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A CONTRIBUTION TO THE STUDY OF ORE CONCENTRATION BY MEANS OF THE CONCENTRATING TABLE

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Abstract: *Factors are considered which determine the economic efficiency in ore concentration by means of concentrating tables.*
Relations are given whieh greatly help those concerned with ore eoncentration, since experimental work is considerably reduced, in specifying values for the variables by which oprtimum economic efficiency is obtained.
Furthermore the process is stated of manipulating these relations for performing the ealculations necessary to obtain the values which yield the maximum economic results.

INTRODUCTION

One of the most important ore concentrating devices by the hydrodynamic method is the well-known «concentrating table».

The principle on which ore concentration by the concentrating table is based, makes use of the different velocities at which particles of the same size but with different physicochemical properties move on a flat inclined surface by the action of flowing liquid.

The factors determining the functional parameters hy which optimum results are obtained are: the size, densities and shapes of the particles as well as the nature of the table surface and the liquid.

Of the factors just stated, the first two are undetermined since it is both theoretically difficult and practically disadvantageous to prepare a sample of two or more materials in mixture, containing particles of equal size but no locked ones. In other words our actual task is accomplishing optimum results in concentrating granular materials consisting of particles inside a certain range of sizes and densities.

The maximum value in the range of sizes is a function of the physicochemical properties of the ore and the current economic and technical conditions, while the boundary values in the range of particle densities are the densities of the minerals to be concentrated.

The factor «shape» is known for the majority of minerals while the factors «nature of table surface» and «nature of liquid» are chosen by the occasional investigator.

This study aims at contributing to the field of ore concentration which is particularly important in our country's industrial and hence economic development.

The study comprises two sections: the theoretical and the calculating.

The theoretical section, in which some approximative acceptances are carried out, does not solve this complicated problem in a strictly mathematical sense, but it provides the investigator with some relations which orientate him and relieve him of a considerable amount of experimental work.

In the calculating section results obtained from concentrating a mixture of pyrite and limestone are set forth.

THEORETICAL SECTION

Relative sliding velocity.

Tbe equation which gives the maximum sliding velocity of a particle of diameter D, density ρ_p and out-of roundness coefficient K, sliding on an inclined surface at an angle a^0 to the horizontal by the action of a film of flowing liquid with density ρ, viscosity coefficient n, and depth z, is:[1a]

$$U_{max} = D^2 \frac{g\sin a}{2n} \left[\frac{(\rho_p - \rho)\ (1 - n_D \cot a)}{9k} - \frac{3}{8} \rho \right] + D \frac{g\sin a}{2n} \rho z \qquad (1)$$

Where n_D is the coefficient of dynamic ftriction between the particle and the surface on which it slides. Its value is a function of the sliding velocity.

The relative velocities of two particles A and B of diameter D, densities ρ_A and ρ_B and out-of roundness coefficients K_A and K_B, sliding on the same inclined surface, are:

$$U_A = x^2 \frac{8 (\rho_A - \rho)(1 - n_A \cot a) - 27 K_A \rho}{72 K_A} + x\rho \quad (2)$$

$$U_B = x^2 \frac{8 (\rho_B - \rho)(1 - n_B \cot a) - 27 K_B \rho}{72 K_B} + x\rho \quad (3)$$

where $x = D/z$, $0 < x \leq 1$

For values of U_A and U_B inside narrow limits, coefficient of dynamic friction n_A will be approximately equal to coefficient of dynamic friction n_B, that is, $n_A \simeq n_B = n_D$, therefore:

$$U_A = x^2 \frac{8 (\rho_A - \rho)(1 - n_D \cot a) - 27 K_A \rho}{72 K_A} + x\rho \quad (4)$$

$$U_B = x^2 \frac{8 (\rho_B - \rho)(1 - n_D \cot a) - 27 K_B \rho}{72 K_B} + x\rho \quad (5)$$

By using the equations above and for a certain slope of the concentrating table, it is possible to calculate the suitable range of «diameters» of particles consisting of materials A and B in a mixture such that the relative sliding velocities of all particles A may be different from those of particles B.

Assuming that the sliding surface is perfectly smooth, that is, $n_D = 0.20$, fig. 1 and 2 present a graphical representation of equations 4 and 5, for two materials A and B.

a. Fig. (1) : Line MN, the particles of material B, with maximum relative velocity $U_{B\,max}$, are of «diameter» $x = 0.48$ and have the same relative velocity as the particles of «diameter» $x_1 = 0.31$ of material A.

Consequently all particles of material A inside the «diameter» range x_1 to 1, have relative velocities higher than those of all particles of material B.

According to what is stated above it follows that it is possible to separate particles A from particles B when the mixture is of size analysis $-1.00 + 0.31$ expressed in terms of D/z.

b. Fig. 2: Line MN, here the particles of material B with maximum relative velocity are those of «diameter» $x = 0.73$ while the particles of «diameter» $x_1 = 0.49$ of material A possess this same relative velocity.

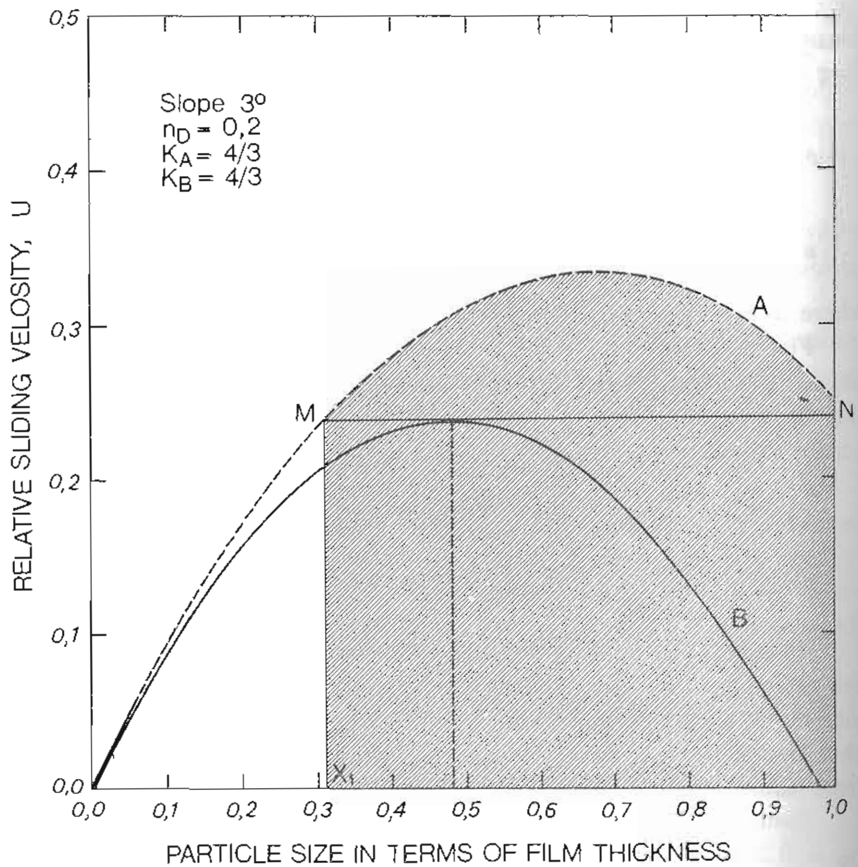

Fig. 1

In this latter case the most suitable size analysis for separation is —1.00 + 0.49 expressed in terms of D/z.

By comparing the two diagrams it is evident that the greater the slope of the table is the higher the velocities of the same diameter particles in a material become and the narrower the diameter range, of particles in the two materials being separated, gets.

From what is stated above it follows that, from a strictly theoretical point of view, an ideal solution to the problem of ore concentration by means of the concentrating table, would be the separation of the materials being processed by screening, into size fractions, each of which would consist of particles of the same diameter and then their concentration on a properly adjusted table.

Since, however, the range of particle diameters of a material obtained by comminution, is continuous, the number of fractions each of which consists of particles of the same diameter, is infinite; therefore tbe «ideal» solution is unattainable.

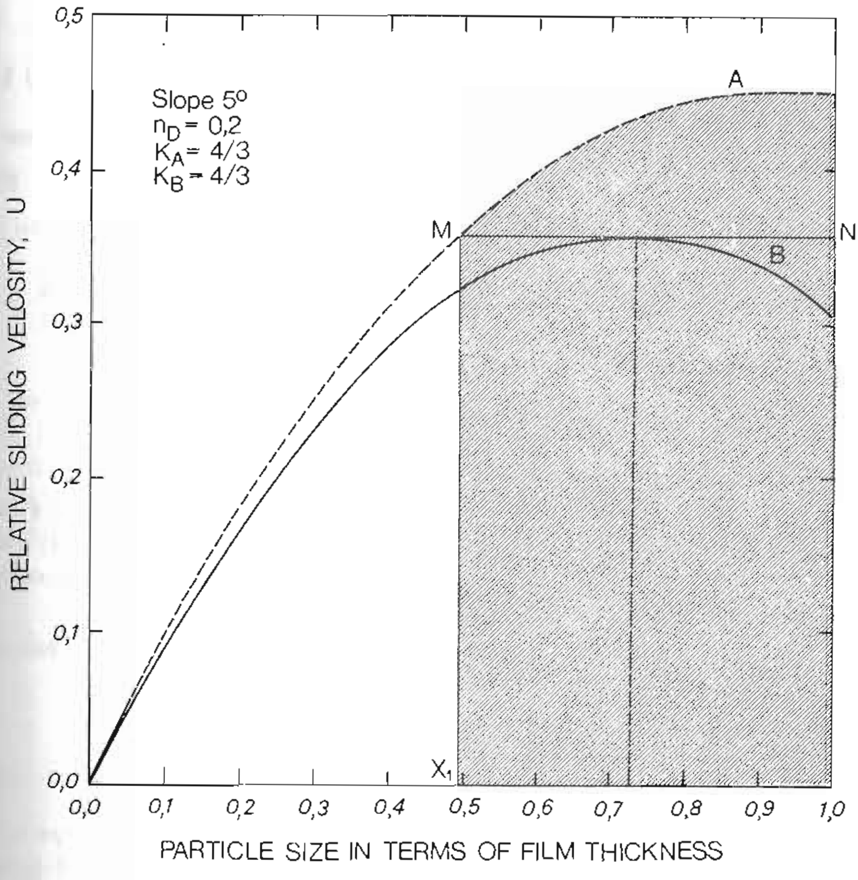

Fig. 2

Instead of the unattainable «ideal» solution it would be possible to apply a solution approximating the «ideal» one, by separating the material, screening it in standard sieves, into the narrowest franctions possible and by concentrating each franction on the suitable table.

Applying this sort of processing involves large screening installations a multitude of concentrating tables and moreover a large staff.

A practically optimum solution for tackling the above disadvantages, is adjusting the functional parameters of the concentrating tables in such a way that the area of the shaded segments of diagrams, Fig. (1) and (2), may be the largest possible, in other words, that we may accomplish conditions of differentiating the velocities of the processed particles (line MN) and at the same time obtain the highest particle velocities possible and a wide range of particle diameters[16].

Optimum production parameters.

From Fig. (1) and (2) it follows that the value of x_1 is found by solving equation:

$$U_{B\,max} = U_A \qquad (6)$$

that is, by using equations (4) and (5),

$$4\,\frac{8\,(\rho_A - \rho)(1 - n_D\cot a) - 27K_A\rho}{72K_A}\;\frac{8(\rho_B - \rho)(1 - n_D\cot a) - 27K_B\rho}{72K_B}\,x^2 +$$

$$+ 4\rho\,\frac{8\,(\rho_B - \rho)\,(1 - n_D\cot a) - 27K_B\rho}{72K_B}\,x + \rho^2 = 0 \qquad (7)$$

One of the roots x_1, the lesser of the two, of equation (7) gives the lowest limit of the «diameter» range of the particles x_1 to 1, suitable for concentration, for a given value of the expression ($1 - n_D\cot a$) and of ρ, ρ_A, ρ_B, K_A and K_B.

If, for the sake of brevity in the mathematical operation below, in equations (4) and (5), we put,

where:
$$\frac{8\,(\rho_A - \rho)\,(1 - n_D\cot a) - 27K_A\rho}{72K_A} = M \qquad (8)$$

and:
$$\frac{8\,(\rho_B - \rho)\,(1 - n_D\cot a) - 27K_B\rho}{72K_B} = N \qquad (9)$$

we obtain:
$$U_A = Mx^2 + \rho x \qquad (10)$$

$$4MNx^2 + 4N\rho x + \rho^2 = 0 \qquad (11)$$

The area of the shaded surface, Fig. (1) and (2) will be given by the integral :

$$E=\int_{X=X_1}^{X=1} U_A\,dx = \int_{X=X_1}^{X=1} (Mx^2 + \rho x)\,dx = \left[\frac{Mx^3}{3} + \frac{\rho x^2}{2}\right]_{X=X_1}^{X=1} \tag{12}$$

or:

$$E = \frac{M}{3} + \frac{\rho}{2} - \frac{Mx_1^3}{3} - \frac{\rho x_1^2}{2} \tag{13}$$

if we put:

$$x_1 = \rho\frac{-N - \sqrt{N^2 - MN}}{2MN} \tag{14}$$

we obtain:

$$E = \frac{M}{3} + \frac{\rho}{2} - \frac{M}{3}\left[\rho\frac{-N - \sqrt{N^2 - MN}}{2\,MN}\right]^3 - \frac{\rho}{2}\left[\rho\frac{-N - \sqrt{N^2 - MN}}{2\,MN}\right]^2 \tag{15}$$

From equation (15) it is possible to calculate the value of the expression ($1-n_D\cot a$) and concequently also the value x_1, for which E takes its maximum value, by the method of successive approximations.

By solving equation (7) in terms of the expression ($1-n_D\cot a$) the following relation is obtained:

$$(1-n_D\cot a) = -\frac{9\rho}{16x_1}\left[\frac{8-3x_1}{\rho_A-\rho}K_A - \frac{3x_1}{\rho_B-\rho}K_B - \sqrt{\left(\frac{8-3x_1}{\rho_A-\rho}K_A + \frac{3x_1}{\rho_B-\rho}K_B\right)^2 - \frac{64\,K_A\,K_B}{(\rho_A-\rho)(\rho_B-\rho)}}\,\right] \tag{16}$$

The equation (16) gives the value of the expression ($1-n_D\cot a$), n_D being known we obtain the suitable slope of the concentrating table for processing materials of specified «diameter» range x_1 to 1 and ρ, ρ_A, ρ_B, K_A, K_B being known.

Liquid supply

The liquid supply[1c] required to form a film of flowing liquid of depth z, density ρ and viscosity coefficient n, on an inclined surface free of particles, of length L and at an angle a^0 to the horizontal is:

$$Q_v = \frac{\rho g \sin a}{3n} z^3 \cdot L \quad cm^3 \cdot sec^{-1} \tag{17}$$

for such a surface covered completely by monolayer spherical particles of a diameter range x_1 z to z, is:

$$Q_v = \left[1 - \frac{\pi(1 + x_1)}{8}\right] \frac{\rho g sina}{3n} \cdot z^3 \cdot L \; cm^3 \cdot sec^{-1} \qquad (18)$$

From the relations considered above it follows that: all relations refer to relative particle velocities which are inside relatively restricted limits (between horizontal line MN and the maximum value of curve A which is inside the «diameter» range of particles, x_1 to 1, (Fig. (1) and (2)).

This induces us to accept that $n_A \approx n_B = n_D$, since the value of the dynamic friction coefficient is a function of the sliding velocity of the particle.

The calculated value of x_1 is a function only of the physical properties of the particles to be concentrated and of the density of the liquid used.

The calculated value of product $n_D$cota, is also a function only of the physical properties of the particles to be concentrated and of the density of the liquid used.

The nature of the inclined surface, affects only the relative value between ange a^0 and dynamic friction coefficient n_D.

Since the dynamic friction coefficient for perfectly smooth surfaces is known, $n_D = 0.20$, the inclination angles of the concentrating table for performing experiments, must satisfy the relation:

$$cota < \frac{c}{0.2} \qquad (19)$$

where:

$$c = n_D cota, \text{ calculated}$$

Economic efficiency

It is know that in a production process it is possible to adjust the production conditions, so that, the product may be of high or relatively low purity.

It is also known that, the higher the purity of a product is, the higher its production cost and commercial price rises and vice versa.

From what is stated above, it is evident that in a production process we must adjust the production conditions so that, we may obtain the maximum economic efficiency.

In mineral dressing processes the formula used for calculating the economic efficiency E_e is the following:(1d)

$$E_e = 100 \frac{q \cdot P_1}{f_B P} \qquad (20)$$

where: q = weight of product in tons, taken from 1 ton of raw material (ore).

P_1 = price per ton of product, this is a function of its purity.

P = price per ton of absolutely pure product (mineral B).

f_B = percentage of raw material (ore), in mineral B.

CALCULATING SECTION

Material under investigation

The ore used for calculating the basic relations, was pyrite ore (FeS_2) of a 25% content, with limestone as gangue and with the following data:

size analysis: — 20 mesh Tyler (D = 0.833 mm)

density of pyrite: $\rho_B = 5{,}0$ gr cm^{-3}

out-of roundness coefficient of pyrite: $K_B = 4/3$

density of limestone: $\rho_A = 2{,}7$ gr cm^{-3}

out-of roundness coefficient of limestone: $K_A = 5/4$

length of the concentrating table: L = 100 cm

price per ton of the conce trate: $P_1 = 3{,}5C_B^2 + 10C_B$ U.S. $

where C_B represents pyrite content in the concentrate, $C_{B}max = 1$.

Calculating x_1 and $(1-n_D cota)$.

The calculation of the value of x_1 and the expression $(1-n_D cota)$ is carried out by means of equation (15). In table I. below we give the value of the expression $(1-n_D cota) = -1{,}50$ for which E_{max} and at the same time $x_1 = 0.366556$.

TABLE 1

$1-n_D cota$	$M = \frac{8(\rho_A - \rho)(1-n_D cota) - 27K_A \rho}{72K_A}$	$N = \frac{8(\rho_B - \rho)(1-n_D cota) - 27K_B \rho}{72K_B}$	$x_1 = \rho \frac{-N-\sqrt{N^2-MN}}{2MN}$	$M/3$	$\rho/2$	$-Mx_1^3/3$	$-\rho x_1^2/2$	$E = \frac{M}{3} + \frac{\rho}{2} - \frac{Mx_1^3}{3} - \frac{\rho x_1^2}{2}$
-1.40	-0.586556	-0.841617	-0.383129	-0.195518	0.5	0.010996	-0.073394	0.242083
-1.50	-0.601667	-0.875000	-0.366556	-0.200556	0.5	0.009878	-0.067182	0.242140
-1.60	0.616778-	-0.908333	-0.351383	-0.205592	0.5	0.008220	-0.061735	0.241592

Since, however, in the Tyler sieve[2] series, the sieve with a mesh opening which is the closest to the calculated value of x_1, is $1/(\sqrt[4]{2})^6 = 0.353553 \simeq x_1$, this second value is of necessity used as the optimum one.

Thus the size fractions into which the material to be concentrated must be separated by screening are:

$$-D+Dx_1, \; -Dx_1+Dx_1^2, \; \ldots\ldots$$

or

$$-0.833+0.295\text{mm}, \; -0.295+0.104\text{mm}, \; \ldots\ldots$$

or

$$-20+48\text{mesh}, \; -48+150\text{mesh Tyler} \; \ldots$$

To the value x_1 used of necessity there corresponds a new value of the expression ($1\text{-}n_D\cot a$) which is calculated by means of the equation (16), thus:

$$1\text{-}n_D\cot a = -\,1,5850 \qquad (21)$$

By means of relation (21) and for a series of supposed values of dynamic friction coefficient n_B, e.g. 0.20, 0,21, 0.22.....there is calculated a series of angles a^0 for performing experiments.

Thus we have obtained table 2 which gives angles a^0 for each value of dynamic friction coefficient n_D.

TABLE 2

n_D	0.20	0.21	0.22	0.23	0.24	0.25	0.26	0.27
a^0	4°25'	4°39'	4°52'	5°05'	5°18'	5°31'	5°45'	5°58'

Calculating the required water supply.

The calculations are carried out by means of equation (18), the results provided by table 3. refer to the first size fraction (—0.833+0.295 mm).

TABLE 3

a^0	4°25	4°39'	4°52'	5°05'	5°18'	5°31'	5°45'	5°58'
Qv Lit/min	4.10	4.30	4.50	4.70	4.90	5.10	5.30	5.50

Experimental determination of economic efficiency E_θ, in relation to feed rate F at a fixed angle of inclination.

A series of experiments performed at a fixed angle of inclination of the table $a^0 = 4°25'$, and at a different feed rate each time, have given results of concentrate of weight q and pyrite content C_B. Table 4 below contains these results.

From the data in columns 1 and 5 of the table we obtain the relation which gives the economic efficiency in terms of feed rate F at a fixed angle $a^0 = 4°25'$, that is,

$$E_\theta = -358,10F^2+32,72F \qquad (22)$$

Column 6 of the table gives the values of E_θ calculated by means of equation (22).

TABLE 4

1	2	3	4		5	6
F t/h	q t	C_B %	$P_1 = 3.5C_B^2 + 10C_B$ U.S. $	E_e	$=100\frac{q \cdot P_1}{f_B \cdot P}$ %	$E_{e\ (calc)}$ %
0.0300	0.4040	47.10	5.50		65.80	65.95
0.0350	0.3550	56.30	6.70		70.50	70.60
0.0400	0.3030	66.60	8.20		73.60	73.60
0.0450	0.2800	71.60	9.00		74.70	74.70
0.0500	0.2690	73.60	9.30		74.10	74.10
0.0550	0.2490	76.60	9.70		71.60	71.60
0.0600	0.2780	66.60	8.20		67.50	67.40
0.0650	0.3140	55:40	6.60		61.40	61.40
0.0700	0.3350	46.10	5.40		53.60	53.60
0.0750	0.3550	37.50	4.20		44.20	44.00

In the same way functions like (22) are also obtained for the remaining angles of inclination a^o and thus table 5 results.

TABLE 5

a^0	E_e %
4°25′	$-358.10F^2 + 32.72F$
4°39′	$-289.70F^2 + 31.31F$
4°52′	$-256.70F^2 + 30.47F$
5°05′	$-238.90F^2 + 29.81F$
5°18′	$-231.40F^2 + 29.24F$
5°31′	$-232.50F^2 + 28.68F$
5°45′	$-243.60F^2 + 28.03F$
5°58′	$-265.70F^2 + 27.29F$

Manipulating the data of table 5 for calculating parameters of maximum economic efficiency.

From table 5 by calculating the values F for which E_e is maximum, we obtain columns 3 and 4 of table 6.

By proper mathematical manipulation of the data in columns 3 and 4 in connection with the data in column 1, we obtain relations giving the feed rate F and economic efficiency $(E_{emax.})a^o$ in terms of angle a^o.

TABLE 6

1 a^0	2 E_e	3 $(E_{emax.})a^0$ %	4 F t/h
4°25′	$-358.10F^2 + 32.72F$	74.74	0.04568
4°39′	$-289.70F^2 + 31.31F$	84.60	0.05404
4°52′	$-256.70F^2 + 30.47F$	90.42	0.05935
5°05′	$-238.90F^2 + 29.81F$	92.99	0.06239
5°18′	$-231.40F^2 + 29.24F$	92.37	0.06318
5°31′	$-232.50F^2 + 28.68F$	88.44	0.06168
5°45′	$-243.60F^2 + 28.03F$	80.63	0.05753
5°58′	$-265.70F^2 + 27.29F$	70.07	0.05136

$$F = -80.17\sin^2 a + 14.72\sin a - 0.6124 \quad (23)$$

$$(E_{emax})_a = -1139.67\sin^2 a + 204.53\sin a - 8.2448 \quad (24)$$

Finally, from equations (23) and (24) we obtain the optimum angle of inclination a^0 and the optimum feed rate F for maximum economic efficiency, that is:

$a^0 = 5°09'$

$F = 0.063$ t/h

$E_{emax} = 93,16\%$

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ΠΕΡΙΛΗΨΗ

ΣΥΜΒΟΛΗ ΣΤΗ ΜΕΛΕΤΗ ΕΜΠΛΟΥΤΙΣΜΟΥ ΜΕΤΑΛΛΕΥΜΑΤΩΝ ΔΙΑ ΤΗΣ ΤΡΑΠΕΖΗΣ ΕΜΠΛΟΥΤΙΣΜΟΥ

Ὑπὸ

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Μελετοῦνται οἱ παράγοντες ποὺ καθορίζουν τὴν οἰκονομικὴ ἀπόδοση κατὰ τὸ διαχωρισμὸ ὀρυκτῶν διὰ τῆς μεθόδου τῶν τραπεζῶν ἐμπλουτισμοῦ.

Δίνονται σχέσεις μὲ τὴ βοήθεια τῶν ὁποίων αὐτοὶ ποὺ ἀσχολοῦνται μὲ τὸν ἐμπλουτισμὸ μεταλλευμάτων διευκολύνονται, περιοριζόμενου τοῦ ὄγκου τῆς πειραματικῆς ἐργασίας, στὸν ἐντοπισμὸ τῶν τιμῶν τῶν μεταβλητῶν, διὰ τῶν ὁποίων ἐπιτυγχάνεται ἡ μέγιστη οἰκονομικὴ ἀπόδοση.

Ἐπίσης ἐκτίθεται ἡ διαδικασία τῆς χρησιμοποιήσεως τῶν σχέσεων, ὥστε νὰ ἐξαχθοῦν οἱ τιμὲς τῶν παραμέτρων ποὺ παρέχουν τὸ μέγιστο οἰκονομικὸ ἀποτέλεσμα.