^{--}, NO_3^-, HCO_3^-, PO_4^-, etc.
Biological	Bacteria, viruses and small organisms
Radiological	Uranium Tritium and other radioactive substances from mine tailings

Table 1. Typical contaminants in mine wastewater (adopted from Sivakumar et al., 1992)

The physical and chemical type of pollutants are the most critical in most mining industries, particularly so, for the coalmines. Some of the important physical and chemical type of pollutants are discussed in the following sections.

Temperature: The temperature of the water is an important indicator of the biochemical activity. Every 10°C rise in temperature doubles the biochemical activity, within the temperature range of 5 to 30°C. Higher temperatures may result in the killing of aquatic organisms. However, there are very few mining operations, which add excess heat to the mine effluent. As such, thermal pollution is not considered to be a problem from mining operations.

pH: The pH of water is the measure of molar concentration of hydrogen ions in solution.

$$pH = - \log_{10} [H^+.] \quad (1)$$

The solubility of metals in water is pH dependent. Low pH values result in soluble species and high pH induces precipitation of metal oxides. The pH scale range from 0 to 14 and 7.0 is termed “neutral pH.” An important consideration with high sulfur content coal is the reaction of sulfur, oxygen and water and in the presence of bacteria forms sulfuric acid and lowers the pH. A pH of below 6.5 may be corrosive to plumbing fixtures and reticulation and the general guideline value is within 6.5 and 8.5 to all mine water discharges.

Suspended solids (SS): SS is the concentration of solid matter in suspended form and gives rise to one of the most common and visible water pollution problems in receiving water. Dark colored suspended particles associated with coal mining effluents may be considered by the public as unnatural. Suspended solids are the fractions of the undissolved substances in a water sample retained in a glass-fiber filter paper of 0.45 µm pore size. SS consists of silt and other fine ore material, which has the ability to remain in suspension for a prolonged period. However, given sufficient detention time, in most cases they will settle. Generally, accepted discharge limit on SS is 30 mg/L. These discharge limits vary widely from region to region and country to country.

Various sizes of suspended sediment particles can be discharged in mine effluents. The settling characteristics of these particles vary with the size, shape, density of mixture and several other factors.

Total Dissolved Solids (TDS) and Electrical Conductivity (EC): TDS refers to the Total Dissolved Solids content of a water sample. Electrical Conductivity (EC) is the numerical expression of the ability of aqueous solution to carry an electric current. High level of mineralization is a typical characteristic of many coal mining discharges. In most cases, a direct relationship between Electrical Conductivity and TDS can be established. This makes determination of TDS easier as EC can be measured readily with an instrument. Department of Resources and Energy (1983) has proposed the following relationship for Australian surface waters:

$$TDS = 0.62\ EC \qquad (2)$$

where,
TDS = total dissolved solids, mg/L
EC = electrical conductivity, µS/cm

The electrical conductivity for some typical sources of water is given in Table 2. As seen in the table, the electrical conductivity for mine water can be substantially high due to the presence of dissolved salts.

Sources of water	Electrical conductivity, µS/cm
Distilled water	0.5–2
Tap water	60–100
River water	200–800
Mine water	1000–10 000
Sea water	35 000

Table 2. Electrical conductivity of typical sources of water (Sivakumar et al., 1992)

Turbidity: Turbidity is a measure of fine suspended matter in water. The suspended matter scatters light and give a “cloudy” appearance. Hence turbidity is an indirect measurement of suspended matter. Increased turbidity in surface water may become objectionable since it limits light penetration and increases heat absorption. Particles causing turbidity can also be a medium of absorption and transport for bacteria. Turbidity is generally measured by a light scattering nephelometer. A light is passed through the sample and reflected light is measured as turbidity in Nephelometric Turbidity Units (NTU). In coal mine water for example, light is absorbed by coal particles rather than reflected. Turbidity measurements are not needed for mine effluents, but may be useful for receiving water impact studies.

Alkalinity: Alkalinity is defined as the quantity of negative ions, which will react to neutralize hydrogen ions. It is a measure of water's ability to neutralize acids. The principle components are bicarbonate (HCO_3^-), carbonate (CO_3^{--}) and hydroxide ions. Alkalinity is usually expressed in mg/L as $CaCO_3$. Water with very high alkalinity is caustic and cannot be used for many purposes. However, in mine waters, if excess alkalinity is present, pH reduction due to the biochemical reaction of sulfur compounds with water, can be avoided.

Acidity: Acidity in mine water results from the dissolution of carbon dioxide or sulfuric acid. The key effect will be that the pH will be reduced and the unwanted metals dissociate into the solution. pH adjustment is necessary before acidic wastewater can be discharged into a receiving water.

Chlorides: Chloride is naturally present in water in small quantities depending on the geological formations with which the water has been in contact. However, chlorides have been reported to have an adverse affect on metals associated with water handling systems (Peavy and Jennings, 1981). At higher concentration, it may also accelerate corrosion rates in the pipe systems. Water with excess chloride concentration is unsuitable for irrigation or domestic supplies.

Sulfates: Sulfates also exist naturally in water, which has contacted mineral deposit such as gypsum. But biological oxidation of pyrites results in dissolved sulfates, which can add significant concentration, even if fresh water is used as a carrier medium. Excess concentrations of sulfate have a laxative effect on the consumer and an unpleasant taste.

Nutrients (Nitrogen and Phosphorous): Nitrogen can be organic, ammonia or in other oxidized forms such as nitrites and nitrates. The nitrogen content in mine wastewater (except in the case of domestic effluent) is usually very small and in mine water it may not be a problem.

Phosphorous occurs in water as phosphates. The term "phosphates" include soluble orthophosphates and condensed phosphates in the form of precipitates. Phosphorous is an essential nutrient for plant growth. Excessive concentrations discharged to receiving waters such as streams and lakes, will eventually lead to eutrophication due to excessive plant growth "algae blooms." Discharge of excess phosphate could be a problem in phosphate mines, in all other mines, phosphate may not be present in significant quantities.

Non-toxic Metals: The metals such as Na, K, Ca, Mn, Fe and Mg are essentially non-toxic and are found in varying concentrations in mine waters. The Ca and Mg ions essentially add hardness to the water whereas Fe and Mn ions cause discoloration in water. Deposition in the pipe handling system may also occur.

Toxic Metals: Metals such as aluminum, zinc and barium may be found in mine waters relating to the coal industry. The concentrations are usually small. However, in the metalliferous mining industry, depending on the type of processing used, mine effluents may contain arsenic, cadmium, chromium, copper, gold, lead, mercury, vanadium and in the case of uranium mining, other radioactive substances may be present.

The characterization, assessment and control of these discharges, in active as well as discontinued mines are an important part of an overall environmental control program. The effect of heavy metals on the aquatic environment is considerable if discharges are not controlled. pH has significant effect on the solubility of metals in water. At alkaline pH conditions, metals tend to form compounds with hydroxides and carbonates, and precipitates out. At acidic pH conditions, soluble metal compounds are formed. For example, the solubility of lead changes from 0.21 mg/L at pH = 6 to 2072 mg/L at pH = 4.

2.1 Mine Water

This type of wastewater is generated in those mines where underground mining is practiced. The source for mine water is essentially from seepage of excavated area of the mine. The mine water is collected in underground sumps with a nominal retention time. There is an opportunity for recycle of mine water in the areas of fire fighting and underground dust suppression within the mining operation.

The quantity of the mine water greatly depends on the level of ground water table and the ground conditions. The quality of the mine water varies widely from mine to mine depending upon the local conditions. The main pollutants of the mine water are dissolved minerals from the aquiferous rock strata. Typically, the suspended solids (SS) levels of this stream are extremely low (Wingrove, 1997). From the literature data (Rozkowski & Rozkowski, 1994; Singh, 1994; Sivakumar et al., 1994b) a typical range of characteristics for the mine water can be identified as follows:

- High total dissolved solids (500 - 2000 mg/L)
- High hardness (500 - 2000 mg/L as $CaCO_3$)
- Low suspended solids (10 - 100 mg/L)
- Low BOD (< 5 mg/L)
- Low COD (10 - 100 mg/L)
- Near neutral pH (7-9.5)
- High conductivity (600 - 10,000 µs /cm)
- High apparent color (30 - 600 Units)
- Moderate concentrations of other minerals (Na, Mg, ca, CO_3^-, Cl^-, SO_4^{2-} and trace elements such as, Al, Fe, etc..)

As seen above, the mine water contains considerable amount of dissolved minerals, which give high hardness to the water. In the case of acid mine drainage, the pH can be as low as 2 - 3. This low pH is mainly due to the oxidation of sulfides.

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Bibliography

ARR (1998a). *Australian Rainfall and Run-off*, Volume 1, Book 2, *Design Rainfall Considerations*, The Institution of Engineers Australia, Canberra, p49.

ARR (1998b). *Australian Rainfall and Run-off*, Volume 1, Book 4, *Estimation of Design Peak Discharges*, The Institution of Engineers Australia, Canberra, p69.

ARR (1998c). *Australian Rainfall and Run-off*, Volume 1, Book 8, *Urban Stormwater Management*, The Institution of Engineers Australia, Canberra, p78.

ARR (1998d). *Australian Rainfall and Run-off*, Volume 2, *Rainfall Maps of Australia*, The Institution of Engineers Australia, Canberra.

Clean Waters Act (1970). New South Wales Government, Australia.

Department of Environmental Planning (1984). *Water quality aspects of the environmental assessment of underground coal mining*. Department of Environment and Planning, Australia.

Department of Resources and Energy (1983). *Water 2000*. Consultants reports 7 and 8. Water Quality and Salinity Issues, AGPS, Canberra, Australia.

DLG, NSW EPA, NSW Health, Land & Water Conservation and Department of Urban Affairs and Planning (1998). *On-site sewage management for single households*. Department of Local Government, NSW, Australia. [Gives overview of various on-site waste treatment and disposal options currently used.]

Dharmappa H. B., Wingrove K., Sivakumar M., and Singh R. (2000). Wastewater and stormwater minimization in a coal mine. *Journal of Cleaner Production* **8**, 23–34.

Freeman H. (1990). *Hazardous waste minimization*. McGraw Hill Publishing Company, New York. [Explains the general principles behind waste minimization in an industrial and corporate environment.]

Ives K. J. (1980). Deep bed filtration: Theory and practice. *Filtration & Separation* **17**, 157. [Provides fundamental and theoretical details on the operation of granular filtration process.]

Kawamura S. (1991). *Integrated design of water treatment facilities*. John Wiley & Sons, Inc. New York. [Explains the design and operation of various processes used in water purification.]

Kesseru, Z. (1994). *In-mine sealing of water inrushes*. Fifth International Mine Water Congress, Nottingham, 18–23 September. pp. 269–280.

Martin L. (1986). Waste reduction: the case for stopping wastes at their source. *UNEP: Industry and Environment* **9**(4), 35–37.

Metcalf & Eddy Inc. (1991). *Wastewater Engineering: Treatment, Disposal, and Reuse*. New York: McGraw Hill Inc. [Provides basic details on the Municipal wastewater treatment and disposal.]

Middlebrooks E. J. (1982). *Water reuse*. Ann Arbor Science, Michigan.

National Coal Board (1982). *Technical management of water in the mining industry*. National Coal Board Mining Department, London. [Provides a comprehensive analysis on the management of water and wastewater generated from a coal mining industry.]

NHMRC (1996). *Australian drinking water guidelines*. National Health and Medical Research Council, and Agricultural and Resources Management Council of Australia & New Zealand.

Overacash M. R. (1986). *Techniques for industrial pollution prevention: A compendium for hazardous and non-hazardous waste minimization*. Lewis Publishers, Inc. Michigan. [Provides extensive number of case studies on the application of cleaner production principles to various industries.]

Peavy H. S. and Jennings P. W. (1981). *Water pollution potential of coal: slurry pipelines*. Technical Report. Bozeman, MT: Montana State University. p. 89.

Rozkowski A. and Rozkowski J. (1 994). Impact of mine waters on river water quality in the upper Silesian Coal Basin. Fifth International Mine Water Congress, Nottingham, 18–23 September, pp. 811–821.

Rubinstein Y. B., Perelyaev Y. N., and Badenikov V. J. (1994). *Multisectional technology of wastewater purification*. Fifth International Mine Water Congress, Nottingham, 18–23 September, pp. 673–678.

Singh G. (1994). *Augmentation of underground pumped out water for potable purpose from coal mines of Jharia Coalfield*. Fifth International Mine Water Congress, Nottingham, 18–23 September, pp. 679–689.

Sivakumar M. (1992). Mine water quality and pollution. In R. N. Singh, *Minewater: Origin, Inflow Prediction, and Control*. University of Wollongong, Australia. [This book delves extensively into the origin, characteristics and management of mine water.]

Sivakumar M., Singh R. N., and Morton S. G. S., (1992). Mine water effluent quality in the Illawarra region. *Mine Water and The Environment* **11** (2), 1–10.

Sivakumar M., Morton S. G. S., and Singh R. N. (1994a). *Case history analysis of mine water pollution in New South Wales, Australia*. Fifth International Mine Water Congress, Nottingham, 18–23 September, pp. 823–834.

Sivakumar M., Singh R. N., and Morton S. G. S. (1994b). Mine water management and control in an environmentally sensitive region. *Mine Water and The Environment* **13**(1), 27–40.

USEPA (1976). *Effectiveness of surface mine sedimentation ponds*. EPA-600/2-76-117, Washington, DC.

USEPA (1993). *Storm water management and technology*. Noyes Data Corporation, Washington, DC.

Wills B. A. (1988). *Mineral Processing Technology*. 4th Edition. New York: Pergamon Press.

Wingrove K. (1997). Wastewater management in Illawarra coal mines. BE thesis, University of Wollongong, Wollongong, Australia.

Woolhiser D. A. (1975). Simulation of unsteady overland flow, Chapter 12 of *Unsteady Flow in Open Channels*, Volume II, eds. K. Mahmood and V. Yevjevich, Water Resources Publications, Fort Collins, Colorado.

World Health Organization (1984). *Guidelines for Drinking Water Quality*. Vol. 1, *Recommendations*. Geneva: WHO.

Yao K. M., Habibian M. T. and O'Melia C. R. (1971). Water and wastewater filtration: concepts and applications. *Environmental Science & Technology* **5**, 1105–1112.

Biographical Sketches

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