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COMPLEX ORE MODELLING, TEXTURE, AND MINERAL LIBERATION

A review of modern stereological approaches to the mineral texture characterization and major mineral liberation models is presented. Techniques are proposed for acquiring numerical indices describing the applied industrial mineralogy and mineral treatment processes. Various systems for establishing the mineral liberation depend on new laboratory techniques and devices, the most important of which is the image analyser supported by fast computer, microanalysers, and electronic microscope.

Prediction procedures are proposed in the paper for mineral behaviour in respect of its liberation during the comminution.

A new approach to the mineral liberation is presented, based on different mineral behaviours during continuous milling of a multiphase ore. The intensity of mineral liberation from a real multiphase system has been found to depend on composition and the grind of fineness of each of the system constituents. Different behaviours of minerals of the given paragenesis, in respect to grinding or milling, had a direct effect on the liberation intensity - each of the constituents - and even more on the total liberation degree function.

The identified milling selectivity allowed measuring and predicting the optimum liberation for each mineral, at the lowest grind fineness, which opened an approach to the problems of energy saving and technological scheme economy.

INTRODUCTION

All models of physical valorization of minerals are based on mineral aggregate comminution for liberation of heterogeneous mineral species one from another and, using the differences in physical properties of minerals, for separation of the mixture into its components. As the key step in the industrial processing of mineral ore and the first precondition for an optimum mineral liberation for its valorization, comminution is the most costly operation of the mineral processing. The grinding fineness is a measure of comminution in any mineral liberation analysis (Wt, % finer, -53 micron).

The degree to which a mineral will be liberated from accessory materials or another mineral is an important information in an economic evaluation of a technological scheme. Considerations of this information are not new, as the researches in this field date some fifty years back and are yearly increasing in number. A strong impetus to the research has been certainly given by the continuous rise in energy

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costs, which maintained and increased the interest in mineral liberation both in early stages of a design and in stages of technological mineral treatment.

Separation of minerals by comminution - fragmentation and milling - is primarily dependent on structural-textural characteristics of the ore. Characterization of a variety of textures and modeling complex systems, such as mineral ores, have been the concern of many researchers who studied mineral liberation for many years. A swift and relatively accurate estimate of the total mineral liberation is the main target, because it brings a saving in milling energy, a higher recovery of valuable minerals and the best concentrate quality.

This paper is an attempt at presenting a model of the liberation process which can be used for ores of the same genetic type but different proportions of valuable minerals - constituent, at variable grind finenesses, in establishing the regularity in the mineral liberation degrees. Based on the experimentally established and described regularity, the liberation intensity of a selected mineral will be predicted at a variable real grind fineness, limiting the tests to a very narrow range of particle sizes (integrated size-reduction in plant), Malvik (1982).

HISTORICAL DEVELOPMENT OF LIBERATION MODELS

Complex processes of mineral components liberation from ores required as a principal scientific method the use of a *modeling method*. This method was developed from the classical method of analogy; it is based on the assumed similarities in phenomena and objects.

The first model of mineral ore, known by its relationship of phases as the "two checker boards" model, proposed by Gaudin (1939), had an important place and a historical role. Its concept was very simple, based on phased textures in a system and specific breaking by planar parallel planes. A grain in Gaudin's (1939) model had a cubic shape, monosized, and the texture had not stochastic elements, and was not measurable. This model, however, is a base on which new approaches are attempted to model mineral ores and liberation processes.

Only thirty years later, Wiegel (1964) and Wiegel and Li (1967) developed Gaudin's model (1939) and proposed a new one which was named "Rubik's cube" on its phases relationship in the system. It was also a monosize model, without stochastic elements, but more realistic, offering plausible information about the liberation process. Wiegel (1975, 1976) developed further his model giving evidence of the integrated size reduction and liberation models. Based on the probability calculus, the model has found a limited application for certain mineral materials. Its approach is deterministic.

Bodziony (1965a, 1965b) did not propose a mineral liberation model, but has been regarded as a pioneer in texture geometrization and characterization systems such as mineral material, who much contributed to the development of modeling. Textural characteristics, in this approach, are applicable to any grain shape or size; the phase corresponds to a regular, normal distribution of constituents and possesses stochastic elements. A working model could not be developed at the time, because this field of mathematics was still underdeveloped.

Steiner (1975) used some of the arguments that had been presented by Amstutz and Giger (1972) and earlier by Amstutz (1960, 1965, 1970) on stereological texture characterization to predict particle composition and species after breakage through a study of interphase specific surface area. The model is applicable only to pre-treated standardized material, and the nature of its texture corresponds to any relationship of phases, without limitations in respect of grain shape or size, and has stochastic elements.

Miller and Reid (1982) made a new approach to liberation modeling through a function of specific surface area and expressed it as a *cumulative liberation yield* (CLY). The introduced concept of texture characterization and quantification of liberation or composition, a *normalized probability of mineral association* as a measure of the mineral association incidence degree is the essence of this approach. Mineral liberation as a function of the size of interphase surface area was mentioned in Steiner (1973), but a working model was not developed.

Andrews and Mika (1976) regarded liberation as a process inseparable from comminution and proposed a simultaneous analysis of the two processes by a selection function and a breakage function.

The generally accepted concept of mineral ore and liberation modeling was proposed by King (1975, 1979, 1982, 1983). In his characterization of texture, he departs from any proportions of phases in a system, polydisperse grade, any grain shape; his model allows stochastic elements and measuring for establishing the distribution of random linear segments across the phases. Measured segments are mathematically treated and distributions of phases and fractures along traverse lines are taken for random. Apart from certain remarks on the King's (1975) model, as a "linear fractional liberation", Moore (1983) finds notable deviations from real values in the area of coarse classes. King's model (1979) was tested by Coleman (1983), Finch and Petruk (1984) with certain additions and corrections; they found the accuracy of results satisfactory, provided additional calibration for the given conditions.

The model developed by Klimpel and Austin (1983) uses elements of the earlier models and improves them on the concept of one-dimensional measuring and direct volumetric transformation of measures based on Monte-Carlo simulation. In respect of texture characterization, Klimpel's (1983) model allows any grain shape, considers different variants of grain size and has stochastic elements. Relationship of phases is the basic consideration of Wiegel's (1964) "single grain" variant, or the variant of "extremely nonuniform distribution" of the analysed phases in Gaudin (1939).

The stochastic model by Lin et al. (1984, 1985, 1987) is a new stochastic and phenomenological model. The model allows generation of particles of multiphase elements of extremely irregular shapes. It allows a high flexibility of generation at an ample control possibility of variables. A simulation of folded linear transverse across the generated mathematical space - composite particles - will produce an amount of related information in regard to liberation, transformation functions and correction factors.

A significant contribution to this field is the mathematical model presented by P.Davy (1984). The model characterizes by texture any relationship of phases in a system of unconditioned grain size or shape and its stochastic elements. In his theoretical work, P.Davy (1984) supports the concept developed by Serra (1982). P.Davy (1984) makes a mathematical presentation for a possibility of deriving and verifying a strong relation of textural characteristics and comminution. However, intergranular fracture and preferential breakage in practical cases are very difficult to measure and describe.

Most of liberation models proposed so far greatly differ among themselves in texture characterization or characterization of particles after a system fragmentation. However, there are compatible models (Tomanec,1990). The application of certain, generally accepted methods for establishing mineral liberation should be related to the type and kind of ore.

EXPERIMENTAL CONDITIONS

Size reduction was tested in laboratory on a set of twenty representative samples of Pb-Zn-Cu ore. Representative samples were ground continuously extending the time of milling for observation of mineral grind fineness (Wt, % finer, -53 micron). Material of the whole set of sample was dry ground in a laboratory ball mill in intervals of 1-45 minutes. Ground ore was sieved, each size fraction chemically analysed, assessed, and polished sections specimens prepared for systematic liberation analysis under polarizing microscope and partly on an CAMECA SR 50 image analyser at the Imperial College, London.

MILLING PROPERTIES OF MINERALS

The presently reported studies (Tomanec, 1989, 1990) are concerned with the principle of integrated size reduction and the mineral liberation model for prediction of changes in identity and composition of mineralized particles (both single and composite) in relation to the fineness of grind.

A comminution process in mills, and hence the differences in milling properties of minerals,Tomanec (1989), are determined by the milling kinetics and the time of material retention in the mill, Lynch (1977). While the latter factor is clearly defined, much consideration must be given to the milling kinetics which is determined by selection and the breakage functions, Herbst et al. (1976, 1977), Ruebush (1980, 1982), Fuerstenau (1988). Selection function is in fact a measure of comminution intensity dependent only on physical properties of a mineral, or the amount of mineral in an ore.

Relative milling properties of an ore are conditioned by differential (selective) grinding properties of associated minerals (Fig.1). The established difference in

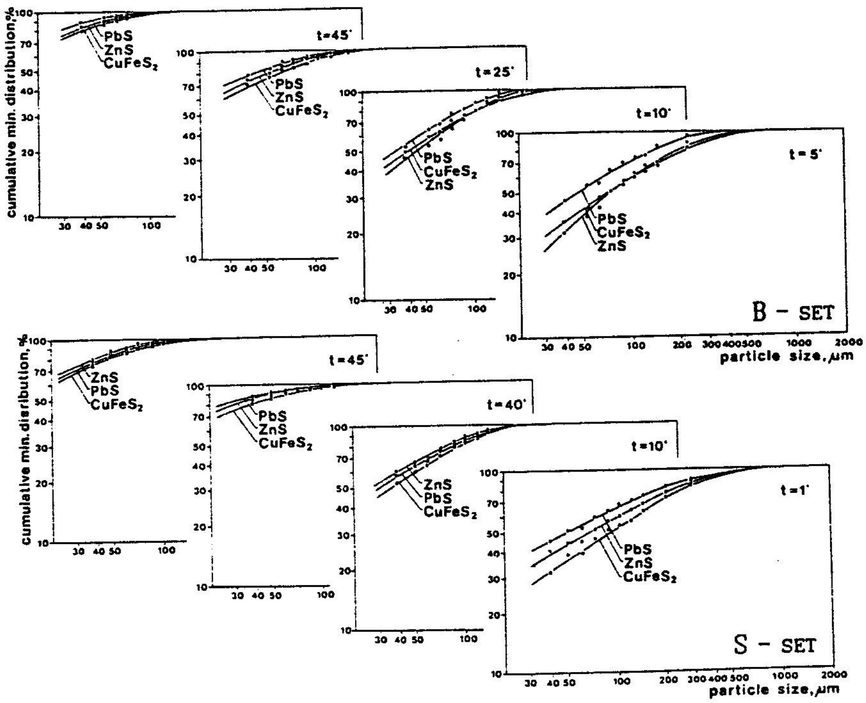


Fig. 1. Relative milling properties of an ore depend on differential (selective) grinding properties of associated minerals. (B-set samples of "rich" ore; S-set samples of "poor" ore)

grinds is not only a consequence of the amount and size of mineral phase aggregates in an ore, but, which is more important for the liberation process, of the strength of bond between the contained mineral phases.

Differential size reduction and selective liberation were verified on an example of minerals of the same genetic type but of different content of analysed minerals and different textural-structural characteristics of rock. Significant differences have been noted in the mineral liberation gradient (yield) for particles of different size fractions.

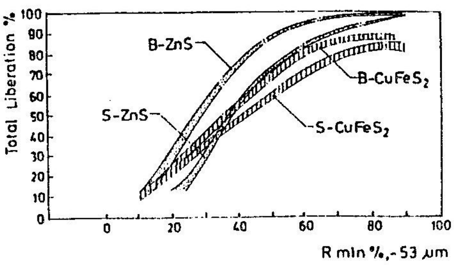
It has been established that different proportions of valuable mineral, as has been known for different genetic type ores, have different behaviours in the milling process, resulting in different liberation degrees of mineral constituents. During the milling, minerals were comminuted at different rates, and the liberation intensities of present minerals were different.

Consequently, minerals will be liberated at different intensities at the same finenesses of grind, but gradients (yield) will not be equal for different minerals in different types of ore. Mineral liberation degrees are different for the same size fractions at different grind finenesses for different minerals or proportions of minerals.

EXPERIMENTAL LIBERATION RESULTS

For developing a model, a sufficiently wide range of mineral grind finenesses was allowed, which resulted in adequate representation of the ore type and its behaviour during the milling.

Fig. 2. Total liberation as a function of fineness of grind for minerals investigated (% recovery of min. in size fraction -53+0 micron) (B-set samples of "rich" ore; S-set samples of "poor" ore)



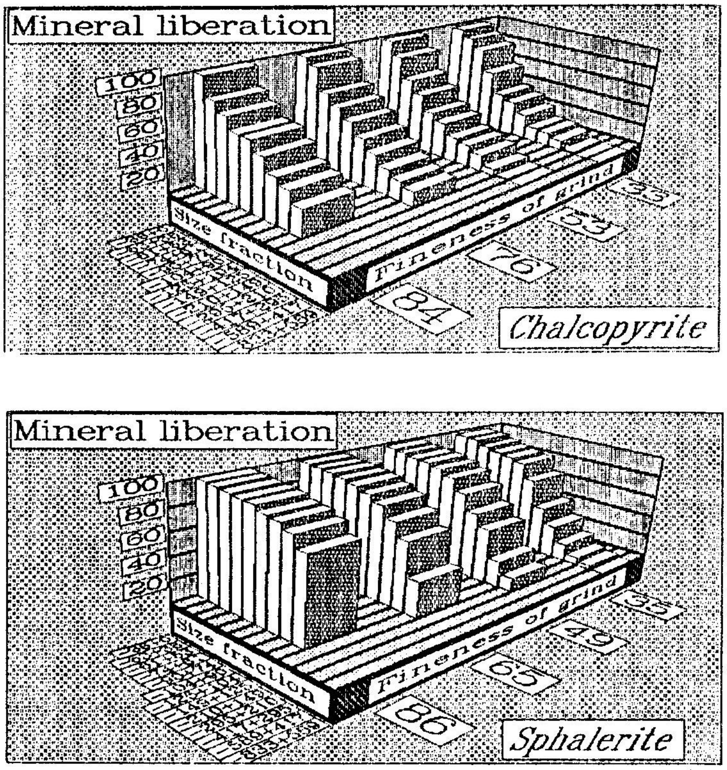


Fig. 3. Degree of liberation as a function of fineness of grind and differential milling properties of minerals

Measurements of systematic changes in mineral liberation by narrow size-classes, while the ore was continuously ground, showed that total liberation of each mineral depended on grind fineness of the mineral (Fig.2). Both grinding and liberation certainly had been influenced by textural characteristics (mineral aggregate size, grain shape and form, mineralization type), ore hardness (cohesive forces within mineral crystal in paragenesis, cohesive forces at adjoining crystal surfaces) and general ore properties (useful mineral content, supergene alteration, secondary enrichment, etc.).

Differences in the mineral comminution rate, and textural differences expressed primarily in mineral aggregate size, were responsible for the difference in liberation gradient at variable grind finenesses of individual fractions.

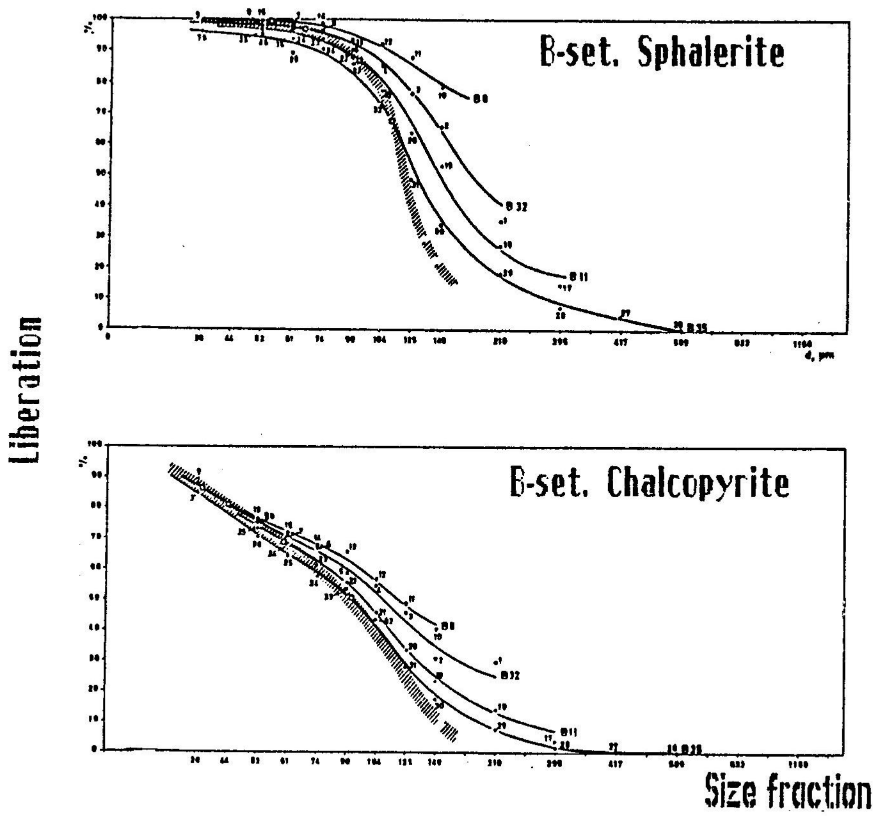


Fig. 3a. Degree of liberation as a function of particle size in a mill product

It has also been found that differences between measured and stereologically transformed values, (Gaudin's "locking factor", "correction factor", Moore (1985)), were not higher than 3% for a high proportion of the measured mineral or were as low as tenths of a percent for high grind finenesses. Unlike these, for low proportions of a mineral of emulsion type texture in chalcopyrite, the differences reached 4% but only within high finenesses field, whereas coarse grinding effect was the same as in a higher proportion of mineral (Fig.2).

This empirical model of mineral liberation as a function of milling properties of selected minerals, illustrated by a diagram in Fig. 3, can be used to read integral degree of mineral liberation at any grind fineness but only based on measurement data of a narrow class of size and the known reference fineness.

CONCLUSION

Based on differential (selective) mineral grinding established on ores of one genetic type, a new empirical model of mineral liberation from a multiphase system has been developed. The model provides for a successful prediction of liberation for any grind fineness of the given minerals.

Optimum fineness of rock comminution - the first and costly target of industrial processing of mineral materials, and the process of mineral liberation essential for concentration results, are considered integrally and regard the acute problem of the present time: saving the deficient energy in technological plants.

The proposed model can be used for any ore of one or similar genetic type to establish reference functions for all useful minerals to measure mineral liberation at variable real grind finenesses. The given standardization can be used to the level of significant changes in structural-textural characteristics and phases proportions in a system.

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W pracy zaprezentowano przegląd współczesnych stereologicznych opisów tekstury oraz ważniejszych modeli uwalniania ziarn mineralnych. Zaproponowano także techniki określania różnych numerycznych wskaźników. Zaproponowano sposoby pozwalające przewidzieć warunki uwolnienia ziarn podczas mielenia.