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Determination of Mineral Proccesing Induced Environmental Impacts

İLGIN KURŞUN
Mining Engineering Department, Istanbul University, Avcilar, Istanbul, Turkey
E-mail: ilginkur@istanbul.edu.tr

In this study, the mineral processing, environmental technology and the application of new or improved methods both of mineral processing and the treatment of solid and liquid wastes is discussed, and to provide the appropriate background to apply mineral processing techniques so as to minimize environmental degradation.

Key Words: Determination, Mineral proccesing, Environmental, Impact.

INTRODUCTION

Mineral processing produces numerous wastes and products that can cause water contamination: tailings, waste rock, laboratory wastes, chemical reagents and contaminated containers (solid wastes), blasting compounds, smelter slag- dusts, spent leached ores and ore stockpiles. In addition, the associated infrastructure that must be developed to support a large mining and processing operation generates sewage wastes, water treatment sludges, oils, petroleum, diesel fuels, etc.[1]

Environmental problems in mineral processing

As noted earlier, natural concentrations of some non-ferrous metals are very low and invariably contain undesired impurities. Hence, the tonnage of waste products in the form of tailings and overburden can be very large, amounting to million tonnes per annum from an individual copper or uranium mine. Due to the in-ground concentration effect, tonnages moved and processed are often of the same order for large copper and iron mines. In relation to all foreseen needs, there are ample resources of all metals to be found in the top mile of the earth's crust. The limitations to winning these metals are the availability of cheap power and, to a lesser degree, practicable technology to isolate and extract deeply occurring metals[2]. Non-ferrous ores are extracted from both open-pit and underground mines, and occasionally from the two in combination. Where a choice is possible from technico-economic considerations, the balance has to be struck between ensuring the health and safety of the mining workers, usually easier in open-pit than underground mines, and the disposal of waste products, which is usually less intrusive in underground than open-pit mines which have the added problem of 'hiding the hole' at closure. Successful restoration of a worked-out underground mine is usually a simpler task than for an open-pit operation[3]. Mineral processing is concerned with the extraction and purification of valuable commodities from the earth. The raw materials produced by mining are highly impure and must be upgraded before they are of use to society. For example, the cleaning of coal to minimize pollution is an area of national and international concern. Energy, raw materials and the environment are some of the most serious problem areas facing the world today. Mineral processing engineers play a key role in solving these problems. The refining of mineral commodities involves a broad variety of problems, mostly associated with the production, handling and separation of solid particles. Particle systems are also critical to many of the processes and products of modern industry: materials, chemicals and electronics as well as minerals. Mineral processing engineers are at the forefront of the science and technology of particle systems, and many of the techniques and procedures used in mineral processing find direct application in other areas. Training of a mineral processing engineer involves interdisciplinary study of chemistry, physics, the geological sciences and engineering with special emphasis on concentration by physical methods; surface chemistry of particles; particle processing; chemical and thermal extraction processes[4].

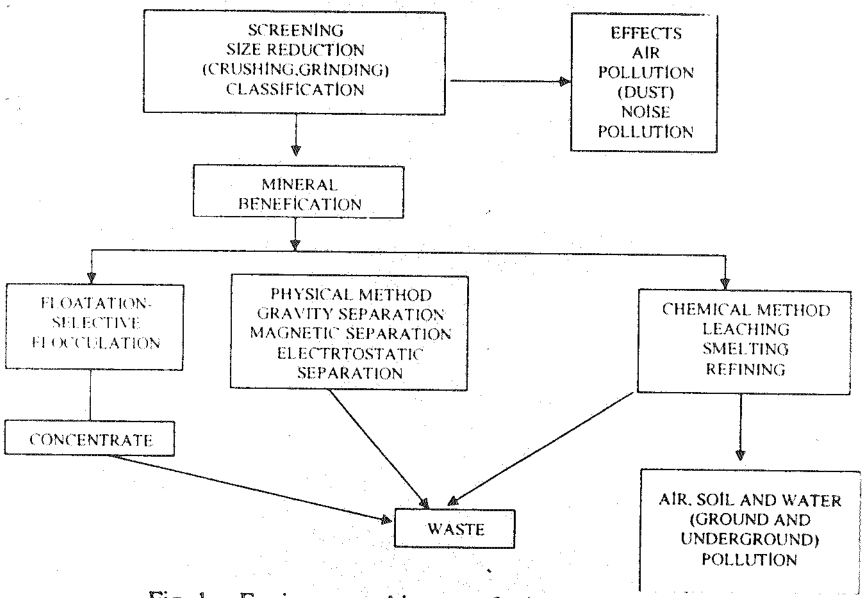

Fig. 1. Environmental impact of mineral processing

Size reduction

Minerals are preferably rough crushed in jaw crushers and subsequently screened, with the oversize being returned for recrushing. The normal fractions are collected in a surge bin. A conveyor transfers the material from there to the fine crusher. Classification to standard sizes involves continuous feedback of the oversize and interim storage of the standard-size fractions. Additional classification and particle-size reduction can be effected in rod or ball mills, with separation of the desired size fractions and raw materials. Milling is the combination of the extracted ore into particles which can be subjected to a recovery process which separates the valuable materials (concentrate) from the valueless material (gangue). The term is now usually used to cover the floatation process (or a chemical treatment process in the cases of alumina production from bauxite; gold and uranium) which is now an essential part of all non-ferrous mining operations. After primary and secondary crushing and screening, milling operations start with grinding in a multiplicity of ball and rod mills. All these processing steps involve dust and noise emissions that can emburden both the workplace and the environment[5].

There are no generally applicable values for the dust quantities encountered, because they depend on the crystalline structure of the minerals and of their geological association, requisite extent of crushing and various engineering factors. However, in view of now-common ore throughputs of up to 50,000 t/d, even minimal proportional dust emissions can put pressure on the soil and vegetation around ore processing facilities. In particular, the attendant deposition of heavy metals can jeopardize human health by way of the food chain and the presence of fibrogenic dust at the work place can cause silicosis or asbestosis. In order to minimize dust pollution, the machinery should be encapsulated[6]. Wherever that would be unfeasible for technical reasons, the dust-laden exhaust air should be collected and put through a dust precipitator. The type of filter to be used depends on the composition and particle-size distribution of the dust. Generally, cyclone filters are used for coarse filtering, while fabric filters serve to remove fine dust particles. Such equipment can achieve residual dust contents (clean gas dust loads) of less than 10 mg m^3. Equipment operators at dusty workstations must be required to wear dust masks (particle respirators). Masks designed for use in very warm climates should have appropriately large filtering surface areas[7].

In the interest of noise control, such facilities must have enclosures with a minimal number of openings. Since processing plants operate around the clock, suitable noise control measures in the form of safety distances, embankments, shielding walls and the like must be planned in at an early stage to preclude excessive prejudice to adjacent residential areas. The only real options for limiting the workplace noise nuisance is to automate and install control centre. The operators of noisy equipment generating high acoustic intensities must be provided with ear protectors and made aware of their importance for preventing noise-induced deafness[8].

Mineral benefication

Such operations, collectively referred to as *beneficiation*, are often carried out near the extraction point, to minimize transport of low-value materials. In contrast, the impacts of beneficiation processes are conditioned more by the material properties of the desired product than by the geological properties of the ore body and its surroundings. Many metals are high-value materials present in their ores at relatively low concentrations. Large quantities of ore may be processed near the mine site, generating commensurately large quantities of waste (tailings). Metal ions are soluble in acid and many beneficiation processes for metallic ores involve leaching by acidic solutions. Materials separation is less of an issue, but sizing may be important. The impact of grinding and sorting operations carried out in these types of materials is more likely to be associated with air quality (airborne particulates) than with solid waste (tailings piles). Beneficiation of coal is advantageous in producing a higher value and cleaner burning product, but the benefits on the consumption end must be weighed against the impacts associated with the beneficiation process. Wet processes in general, even those without chemical additives such as washing, may also be associated with environmental impacts involving the discharge of wastewater. Ore processing facilities use water for separating buoyant and nonbuoyant, *i.e.*, floating and nonfloating, materials: in cyclones and screen classifiers for grading by gravimetric separation or for pulp preparation, where water serves as a working medium for separating the useless material by gravimetric means and for eliminating suspended solids from the concentrate. The overall water requirement varies widely, depending on the type of raw material, the nature of the deposit and the processes employed. Dense-medium techniques are used exclusively for the coarse-size range, with medium solids consisting of magnetite, lead glance (galena), ferrosilicon and, occasionally, heavy spar (barium sulfate). Between 0.3 and 1 g of sodium hexametaphosphate can be added per litre of pulp to reduce its consistency. The water used in heavy media separation processes should be recirculated. Accordingly, the entrained solids have to be separated out in settling tanks, irrigated electrostatic precipitators or hydrocyclones. Even if the water from pulp regeneration is recirculated, the fresh water requirement can still amount to 0.5–1.5 m^3/ton of crudes. The process water should be appropriately treated and recirculated. Processes in which the water is discharged into a recipient body on a once-through basis can cause silting and contamination of the receiving water due to high sediment contents and residual chemical additives. The surface and gravitation water (percolation) from rubbish dumps should be collected by way of an impermeable peripheral trench and tested before being released to a recipient body. Moreover, before the water is discharged, its settleable solids content must have been ascertained as appropriate to the outlet channel's own sensitivity and intended use. Depending on the material composition of the tailings in the pond and/or of the rubbish in the dumps, additional testing for the presence of environmentally relevant pollutants such as heavy metals and processing chemicals may be necessary. The treatment required for the impounded water may consist merely of settling in an appropriate basin or, depending on the entrained substances, of physico-chemical processes (*e.g.*, precipitation, flocculation, chemical oxidation, evaporation etc.).

Floatation-Flocculaiton

Froth floatation, by far the most widely used concentration method, is based on conferring hydrophobicity to the individual particles and hence assisting their attachment to air bubbles. Particles with higher mineral content then rise to the surface of a froth which is skimmed. The remaining barren particles become tailings. The floatation reagents used tend to be specific for particular processes.

Concentration by floatation is achieved with the aid of floatation agents. Special chemicals induce physico-chemical surface reactions that are useful for separating and separately concentrating mixed and disseminated ores that have been sufficiently comminuted to eliminate most intergrowth between the constituents of interest. Consequently, the solid contents of floatation slimes in part occupy the microfine to colloidal size range. Since such slimes sediment out very slowly, part of the process water can be recovered more quickly by dewatering the floatation products in thickeners. The still-wet mining wastes (tailings) are then pumped into settling tanks and given ample time–perhaps a week–for extensive sedimentation of solids. The liquid phase can be recaptured as gravitation water.

Among the various floatation agents, distinction is made between collectors, frothers and modifiers. Collectors or collecting agents are surface-active substances that make the surface of the ore water-repellent. Organic compounds serving as collectors are selectively employed according to the type of ore. In the floatation of sulfide ore, for example, between 10 and 500 g of xanthate is needed per ton of ore, while anywhere from 100–1000 g of sulfonates or unsaturated fatty acids are consumed per ton of nonsulfide ores.

Frothers, or frothing agents, which influence the size of air bubbles and help stabilize the froth in the floatation apparatus, include terpenes, cresols, methyl isobutyl carbinol and monomethyl esters of various propylene glycols. Consumption levels run between 5 and 50 g/t for floatating crude sulfide ores.

The modifiers or modifying agents, include chemicals for regulating the pH: lime, soda and caustic soda for adjusting the alkalinity and predominantly sulfuric acid for acidification. Passifiers and actifiers, which are used to intensify the differences between the water-repelling properties of the ores to be separated, include copper sulfate and zinc sulfate. Alkali cyanides serve in the selective floatation of sulfide ores. The amounts required range from 1–10 g/t ore. Sodium sulfide, dichromate, water glass and complexing agents also belong to the group of selective floatation agents.

Many floatation agents and other chemical additives constitute a hazard to water. Consequently, carefully monitored dosing apparatus is required to preclude overdosing and special safety requirements must be met by plant and equipment used for storing, decanting, handling and using such hazardous-to-water floatation agents. The facilities must be designed to safely preclude contamination of surface water and groundwater to an extent reflecting both the pollutive potential of the substances in question and the protection requirements of the relevant locations, *e.g.*, potable water protection areas. Impervious, chemical-resistant, drainless collection and holding vessels must be provided to the extent necessary for intercepting in a controlled manner any media that may escape as a result of leakage, overfilling or accidents. The retention volume must suffice to hold back the escaped substances until such time as appropriate countermeasures can be brought to bear. Additional safety precautions include double-walled storage tanks, overflow prevention devices and leakage sensors.

Chemical processes

Leaching is the concentration method favoured in some operations, sometimes in conjunction with floatation. The largest-scale example is the separation of alumina from bauxite by the Bayer process in which caustic soda is used to dissolve out the hydrated aluminium oxide; others are the use of sulfuric acid to acid-leach uranium oxide and some copper oxide ores and the use of sodium cyanide in the extraction of gold. Disposal of spent leaching solutions after metal ion recovery may present wastewater problems. Non-metals, such as quarried stone, limestone, sand and similar materials may be more directly usable as extracted. Solvent extraction processes may present even more difficult challenges in minimizing the release or disposal of spent solvents.

Smelter wastes such as slag and dusts can also result in contamination of surface and ground waters. Smelter slags, despite numerous claims by industry, often release contaminants, especially where the reacting waters have unusually high or low pH, and/or are salty or briny. Smelting (heating up ore to separate it from the gangue) produces very large amounts of air pollutants, notably as SO_2 (sulphuric oxide, responsible for acid rain).

Metallurgical processing typically involves the isolation of a metal from ore concentrates by phytometallurgical, hydrometallurgical or electrometallurgical methods, singly or in combination. Phytometallurgical processes such as roasting and smelting result in atmospheric emissions (of sulfur dioxide, particulates and heavy metals) and slag containing toxic metals. Hydrometallurgical methods typically retain pollutants in the aqueous phase only, and those which are not recycled are discharged usually to the tailings pond. Wind entrainment of dry tailings can result in indirect airborne pollution from hydrometallurgical processes. Some of the chemicals used in ore processing (such as cyanide, mercury and strong acids) are inherently hazardous, and their handling, use, storage and disposal should be carefully controlled in the interests of health and safety, and the environment.

Roasting

The processing of sulfide ores includes roasting. The roasting gases contain large amounts of sulfur dioxide and therefore require gravitational separation (inertial impaction) and electrostatic precipitation. Further processing of the incidental sulfur dioxide should be obligatory, because release of the unprocessed roasting gases would unavoidably destroy most of the vegetation around the roasting plant. It is particularly important that the feed and discharge devices on the roasting furnace be airtight. Fabric filters mounted on the roasted-ore silo can extensively preclude dust emissions. To the extent that the blowers give off too much noise, their encapsulation is recommended. A chlorinating roasting process may involve the formation of polychlorinated dibenzodioxins and furans in the exhaust gas, the roasting residue and/or the slag, depending on the operating conditions and on the nature and extent of organic substances. Whenever the formation of any such harmful substance is detected in connection with a chlorinating roasting process, the operating conditions must be altered such as to minimize the level of emissions.

In addition to flotation, leaching and amalgamation also serve as separation processes. In gold mining, for example, the gold is extracted from the gravity-separated concentrate by making it react with metallic mercury to form amalgam. The concentrated residue is then leached with a cyanide solution. Both processes have negative environmental impacts that are very difficult to control. The mercury content of the effluent is particularly problematic, if the wastewater is discharged to the outlet channel without having been treated. It is still an open question as to whether or not the new ion-exchanger resins will, in the long run, be able to bind enough mercury to meet the residual concentration requirements. Leaching involves the use of numerous different chemicals. In gold processing, for example, these include cyanide, lime, lead nitrate, sulfuric acid and zinc sulfate.

The processes themselves also jeopardize the air, water and soil. All measures and precautions that would apply to the concerns of environmental protection and occupational safety in connection with an industrial-scale inorganic chemical process must be allowed for at the planning stage. This would include, for example, capturing the exhaust vapours from the reaction tanks and vessels and installing vapour scrubbing equipment (vapour stacks) to prevent harmful emissions. The aqueous solutions emerging from filter presses should be recirculated and the waste sludge from suction filters must be tested for disposability and treated as necessary. The waste water from amalgamation and leaching processes requires periodical monitoring.

Storage and handling of concentrate; recultivation

If concentrates are stored outdoors and unprotected, wind- and precipitation-induced erosion can pollute the air, the soil and the waters. The ground in the storage area should be sealed to prevent contamination of the top soil. Continuous maintenance of adequate surface moisture and/or covering the ground with mats does not always suffice to prevent all wind erosion. Consequently, the concentrate storage area should be roofed over and enclosed and appropriate measures, *e.g.*, low dumping heights, should be taken to minimize dust generation during loading and unloading.

The extent to which planned heaps and sedimentation facilities would occupy the former life space, *i.e.*, the habitats, of local flora and fauna must be ascertained on a case-by-case basis. The possibility of promptly recultivating slopes should also be examined as a means of preventing wind-and water-induced erosion while achieving a certain degree of ecological compensation.

The nature and extent of early recultivation must be discussed and coordinated with those responsible for regional/landscape planning and defined in a catalogue of measures. If the area in question is to be used for agricultural or horticultural purposes, the anthropogenic pollutive burdens in the stored material and their mobility (pollutant transfer factors) must be accounted for by appropriate measures such as sealing or compacting of the subsoil to interrupt the paths of emission. Even at the planning stage, information should be gathered on the availability of cultivable materials fit for land restoration.

Tailings disposal

Tailings are finely ground host rocks resulting from the chemical extraction of the required minerals. Mineral processing activities sometimes involve grinding the ore, adding various chemicals and possibly several physical separation processes. These processes result in wastes called tailings, which contain numerous metal and non-metal residues from the ore, but also contain high concentrations of the process chemicals. These compounds may include kerosene and other petroleum-based or organic compounds, organic acids, cyanide and related compounds, various acids, lime, etc. At modern operations, these tailings wastes are generally sent to engineered impoundments which are often lined with synthetic liners. At older operations, or in areas of lax oversight, tailings may be disposed of directly into stream channels or into the ocean. (*e.g.*, pre-1997 Southern Peru Copper and Chanaral). Where uncontrolled, these tailings wastes obviously can cause significant contamination of all water bodies. Such solutions are often very high in pH (10–12), and may contain potentially toxic concentrations of numerous metals, radioactivity, non-metals, cyanide and related breakdown compounds and organic compounds.

Even where modern impoundments have been constructed, significant chances for long-term contamination exist. All liners leak to some extent, and this leakage may only be detected after several years of operation or following mine closure. Also, impoundments in Andean countries are often subject to strong seismic events that make construction details very important, and require long-term maintenance of these structures after closure—to prevent both catastrophic failures and chronic leakage from developing. Since many copper ores also contain commercial concentrations of other metals and metalloids like molybdenum, selenium and gold, cyanide compounds are often used in the separation process. Normally, the concentrations of cyanide and related compounds in copper tailings may be toxic to fish, but are much lower than in gold tailings. Collapse of a cyanide and metal-laden tailings impoundment at a gold processing facility in Romania recently caused tremendous damage to rivers, fish, wildlife, crops and water supplies along hundreds of kilometers of rivers in central Europe[28].

Many of the processes described above result in the development of facilities that require long-term maintenance to prevent deterioration and serious contamination from developing, *i.e.*, tailings impoundments (with or without caps and liners), spent heap leach piles, waste rock piles (with and without caps), diversion/ pumpback/infiltration facilities, areas of revegetation, "passive" treatment systems, etc. In addition, several sites in developed countries now have water treatment plants operating after mine closure to correct ARD or other water quality problems. Some are anticipated to operate for decades after closure, or in perpetuity. Such plants and facilities require continual, long-term maintenance and may be the most costly environmental activities associated with mining.

The previous impacts have been labelled water quality impacts. More correctly, these impacts may be described as damages to domestic and municipal water supplies, livestock water uses, agricultural uses, *i.e.*, situations where mine leachates may impact orchards or vineyards, human health, fisheries and aquatic life—freshwater and marine (fish and shellfish), and selected industrial water uses. Such impacts can also have indirect impacts on social, educational and touristic portions of an economy.

The critical issues to consider in evaluating alternative tailings disposal options include:

- the geochemical characteristics of the area to be impounded/inundated by tailings, and potential for leachate migration from tailings;
- seismicity of the area, or other natural hazards and risks that might affect the suitability of potential disposal areas or influence the engineering design;
- other siting issues including conflict with sites of ecological, cultural heritage, agricultural or other importance;
- chemical characteristics of sands, slimes and pond water, and requirements for treatment;
- the water management regime and requirement to discharge effluents (if any) and the degree of treatment required.

Conclusions

Pollution control and the preservation of environmental quality are of major concern to the mineral processing profession. The mining and processing industries produce large quantities of solid waste which must be properly disposed. Process water must be treated for reuse or disposal and processing systems must be designed and operated to minimize air pollution. Many air and water pollution control methods use equipment and processes originally.

Mineral processing produces numerous wastes and products that can cause water contamination: tailings, waste rock, laboratory wastes, chemical reagents and contaminated containers (solid wastes), blasting compounds, smelter slag/ dusts, spent leached ores, ore stockpiles. In addition, the associated infrastructure that must be developed to support a large mining and processing operations generates sewage wastes, water treatment sludges, oils, petroleum, diesel fuels, etc. All can cause contamination of surface and ground waters, whether or not acid rock drainage (ARD) develops.

The processing, handling and transportation of raw minerals can cause substantial environmental pollution by dust evolution. The most effective available means of dust collection and precipitation must be applied to dust containing cadmium, mercury, thallium, arsenic, cobalt, nickel, selenium, tellurium or lead. Quartzose dust (silica dust) can cause silicosis and therefore must be allowed for as an occupational safety consideration. Depending on the mass flow, the material must be analyzed for the presence of the aforementioned heavy metals, and clean-gas limits need to be defined, whereas those for cadmium, mercury and thallium should be lower than those pertaining to the other heavy metals. The workplace dust concentrations must be monitored as a basis for controlling the silicosis hazard. Industrial medical care must be provided for the workers.

The local vegetation is liable to be destroyed by the caustic effects of mineral constituents dissolved by rain. Also, a thick layer of dust can so strongly impede the plants' natural assimilation process that they die off. The soil around processing facilities for ores containing heavy metals can eventually become contaminated. The geogenic contents of the soil should be determined prior to erection of any such facility.

Well-proven dust collecting and precipitating devices are available for use in controlling dust emissions. Their adequate separation efficiency in continuous operation must be monitored. The nature and extent of inspections, preventive maintenance and repair of precipitators should be specified in a service manual.

Under certain unfavourable conditions, an accumulation of heat, an overheated bearing or a spark can trigger the ignition or fulmination of fine dust. Good ventilation, possibly in combination with inertization, pressure-surge-proof encapsulation and/or the use of pneumatic drives, can substantially reduce the hazard.

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