Review

Technological options for waste minimisation in the mining industry

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Abstract

Just as the application of technology in mining processes can cause pollution, it can also be harnessed to minimise, and sometimes eliminate, mine-related contaminants. Waste minimisation can be achieved through decreased waste production, waste collection, waste recycling, and the neutralisation of pollutants into detoxified forms. This article reviews examples of how technology can be used to minimise air, water, land and noise pollution in the mining industry.

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1. Introduction

Although technological advancement has been the leading cause of pollution, there is now a wealth of apparatuses available for minimising, and sometimes completely offsetting, the adverse effects brought about by industrial activity [1,2]. Technological advances often allow a particular task to be performed using less energy and resources [2]. Reduced resource use not only conserves raw materials but can also minimise expenditure and waste [2].

Potential sources of environmental pollution in the mining and mineral processing industry include the following — drainage and sediment run-off from a site, air emissions, spills, dust, destruction of the site as well as surrounding areas, abandoned equipment, plants and buildings, and land instability and degradation [3]. Speaking abstractly, Phillips et al. [4] argue that technological applications have had a profound influence on pollution engineering and control, from computer modelling of chemical and biochemical phenomena to biotechnological solutions [4]. Harnessing appropriate technology for use in the mining industry could go a long way towards minimising on-site wastes.

The purpose of this paper is to review the progress made towards pollution and waste minimisation by the mining industry. The paper examines certain methods of pollution control used for air, land, water, tailings, sulphur and noise by the mining and mineral processing industries, drawing upon case study analysis in the Australian mining industry. Each is examined individually in the sections that follow.

2. Air pollution

There are a number of sources of air pollution, including dust, industrial emissions and flue. Emissions of dust are a large part of the air pollution problem at mine sites. The main sources of air pollution in the industry include unpaved roads, excavation activity, dumps, tips, conveyor belts, open cut and cleared areas [6]. The release of dust into the atmosphere can,
however, be minimised and controlled by applying water to, and enforcing speed limits on, roadways, constructing enclosures over conveyors, re-vegetating soil heaps, and limiting the free fall of rock and soil during dumping processes [6].

Machinery is often used to remove dust particles from emissions [1,5,6,7] because the dust loads in industrial emissions are approximately 100–20,000 times the amount for which filtration systems are designed [5]. Settling chambers (or knock-out pots) and cyclones are used to remove the larger dust particles present in emissions [7,8]. The settling chamber was one of the earliest technologies used for this purpose (see Fig. 1). It consists of a large chamber in the pipeline that reduces the velocity of the gas and, because the travelling speed of the gas is reduced, the larger dust particles settle, and are collected in the base of the chamber. They are generally used for the removal of large particulates – larger than 60 μm [8] – and serve as preliminary cleaners [7]. Trays are often inserted into the chamber to reduce the distance dust particles fall. Although overall collection efficiency is low, settling chambers are generally inexpensive to install and operate [8].

Cyclones, which use centrifugal forces (rather than gravitational forces as in the settling chamber) to separate dust particles from gas, are often included within an overall air pollution control system [7,8]. They have low installation and operating costs, and are relatively small, and therefore, are the most frequently used form of dust collection equipment [7]. The smaller diameter cyclones are generally found to be more efficient, giving a centrifugal force of up to 2500 times gravity. Industry often uses multi-cyclonic systems, which comprise a series of smaller cyclones embodied within a single unit [8]. The efficiency of a cyclone can be increased by reducing the diameter of its interior, increasing its body length, and increasing the ratio of the body-to-gas outlet diameter [1]. The most common cyclonic dust extractor in use internationally is the vertical tangential inlet-type cyclone (Fig. 2). The Ampol Lytton petroleum refinery in Brisbane, Queensland, uses a two-stage cyclone, and the Alcoa bauxite refinery at Kwinana, Western Australia, uses a series of cyclones and multi-clones [6].

For the removal of fine particulate matter measuring less than 5 μm in diameter, the control devices generally deployed include the electrostatic precipitator, the fabric filter (bag-house), and the wet collector/scrubber. Electrostatic precipitation (see Fig. 3) is the most efficient of all techniques for removing solid particles and tiny liquid droplets from polluted gas [1]. The gas containing particulate matter is passed through an intense electric field of up to 50,000 volts (a corona charging field) between two electrodes of opposite polarity [1]. The voltage is applied to negatively charge the dust particles, after which, they are attracted to the positively charged (earthed) collecting electrodes [1,7]. Efficiency is affected by the flow speed of the gas through the electrode system, temperature (of the gas), concentration of the dust, and particle size. The method is capable of removing particles down to 10 nm in diameter [1], and is up to 99.5%
efficient [10]. Although expensive to install and maintain [6], electrostatic precipitation operating costs are generally less because of low energy consumption [1]. The power requirements are approximately 50% of those of comparative wet scrubbing systems, and 25% of equivalent bag filter systems [10]. Electrostatic precipitation is a featured process at Kalgoorlie Consolidated Gold Mines Ltd., Western Australia (the gas passes through electrostatic precipitation before being released into the atmosphere through a 180 m stack), at the Alcoa alumina refinery at Kwinana, Western Australia, and a number of international locations [6].

Fabric filters are often used as an end stage filtration unit, and consist of a layer of woven cloth or felt, which is used to retain solids [6]. This method is very efficient but has two disadvantages. Pressure drops as gases pass through the filtration medium [1]. A mat of collected dust particles forms on the air-entering surface of the fabric and becomes part of the filtration process capable of removing sub-micron dust and fumes, while the fabric serves mostly as the support structure for this mat [7]. Filters of this type are used in the new Redbank Power Station in the Hunter Valley, New South Wales [9,11].

The Venturi Scrubber (see Fig. 4) removes particulate matter and certain gas contaminants from the flow gas by forcing it through a liquid stream, resulting in atomisation of the liquid [1]. High differential velocity between the dirty gas and the liquid droplets causes impaction of the particles, which then agglomerate to form larger droplets. Finally, liquid droplets are thrown against the wall of the separator chamber, after which, the clean gas is discharged out the top [12]. Before the dirty gas is released into a wet scrubber, the temperature must be lowered to well below 100 °C, and the clean gas must be reheated before being discharged into the atmosphere [1]. The water is pumped back through the system until it is no longer capable of holding more particulate matter and dissolved substances. It is then removed for disposal [12]. This process operates at about 85% efficiency for the removal of sulphur dioxide, 30% for the removal of nitrogen oxide, and about 99% for the removal of particulate matter [1].

Thus far, the pollution control technologies discussed have been predominantly designed for the removal of particulate matter from gas emissions. The removal of gaseous pollutants is also a necessity, and is undertaken through the use of specific technologies. For the removal of sulphurous oxides, limestone injection is most commonly used. This is a process whereby limestone is milled with coal and fed into the furnace. Polluted gases are pre-heated and then disposed of into furnaces, where the limestone reacts with sulphur dioxide (SO2) and oxygen (O2) to produce calcium sulphate (CaSO4 or gypsum). This process removes approximately 20–30% of sulphurous oxides. The sulphates, fly ash and un-reacted lime pass through the pre-heater once again before entering the wet scrubber, where they come into contact with water and are subsequently removed to a settling tank. The removal efficiency is approximately 80% for SO2 and 98% for particulate matter [7].

3. Water and land pollution

The management of the release of water, and any dissolved colloidal or particulate matter within it, into the environment, is of chief concern in the mining and allied refining industries. Water is a basic provision in mining, where it is used for dust suppression and drilling, in the washing and processing of mine product, and as an aid in the establishment of vegetation during mine-site rehabilitation. Water is also important for mobilising contaminants, and is the primary medium for removal of on-site pollutants, which often contributes to land pollution [6]. Mining operations interfere with the natural circulation of water as ground water accumulates in pits, which must be removed to prevent flooding. Maximum water recirculation through all circuits is the principal means for reducing water use within a mining system. Major pollutants emanating from surface and underground mining operations include sediments, toxic substances and acids [13]. All treatment systems are also susceptible to failure, which makes sound management practice and the use of back-up secondary treatment systems imperative [4].

In terms of exposure to air and water, tailings from sulphide-rich areas can potentially generate sulphuric acid. Ore bodies containing toxic elements such as arsenic, and cyanide in tailings must also be handled appropriately [14]. In some circumstances, the water utilised in a company’s operations can be recycled and treated, and often, valuable material can be recovered (see Fig. 5). The water can also be recovered and reused once contaminants are removed [19].

Fig. 4. Schematic representation of a Venturi Scrubber [10].
The Portuguese pharmaceutical manufacturer, Hovione, has developed a ‘total approach’ strategy to waste minimisation. Rather than investing in ‘end-of-pipe’ solutions, the company devised a systematic and progressive approach to their waste problem [19]. Since the inception of their recovery system, the company has reduced their solvent purchases by 85% and has achieved a 65% reduction in their chemical oxygen demand (COD). The larger the COD value, the more the oxygen demand from water bodies [19,20].

4. Tailings

One of the main sources of land contamination in the mining industry pollution is mine tailings, which generally take the form of fine-grained slurry with a coarser fraction [14]. The coarser fraction has good consolidation properties whereas the finer fraction consolidates very slowly due to particle size. Excess water can be removed from tailings using dewatering devices such as rake or screw classifiers for coarser particles, and thickeners or filtration mechanisms for finer particles [6]. However, even following the removal of water, tailings generally remain 20% saturated [14].

Tailings are pumped and stored in large dams, which are generally lined with an impermeable geo-membrane (often clay) and are often further lined with a plastic membrane (e.g. at the Ovacik gold mine in Turkey, owned by Newmont Australia), consisting of polypropylene sheeting between two layers of clay [15]. The location of a tailings dam also determines its potential

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Fig. 5. Waste treatment and recovery flow chart as used by Hovione [20].
environmental impact. At the Codelco Copper Mine in Chile, for example, the locations for tailings dams were selected in areas with base material of low permeability, lacking permanent water flow, and where ground water is situated well below the impervious base [16]. The design of a storage system is also a key strategy in minimising pollution. The Mount Keith nickel operation (WMC Resources Ltd) utilises a central discharge facility to store tailings pumped from the risers spaced throughout the facility, which deposit with a gentle side slope (approximately 3%) that helps reduce erosion and saline seepage into ground water. The structure of the tailings is maintained because there is no permanent water storage, and there are no dams to collapse (as is the case with conventional dams, which store tailings and pond water). The facility is surrounded by a perimeter embankment wall, mainly to carry the tailings distribution lines [17].

As previously explained, one of the most common contaminants in tailings — particularly those generated in Australia — is cyanide. Much of the water contaminated with cyanide is recirculated and reprocessed to minimise the consumption of cyanide (an expensive process), although some is released from the system as tailings water [6]. At the Ovacik gold mine in Turkey, the cyanide-containing tailings are treated in a cyanide-destruction plant, and then discharged to the tailings dam [15]. The INCO-SO$_2$ process has become the chief cyanide-destruction measure used in the gold processing circuit. In the INCO-SO$_2$ process, SO$_2$ and air are added to the cyanide-infested tailings, and copper sulphate is added to catalyse oxidation and precipitate iron cyanides into soluble copper salts. Ferric sulphate is then added to precipitate arsenic and antimony, and to suppress residual iron cyanides. More ferric sulphate is added to further reduce the presence of antimony. The concentration of cyanide discharged to the tailings dam is less than 1 ppm (1 mg/L). Cyanide is also degraded in tailings through a complex cycle of chemical reactions within the sedimentary layer, the aqueous region, and the air (Fig. 6).

5. Sulphur compounds

The containment and safe disposal of sulphur compounds pose another environmental challenge at mine sites. The Australian mining industry produces hundreds of millions of tonnes of waste rock, coal rejects and tailings every year, much of which contain sulphide minerals. If left exposed to the air, they can oxidise and form sulphuric acid (H$_2$SO$_4$), which, without neutralisation, can solubilise available metals, and if leached from the dam, pose a significant environmental hazard [6].

Sulphuric acid can be reduced by restricting the exposure of tailings to oxygen, and through minimising
water movement into tailings. The Mount Leyshon gold mine in Queensland deploys both of these strategies to reduce the production of sulphuric acid in tailings. The tailings dump was “sealed” with porphyry to a thickness exceeding 1 m and compacted. This minimises the entry of oxygen and maximises run-off, therefore minimising possibility for seepage from the surface (see Fig. 7).

Before disposal into water courses, acidic mine effluent requires treatment in order to achieve a suitable pH, remove iron and heavy metals, and reduce sulphate content.

The Mount Lyell copper mine, as well as many of the smelters in Queenstown, Tasmania, produces substantial amounts of sulphur dioxide (SO₂) gas which, in wet climatic conditions, produce sulphuric acid rainfall. Episodes of acidic deposition, along with the timber logging that occurs to supply mines and feed smelters, have ravaged the landscape (see Fig. 8). Waste tailings were also deposited into the Queen River, which flows into the King River and downstream to Macquarie Harbour, forming a tailings-rich delta at the river mouth [6].

In underground mining operations, ground water accumulates and must be removed in order for activities to continue. The composition of the effluent depends on the constitution of the surrounding soil, the ore being mined, and the depth at which excavation occurs. Minimisation of acidic mine effluents can be achieved by redirecting run-off into drainage basins off-site, and by segregating ground and surface waters. Corrosive acidic water can cause structural damage to mined metal and concrete components of bridge pylons, turbines, and the walls of dams [21].

Approximately 50% of the coal mines in the Upper Hunter Valley region of New South Wales experience a problem with the inflow of ground water, which exceeds all on-site opportunities for consumption. The water is generally saline and must be stored on-site until the Hunter River flow rate is high enough to sufficiently dilute the short duration, high rate discharges. Coincidentally, the high flow-rate conditions occur when there is widespread rain in the catchment area, at which time, the river water is used least for irrigation purposes [6].

There are other options available for treating of acid mine waste. Notable options include repeated pumping to retain control over drainage, and plugging the drainage points to allow mine to refill (only useful once mining is completed in the location) [20]. In 1999, MIM Holdings (now owned by Xstrata) was awarded the Environmental Excellence Award by the Australian Minerals and Energy Environment Foundation for their Internally Drained Rehabilitation (IDR) technique [22], which was developed at Oaky Creek in the Bowen Basin of Queensland, and is now utilised at MIM’s Newlands coal mine (also in the Bowen Basin) as well. The IDR technique was specifically developed to manage with low, irregular rainfall and elevated soil salinity. Water is captured in a series of shallow terraced ponds, and drains internally, leaching out salt, in turn, improving the soil quality, minimising erosion and preventing run-off [22].
6. Noise pollution

Noise pollution can prompt workers to make compensation claims (for hearing loss). Noise in industry originates from processes causing impact, vibration, friction or turbulence [1]. It can be minimised and controlled through the use of various strategies, including the following:

- Ensuring adequate separation between operations and residential developments.
- Locating haulage roads sufficient distances from residential areas and with maximum screening by hills and ridges — where possible — and maintaining roads.
- Enclosing high noise producing machinery within acoustic enclosures.
- Constructing earth mounds along or around high noise areas. A barrier of this type is currently utilised between the Fimiston open-pit mine and the city of Kalgoorlie-Boulder.
- Limiting operating hours — adequate scheduling of the noisiest operations should occur during the day when the impacts are less significant [6].

A decision should be made during the design and planning stage of an operation to account for the likely noise production and emissions, and could involve such aspects as the layout of the facility, the location of the (often) purpose-built residential areas, and the location of roadways to, and from, the site [1]. It is most cost effective to control sources of pollution in the design stages and work processes wherever possible.

7. Conclusion

Worldwide, there is much legislation that penalises companies that pollute the environment. This review has examined various options in practice for reducing pollution at mining operations, which help ensure legislative compliance. The review only touches on the wealth of technological options available but nevertheless illustrates how marked waste minimisation can be achieved at mines through the implementation of advanced apparatuses and improved site design.

References