MINERAL COMMINUTION AND SEPARATION SYSTEMS

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Contents

Summary

The objective of mineral processing is to render mineral resources beneficial to the modern life of the humankind. Mineral resources occur as a textual intergrowth of various mineral components, and as extracted from the ore body, they are not useful as they are. Essentially the technology of mineral beneficiation resides in the separation of the mineral components by the least energy-intensive means, and in many cases the solution to this is separating them by the physical rather than the chemical procedures, even if the final stage of separation of the elements aimed at will have to have resort to chemical treatment methods in most cases.

Mineral processing consists of the technology based on a wide variety of basic sciences such as: stochastics, mineralogy, physics, electronics, magnetics, chemistry, surface chemistry, colloid science, bio science besides mechanical engineering and flow dynamics. Major process operations are largely related to particulate technology and consist of size reduction (or comminution) by crushing and grinding for the liberation of minerals, separation of mineral particles by various principles and a number of operations associated with them. However, most of the processes are basically physical (or mechanical), even if chemical effects may play important roles.

Discussion is also extended to the treatment of the solid wastes and wastewater occurring from the mineral processing plants, and also to the environmental problems associated with the development of mineral resources and their treatment. Especially important is that the knowledge explored for mineral processing and extraction technology should be applied to the recycling of materials and protection of the environment.

1. Significance of Mineral Beneficiation

Beneficiation of minerals, also called mineral processing, implies processing of mineral resources to enhance its potential value to the benefit of the humankind. The mineral resources as mined, or the 'run-of-mine ores' or 'raw ores', are not uniform in their composition of constituents, may be too coarse and/or unstable in size consist, and furthermore, in many cases, too poor in grade to be utilized for sustaining our modern life. In other words, if we venture to extract the valuable metal components included in such ores, we have to spend inhibitive cost and/or energy to recover only a small amount of refined metals from them. To circumvent such issues, we generally need to process the run-of-mine ores prior to final smelting and refining stages, which require too much energy consumption by rendering less energy intensive procedures, based mainly on physical rather than chemical principles.

To be more specific, let us take the example of a copper ore whose grade, or copper content, is only 1% by weight. Let us assume that the sole copper mineral species in this ore be chalcopyrite, which is one of the most popular copper minerals found in copper ores in our planet. The chemical formula of chalcopyrite is known to be $CuFeS_2$. Calculating from the atomic weights of these constituent elements, one part of copper entails 3.46 parts of chalcopyrite. Physical means of processing without chemical decomposition of chalcopyrite enables us to attain the copper concentrate whose ultimate copper grade is 1/3.46 = 0.29 = 29%. For a range of practical reasons to be discussed below, this ultimate grade of copper concentrate cannot be attained, but the grade of copper concentrates is generally in the range of 20 to 25%.

If, on the other hand, we extracted copper from this ore by dissolving by some chemical or by melting by heat, we would need enormous energy, which would entail too much cost to us to inhibit efficient usage of the metal for our life.

Turning back to the discussion of beneficiation, let us deal with the case of coal that comprises the most important fossil energy resources together with petroleum, with much larger quantity of potential reserves than the latter. Beneficiation of coal is called 'coal preparation' in the broader sense or 'coal cleaning' in the narrower sense of the term. In the traditional convention, the term 'coal preparation' is common, and 'coal cleaning' is used to specify the techniques to separate the part richer in pure coal constituent in the raw (or run-of-mine) coal. Recently the term 'advanced coal cleaning' is often used, too, to specify the process to obtain more purified coal products compared to those attainable by the conventional coal cleaning technology.

Thus, for example, the ash content of clean coal is 6 to 20% in the conventional and present coal market, while the target of (advanced) coal cleaning is to produce higher grade clean coal introducing novel techniques, to attain the ash content of 3% or even less.

Here again, we should note that coal preparation is essential for most cases to avoid inefficient utilization of our precious natural resources.

2. Overview of Mineral Processing Systems

Only a small part of the total volume of the raw ore is recovered as the concentrate, while the residuals have to be discarded. The large volume of the waste material discharged from the mineral processing plant, or the concentrator, is used for filling the cavity resulting from mining, disposed in the tailing dams or heaps or both. It is reasonable in most cases, too, in order that the transportation cost can be reduced and that the space for discarding the large volume of wastes can be guaranteed, to locate the mineral processing plant adjunct to the mines where the raw ores are produced.

Most mineral processing operations are conducted with water as the medium. This is called wet process against dry process, which is performed without water. The reason for this is mainly for the advantage or the necessity of the separation process. Normally processing of a ton of ores, several tons of water is needed, even if part of the water required is recovered by recycling. Some separation processes, especially electrostatic separation process, requires that the material should be bone dry. Preference is the dry process in some applications, due to the limited availability of water supply sources or other reasons. In the preparation of non-metallic mineral resources such as cement rocks, aggregates and sands for mortar, dry processing plants are rather common to avoid wastewater treatment circuit necessary for wet plants.

In coal preparation wet processing is in preference to dry processing, wherever water resource is available.

3. Components of Mineral Beneficiation Technology

Processing of mineral beneficiation is composed of a series of unit operations as illustrated in Figure 1 by a simple example. Raw ore, or 'run-of-mine ore', is received by the storage 1 of the crushing plant for temporary storage, and then discharged through the feeder 2 for controlled rate of supply to the primary crusher 3, where coarse particles included are broken. The broken ore is conveyed to the secondary crusher 5 for further stage of crushing. The secondary crusher is arranged with the screen 4 in 'closed circuit' for recycling oversize particles back to the crusher. The breakage may be performed in three stages using different types of crushers depending on the size and other properties of the ore.

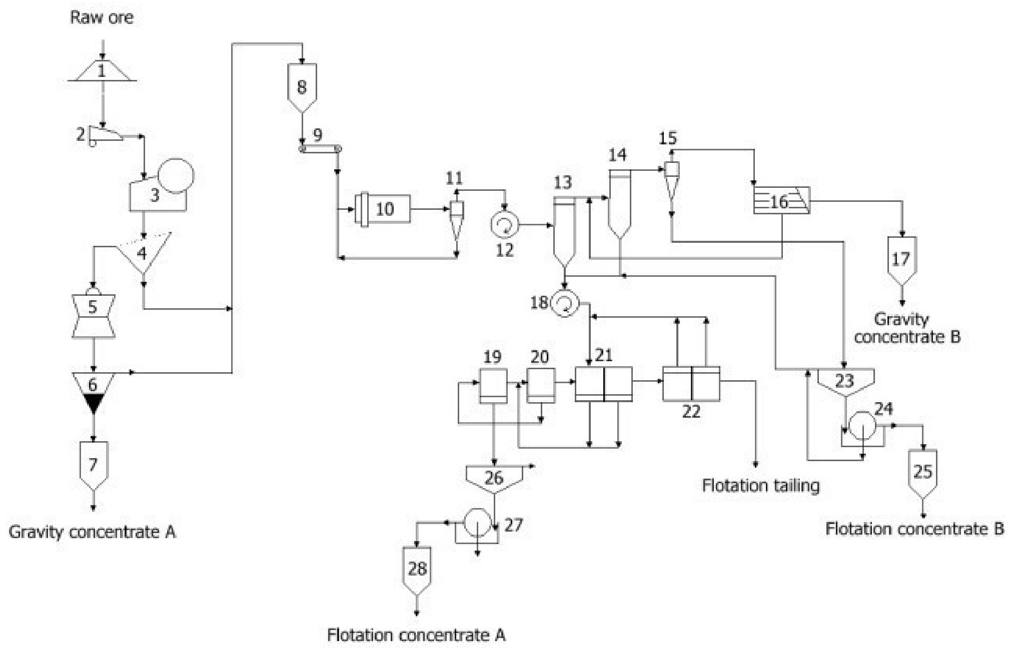

Figure 1: Typical example of the simplified flowsheet of mineral beneficiation plants
1: heap storage 2, 9: feeders 3, 5: crushers 4: screen 6: dense medium separator 7, 8, 17, 25, 28: storage tanks 10: ball mill 11, 15: hydro cyclone 12, 18: conditioning tanks 13, 14: flotation columns 16: shaking table 19, 20, 21, 22: flotation machines 23, 26: thickeners 24, 27: vacuum filters

The discharge from the secondary crusher is processed by the dense medium separator 6 for recovery of coarse-grained high-density mineral prior to further size reduction stage.

The ore thus prepared in the crushing plant is stored generally in a large-volume storage system. The storage system, in most cases, consists of large tanks called ‘mill bins’ 8. In most mines the working hours are 8 to 16 hours per day, and the operation is stopped on holidays, while major parts of the mineral processing plants are operated continuously for several days or weeks. Hence the role of the storage: cushioning between mining and mineral processing operations. Another mission of the storage is a definite degree of homogenization of the ore as well.

The grinding plant is composed primarily of grinding mills 10 and classifiers 11. The grinding process in the flowsheet is followed by a series of separation of specific minerals. In the present flowsheet, flotation plays the main role in separation (or concentration). In this flowsheet we can find two types of flotation equipment, the conventional flotation machines 19-22 and flotation columns 13-14 that represent relatively newly introduced type of the equipment. Supplementary equipment, the shaking tables 16, helps to recover dense mineral particles amenable to gravity separation.

Major parts of the concentrates and the tailings occur from the flotation process, and these are submitted to solid-liquid separation for delivery and/or disposal. The equipment used for these purposes are thickeners 23 and 26, vacuum filters 24 and 27, driers, etc.

As we have briefly observed above, a number of various unit operations are combined together for mineral beneficiation. The overall objective of these unit operations is primarily to liberate valuable mineral components from gangue minerals and then concentrating the mineral components aimed at as efficiently and accurately as possible.

4. Comminution System

To achieve the goal of recovering these concentrates, the raw ore must be reduced to fine size prior to separation. This process is called ‘comminution’ or ‘size reduction’. Generally there are two major objectives for comminution in mineral beneficiation: The first objective of comminution is ‘liberation’. Liberation is the process to unlock composite minerals in the raw ore into more independent particles, and without it we cannot collect the wanted components only. The second objective of comminution in mineral processing is to adjust the size of mineral particles to adapt to the optimum size for the successive separation processes.

Screens and classifiers are used to adjust the particles within prescribed and closer size range. They are arranged in many cases in conjunction with the equipment for ‘size reduction’, or ‘comminution’. Various types of equipment are used for comminution. Crushers are used in the coarse size region, while grinding mills serve for preparing fine products.

Comminution processes are generally preliminary to the separation processes. To avoid excessive cost for grinding and/or disadvantages caused by over-grinding, however, some of the separation processes may be performed in the middle of coarse and fine size reduction stages. Various principles of separation methods and techniques have been developed for separation of valuable minerals from gangue minerals or from other kinds of valuable minerals. These separation methods are based on the differences among the physical properties of various minerals such as shape, susceptibility to size reduction, specific gravity, electro-magnetic susceptibility, surface chemical property, etc. Among these separation methods we will discuss about the most commonly utilized technologies based on gravity and surface chemical and electro-magnetic properties.

Classification of particles by size comprises an important operation in mineral processing. It can be accomplished either by screening through sieves or by applying forces by the medium, water or gas. The latter methods of size separation are called wet classification and dry classification, respectively. In the industrial operations, screening is suitable for separation at relatively large sizes; say above 300 μm, while classification is more adaptable at the size below 300 μm.

Screens are formed by wire mesh, punched metal plate, etc. and, more often than not, the screen surface is vibrated, shaken or rotated to make the particles finer than the mesh size to pass through the openings efficiently.

The most popular type of grinding mills is the tumbling mill as illustrated in Figure 2. The tumbling mill consists of a tumbling cylinder in which the grinding media are charged up to about 30 to 40% of the volume. 25 to 75 mm diameter steel balls are the grinding media that are most popularly used for fine grinding, whereas steel rods are used for coarser grinding. In this context the fineness of grinding depends on the mineral texture of the ore to be ground and other conditions, and the typical fineness of grind (product size) is 37 to 150 μm.

Another type of the comminution system commonly used today is represented by ‘autogenous’ grinding mills. The autogenous grinding mill uses the lumps or the pebbles constituting a part of the raw ore itself as the grinding media instead of steel balls or rods. Since the relative density of the ore particles is generally lower than that of steel, the media particles have to be coarser than steel balls to guarantee sufficient impact forces to break up ore particles, and at the same time, the mill diameter has to be larger. The advantage of the autogenous grinding system, however, is that the comminution circuit can be made simpler, and that the use of costly grinding media can be avoided.

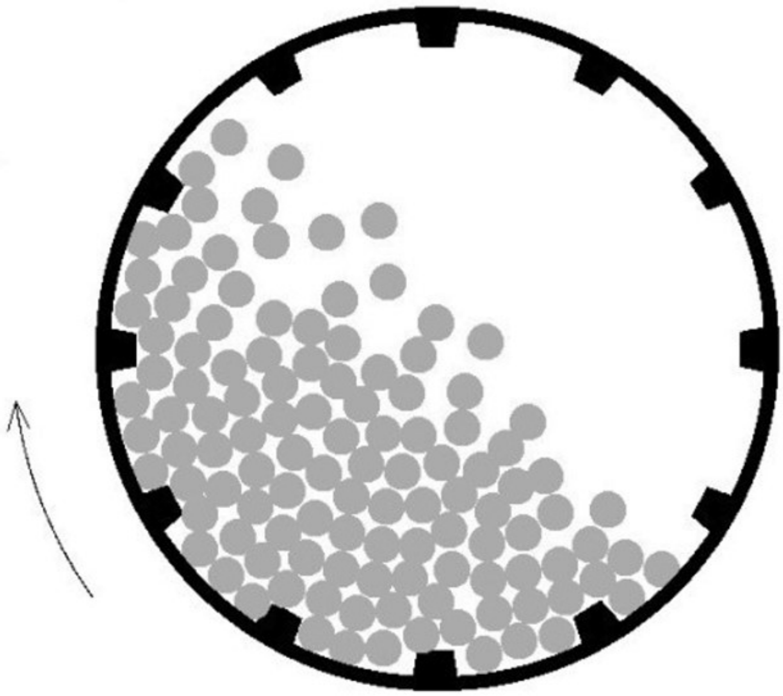

Figure 2: Schematic illustration of the tumbling ball mill in operation

Wet, rather than dry, classification is more popular in mineral processing and coal preparation operations, which are also performed wet. The basic principle of wet or dry classification is common with that of the separation by particle density, which is usually called ‘gravity (or centrifugal) separation’. This general convention is also closely related to the principle of separation of solid particles from aqueous or gaseous medium. Solid-liquid and solid-gas separation, often called settling, thickening, dedusting, etc., according to the objective of the corresponding operations, comprise subordinate but important unit operations in the mineral processing plants. An important difference of classification or gravity (or centrifugal) separation against solid-liquid or solid-gas separation, however, is that the particles should be dispersed individually in the former processes, while flocculation of particles is in favor of the latter separation processes.

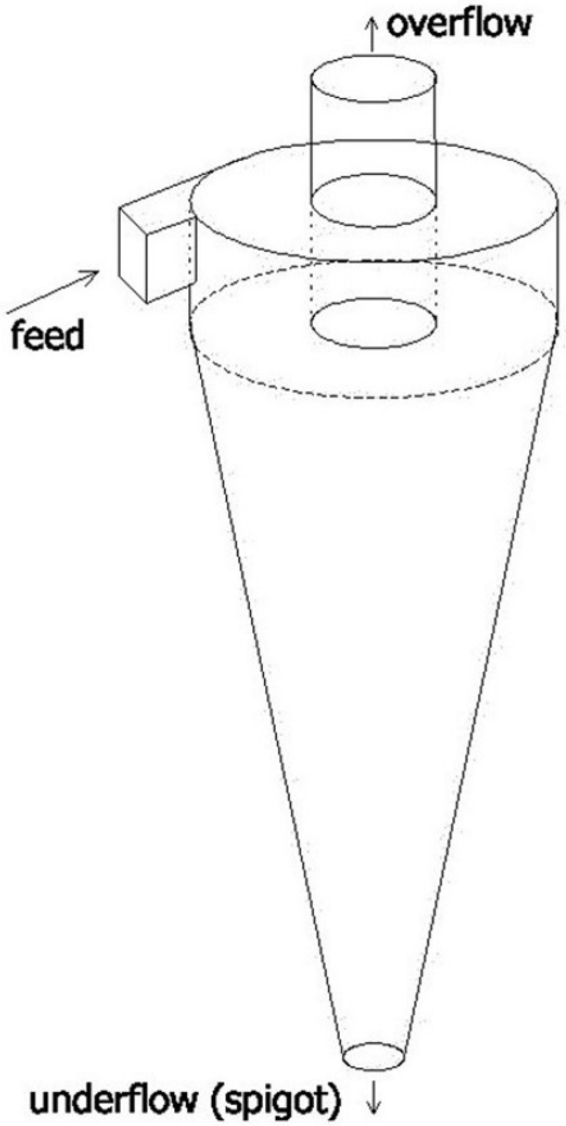

Figure 3: Hydro-cyclone

Figure 3 shows a typical wet classifier called 'hydro-cyclone'. The principle of classification in the hydro-cyclone is as follows: The feed slurry enters the cylindrical part of the cyclone in the tangential direction and passes through the conical part underneath the cylindrical part. Then, by the effect of the centrifugal force developed in the unit, the coarser particles are forced to the vicinity of the wall of the conical part, travel downwards and are discharged through the apex, while the finer particles are entrained in the upward swirl near the air core developed inside the conical part of the unit and discharged through the central inner cylinder called overflow finder.

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Biographical Sketch

Toshio Inoue was born in 1934 in Tokyo, Japan. He graduated from The University of Tokyo in 1957 at the Department of Mining Engineering, Faculty of Engineering. In 1963 he finished the course of the graduate school, the University of Tokyo, and was awarded the degree of Doctor of Engineering for the thesis entitled 'Study of Flotation Kinetics as the Rate Process'. Since 1963 he worked with the University of Tokyo as one of the teaching staff, and from 1981 he was the professor of mineral processing until he retired in 1994.

He is the author or co-author of about 10 Japanese and 4 international books, handbooks and encyclopedias in mineral processing, powder technology and computer technology.

He has also been a member of a number of domestic and international committees for academic activities including the publication of domestic or international journals in mineral processing and powder technology.