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Short Communication

Geology and Economics for Mining and Beneficiation of Low-Grade Ores

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Ore mineralizations in the earth`s crust take place due to complex geological processes resulting in marketable ores that are located in a few places and where the ores are intricately intertwined with low-grade ores (not directly marketable) and gangue materials (having very little market value). Therefore, mining operations with economic profits require adequate high sale value of high-grade and beneficiated low-grade to marketable grade ores; so that the operational costs of mining, beneficiation and disposal of mine-wastes are compensated to result in adequate profits/year.

Five Geological factors such as (i) total reserve(W, tons), (ii) proportions of high-W(H), (iii) low-grade ores W(L), (iv) proportion of gangue 1- W(H)- W(L), (v) high grade A(H) are important. Three are independent as well as two independent assay values, such as, of high-grade A(H) and of low-grade A(L) ores. Economic factors (total of TEN)include profit/year(P) which must be positive, life of mine(L = W/ production rate per year in tons), sale price per ton of marketed ore S(H), capital cost for mine operations C(M), capital cost of beneficiation plant C(B), interest rate on capital costs (r), efficiency of beneficiation plant to upgrade low-grade ores to marketable ores(e), per ton running costs for mining R(M), beneficiation R(B), as well as of disposal of mine-waste R(D). All these fifteen factors are necessary for an economic profitability analysis and to decide whether mining is feasible and whether ore beneficiation is necessary or not and feasible. Profits/year are computed on per year basis for convenience of tax payments and fiscal discipline. Then, the total profit over the entire mine life (L years) is given by PL.

Large mines have considerable, non-marketable, low-grade ores and these should have established beneficiation plants for upgrading and marketing these ores. This is scientifically and economically optimal for profits as well as more acceptable to prevent environmental degradation. However, smaller mines which have little proportion of low-grade ores should be operated without beneficiation plants at mine-site but ore beneficiation should be done by pooling several nearby mines of same metallic/non-metallic ores.

Low-grade ores (non-marketable) are invariably associated with high-grade marketable ores along with gangue materials of little market value in any mineralization in the crust due to complex geological processes which result in very complex interlocking textures and structures among these three components of the ore body. The main problems for a mining company are: (i) How to optimally mine the ore to make sufficient profits per year of mining, so that the project is economically viable; (ii) How to optimally beneficiate the mined low-grade ores to marketable grade(s) in order to augment the profits/ year, and (iii) How to minimize costs of mining, beneficiation and mine-waste disposal and the associated costs of environmental remediation.

Optimal solutions for these mining, beneficiation, waste disposal and environment remediation etc. must include both geological and economic factors. The five independent geological factors included total reserve of ore materials and gangues (W), assay value of high-grade ore A(H) and its proportion in ore W(H), assay value of low-grade ore A(L) and its proportion in ore W(L), a non-independent factor of proportion of gangue in ore W(G), which is equal to 1-W(H)-W(L) and has no economic value but needs to be disposed off as waste at cost.

Ten Independent Economic Factors are Recognized as:

Capital costs of acquiring the mine and mining equipments C(M) and of the beneficiation plant, if required, C(B), interest rate on capital borrowing (r), Running cost/ton of mine operation R(M) and of beneficiation plant R(B), as well as waste disposal cost/ton R(D), efficiency of beneficiation plant (e) with $0<e<1$, market value of saleable ore/ton S(H), and life of mine in years(L) which is dependent on minimum production in tons/year of ore from the mine (W/L or less), profit/year, in rupees, of sold marketable ore (P).The economic variables are mostly dynamic types varying with time, technology, other economic indices; whereas the geological factors are static types that do not change with time. So, the total number of factors is fifteen and these are necessary for feasibility analysis of any mine with or without the associated beneficiation plant at mine site. For smaller mines which have less proportion of low-grade ores, a pooled beneficiation plant operating at an appropriate central site with proportionate profit sharing may be more economic and hence, recommended. More details on liberation of ore minerals by beneficiation and on ore reserve and grade estimation are given in Sahu, (2003; 2008 and 2010), respectively, and also in King, (2001).

Economic Analyses for Mining Operations

The economic analysis of profitable mining operations, with beneficiation plant at mine site and pooled beneficiation plant at some other central site or without any beneficiation plant which can be assessed by simple economic cost/profit (P, per year of mined ore in tons) studies /year basis. This can be multiplied to total reserve of ore (W) to obtain the profit over the life (l year) of mine operation. The profit /year of mining ores (P) without ore beneficiation, is given by:

$$P = (W\ W(H)\ S(H)/L) - (C(M)\ (1+ r)\ (L\ ) - (W\ R(M)/L) - (W-W(H)A(H)/L)\ R(D) \quad (1),$$

where, symbols are already defined in Section I, where P must remain positive. This P about twice (or more) of the cost of mining, beneficiation and waste disposal costs in order to avoid risks due to dynamic economic factors. This equation is non-linear and cannot be linearised to gain further simplicity as the nine different factors in its RHS are complexly interacting among themselves.

However, if the mineralization has high proportion of low-grade ores W(L) with assay value of A(L). It would be prudent to install a mine-site ore beneficiation plant to upgrade the low-grade ores having assay A(L) into saleable high-grade ores with assay A(H). Then, economic analysis for mine operations along with ore beneficiation yields equation 2 as follows:

$$P = (W(\ W(H) + W(L))S(H)/L) - (C(M) + C(B)(1 + r) - L - (\ W\ R(M)/L) - (W - W(H)\ A(H) - W(L)\ e\ (A(H) - (A(L)/L)\ R(D) - (W\ R(B)/L) \quad (2)$$

where all the symbols are defined in Section I. Again, equation 2 is very complex and linear that cannot be linearised further for any simplification. It has five geological and ten economic factors (Total of 15 factors), where P must be positive for installation of a mine-site beneficiation plant to augment the profits for the mine.

It may be noted that equation 2 is more general than equation 1 and reduces to Equation 1 if W(L) is negligible and taken as zero and in which case the mine-site ore beneficiation plant becomes economically unviable with the associated costs C(B) and R(B) also become zeros. However, in a real mining situation W(L) is seldom very low and it would be prudent to use a beneficiation plant at mine site for larger mines. For smaller mines it would be then prudent to pool all low-grade ores from nearby mines to establish a pooled central beneficiation plant with proportionate profit sharing for each mine in the pool. In any case, establishing a beneficiation plant in mining areas is scientifically appropriate, ethical and reduces environmental degradation. In addition, mining industry can earn further profits through sale of mine wastes for land-filling, brick making, road constructions and beautification / landscape planning of damaged areas around mining sites.

(i) Equation 2 is more general than equation 1 and reduces to equation 1 if the proportion of low-grade ores W(L) is negligible or effectively zero. The profit per year (P) in equation 2 must be positive (preferably greater than twice the mining costs to prevent financial risks) for the mine with its beneficiation plant to be feasible and economically viable. Equation 2 should be used for large and very large mining operations, where large amounts of low-grade ores are invariably present. Equation 2 is scientific, ethical, economically optimal for greater profits and environmentally more acceptable than using equation 1.

(ii) Equation 1 (reduces easily from general equation 2) is applicable if negligible proportion of low-grade ores are present, especially in case of smaller mines. In such cases, mine-site beneficiation plant becomes economically unviable and must not be installed.

(iii) The geological factors in eqn.(2)/ eqn.(1) are static type variables whereas the economic variables therein are dynamic which vary over time and/ or space, technology change, mine-sites , costs of mine operation, ore beneficiation operation, waste disposals, sale price of marketable ores, interest rate of loan, and many other time-varying costs such as, wages, transportation, discount rates, government tax laws, etc. The profitability for mining operations has high financial risks as well due to dynamic economic factors, which must also be incorporated in profit evaluation and feasibility decisions.

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