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The Effect of the Parameters of the Grinding on the Characteristics of the Deposit Phosphate Ore of Kef Es Sennoun, Djebel Onk-Tebessa, Algeria

N. Benabdeslam, N. Bouzidi, F. Atmani, R. Boucif, A. Sakhri

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***Abstract*—**The objective of this study was to provide answers for a better understanding of the mechanisms involved during grinding. To obtain a phosphate powder, we carry out sieving - grinding circuits for each parameter influencing the process. The analysis of the average particle size of the different tests carried out served in the first place as a basis for the determination of the granulometric curve area, the characteristics and the granular coefficients, then the exploitation of the different results for the calculation of the energies consumed for the fragmentation of different ore types, the energy coefficients as well as the ability to grind. Indeed, a time of 5 to 10 minutes can be chosen as the optimal grinding time in a disc mill for a % in weight of the highest pass. However, grinding time can influence the granular characteristics of ore.

***Keywords*—**Energy, granular characteristics, grinding, mineralogical composition, phosphate ore.

I. Introduction

ALGERIA is one of the main producers of phosphate in the world, but the Algerian production of this essential substance is low comparing to its important reserves [1]-[4]. Phosphate reinforces its range of market products because of its wide use in agriculture as simple binary and complex fertilizers. In addition, phosphate is used in chemical and pharmaceutical industries. It is important to say that in the near future and with the depletion of the reserves of certain mineral substances from a quality point of view, the mining companies will have to extract ores with poor content which creates a tendency to review the current processing and exploitation methods to meet the national and international demand. Fragmentation always seeks to satisfy requirements for future uses [5]-[7]. Fragmentation is such a costly investment, energy and maintenance operation that can limit the choice and assembly of the apparatus and / or questions the very relevance of the implementation. In fragmentation, the reduction of energy consumption is not the only objective to look for, other objectives are also important: the granular distribution, the mesh of release, the morphology of the grains and the reactivity of surface. Grinding is the comminution stage where it is essential to control the size of the crushed product. Coarse milling results in low recovery of valuable ore, while fine milling results in a high cost because of regrinding [8].

The quantity of a grinding product is generally defined by two characteristics of crushed ore: the size of crushed grains is the quality of the surface of the separated grains (intra or intergranular factor) [6], [7]. As a result, one of the aspects characterizing the efficiency of the comminution phase is the release of valuable gangue minerals with a small percentage of mixed particles [4]. The reduction of the size of the grains, from these same minerals, to a dimension compatible with the concentration process (while ensuring optimum physical and chemical properties for the treatment operations) is also an important aspect [5]. In comminution, the grinding step represents the step, or the operation of reduction is very effective. The cost of grinding can be increased by grinding equipment, and consequently, by the plant. The cost of grinding can reach more than 50% of the total energy used by the concentrator in a mine. A better knowledge of the grindability of the ore would optimize this operation [6]-[8].

The aim of this paper is to study the effect of grinding time on the mineralogical and textural characteristics of the Algerian phosphate ore of the Kef Es Sennoun (Djebel Onk-Tebessa). Several techniques of analysis are used to determine the mineralogical phases as X-Ray diffraction.

II. Material and Methods

In order to achieve this goal, grinding-taming operations were carried out successively by varying the milling time (5, 10, 15, and 20 min) at a mill rotation speed ranging from 600 rpm to 1000 rpm.

In this study, the material below was used: jaw crusher, disc mill, electric sieving machine. The ores are milled in several times (5, 10, 15, 20 min) at a mill rotation speed from 600 rpm to 1000 rpm.

A. Treatment and Preparation of the Raw Material

The phosphate ore samples will first undergo mechanical treatment by crushing, grinding and sieving before their granulometric, mineralogical characterizations.

The treatment serves to reduce the grain diameter. The raw material is in the form of stone with a diameter greater than 10 cm. Using the crushing process, the grain diameter is reduced to a diameter of about 4 mm. The operation of grinding comes

N. Benabdeslam is with the Laboratory of Technology of Materials and Process Engineering (LTMPE), Faculty Technology, University A. Mira, Bejaia 06000, Algeria (corresponding author, phone: +213-771-284-444, e-mail: maleknouaraltmgp@gmail.com).

N. Bouzidi, R. Boucif, and A. Sakhri are with LTMPE, Faculty Technology, University A. Mira, Bejaia, 06000, Algeria (e-mail: nedjmabouzidi@yahoo.fr boucif_rima06@yahoo.fr, raoufsekhri@hotmail.fr).

F. Atmani is with the Research Laboratory in Applied Hydraulics and Environment (RLAHE), Faculty of Technology, University A. Mira, Bejaia, 06000, Algeria (e-mail: farid.af@live.fr)

just after the crushing. Thus, the crushed material undergoes homogenization in order to obtain a homogeneous mineralogical distribution of the sample components.

A dry grinding is carried out to reduce the grain diameters of the raw material in order to promote the representativeness of the results during the chemical analysis. It was carried out by a disc crusher and oscillating rings (FRITSCH pulverisette 9). The particle size analysis is used to determine the distribution of the particles according to their size. Sieving is one of the analysis methods used by means of a sieves series: 4, 2, 1.4, 0.71, 0.50, 0.355, 0.250, 0.180, 0.125 mm. Finally, the sieving matter is weighted using an electronic balance.

The influence of the dry grinding time on the fragmentation efficiency has been studied experimentally using a vibratory disc type "Spray 9". The various granular characteristics (diameters and particle size coefficients) and the mineralogical composition were determined for each parameter used as well as the consumed energies. Grinding tests were carried out at a constant milling speed (V) with a series of samples, weighting 100 g, for different times (5, 10, 15 and 20 min). The mineralogical analysis of the raw phosphate was performed by X-ray diffraction.

B. Characteristics of Particle Size

Characteristic diameters: The characteristic diameters of the ore grain are defined by different diameters of the fractions having the weight % (% passing cumulative) equal to 80, 60, 50, 30 and 10 named by d80, d60, d50, d30, d10 (in mm) respectively. These diameters are directly determined from the granulometric curve of each sample before and after milling at fixed time (t) and velocity (V) conditions. These parameters are used to qualify fragmentation.

Reduction ratio: The reduction ratio (RR) is the ratio between the diameter of fresh ore and ore milled, therefore the diameter of ore before and after grinding. According to the theory of fragmentation of Bond, the D80 is the diameter of 80% thus passing noted RR:

$$RR = D_{80}/d_{80} \quad (1)$$

Characteristic coefficients:

- Coefficient of uniformity (Hazan coefficient): The coefficient of uniformity (Cu) represents the ratio of the coarser grain diameter to the smaller grains of a given ore, defined by:

$$Cu = d_{60}/d_{10} \quad (2)$$

The more homogeneous the ore, the lower the uniformity coefficient is. At the extreme, if a mineral was of identical particles, its coefficient of uniformity would be 1, these particles having all the same diameter. The importance of the differences between them is then maximized. Conversely, too much dispersion of the particle size is present. In such a case, the smaller grains are placed between the larger grains to fill a portion of the voids. The grain size of a material is spread or narrowed, if:

- Cu > 2.5: the particle size is spread and dispersed.
- Cu <2.5: the particle size is tight.
- Curvature coefficient: The curvature coefficient (Cc) comes in addition to the Hazan coefficient and makes it possible to determine whether the particle size is well graduated or incorrectly graduated:
- 1 <Cc <3: the well graded particle size (well distributed continuity)
- Cc <1, Cc> 3: the granulometry is poorly graduated (poorly graded continuity)

It is generally defined as follows:

$$C_c = d_{30}^2/d_{10}d_{60} \quad (3)$$

- Aire under the grain size curve: Particle size distributions are usually presented by plotting the % of the cumulative fraction as a function of particle size. However, comparing several curves can be difficult using this approach. To obtain a preliminary assessment of the particle size reduction following a fragmentation operation, it is possible to graph the cumulative percentages passing from a grinding product (Y) as a function of those of the feed (X).
- Determination of energies consumed by fragmentation (W, E)

The amount of energy consumed during grinding is divided into various positions: the moving parts of the equipment, transfer of material into the grinding zone (dispersion and pre-mixing), energy necessary for the fragmentation of the material to be broken. We mention that the amount of energy actually used to break the particles is 1 to 7% of the total energy expended. A significant proportion of the energy is transmitted to the ore through the friction effect of the grinder rings. Many works have been done to quantify the energy consumed during grinding according to the properties of final products (diameters). Bond's empirical procedure is often used to estimate the energy of an intermediate-sized ore. It is expressed by the formula (4):

$$W = 10W_i(\sqrt{\frac{1}{D_2}} - \sqrt{\frac{1}{D_1}}) \quad (4)$$

where D_1 and D_2 are the grain size before and after the fragmentation leaving 80% of the ore, respectively.

Wi: work index of phosphate ore (Wi = 11 kWh/t). Depending on the power of the device, the grinding time and the mass to grind, the energy consumed is calculated by the relation below:

$$E = P.t/M \quad (5)$$

where energy E is obtained in kWh / kg, P is the power of the appliance in W, t is the grinding time in hours, and M is the mass of crushed material (kg).

III. Results and Discussions

The results of the particle size analysis carried out for each fixed operating condition are presented in Figs. 1-6. The passing cumulative % will serve as a basis for the calculation of the various granulometric characteristics defined previously.

From these results, it is deduced that the percentage of pass as a function of sieve openings increases similarly so that the majority of the samples reach a maximum of 99.99% by weight. This is explained by the almost total reduction of coarse particle fractions of + 0.5 mm. Indeed, the high grinding time does not affect the passage in% of each size fraction. On the other hand, for the type of crusher used, it can be seen that from 5 to 10 min gives the same weight % of passing regardless of the milling speed operated were obtained from 20 to 25 min. Furthermore, the time of 5 to 10 min can be chosen as the optimum grinding time in a disk mill for a higher wt.% of the largest pass. However, grinding time can affect the granular characteristics of the ore.

Exploitation of the granulometric analysis results enabled us to calculate the area below the grain size curve by the presentation of % passing product as a function of w% passing from the feed, as well as its evaluation in a function of time and at different grinding speeds studied for a first evaluation of grinding efficiency (Figs. 3-7).

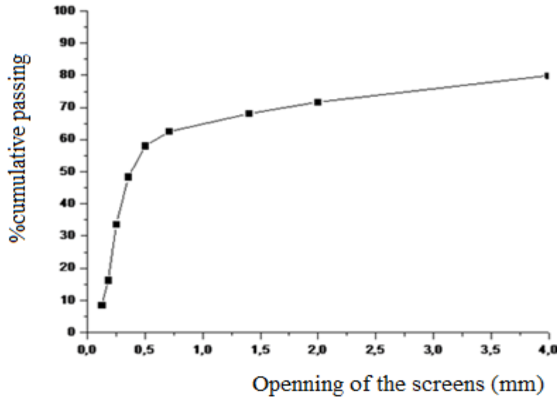
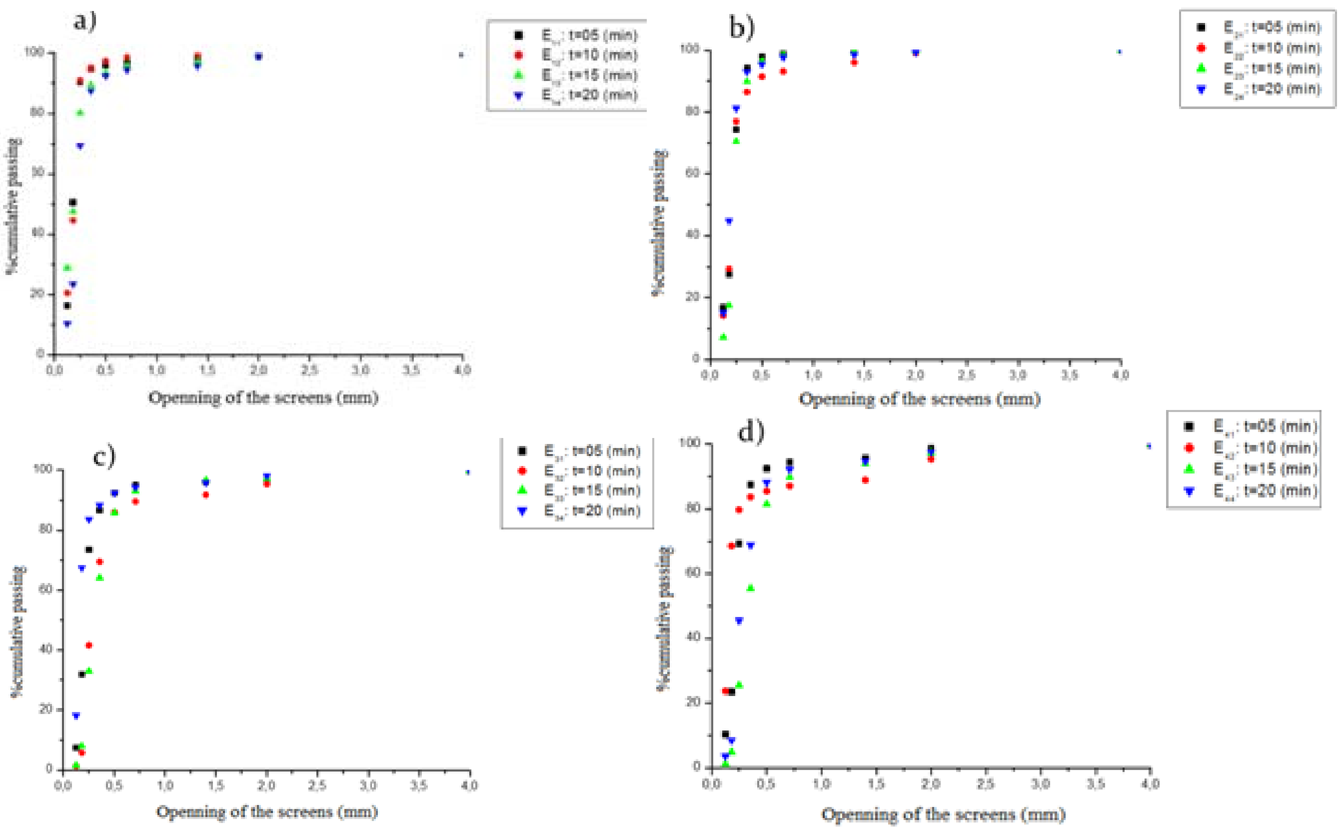


Fig. 1 Granulometric curve of ore samples before grinding



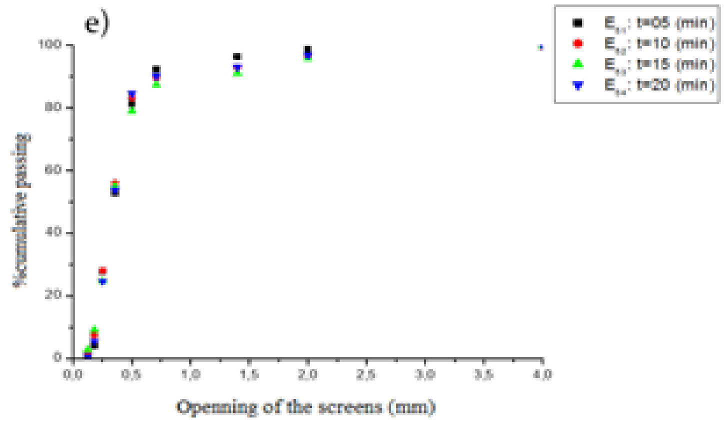


Fig. 2 Granulometric curve of the samples of ore after grinding in various times, (a) v= 600 rpm, b) v=700 rpm, c) v=800 rpm, d) v=900 rpm, e) v=1000 rpm)

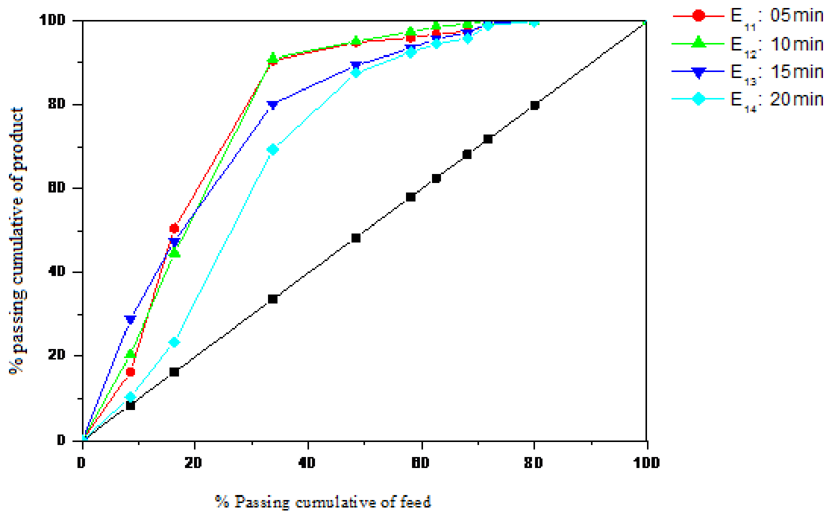


Fig. 3 Cumulative % change from product to% cumulative from feed to different milling times (V = 600 rpm)

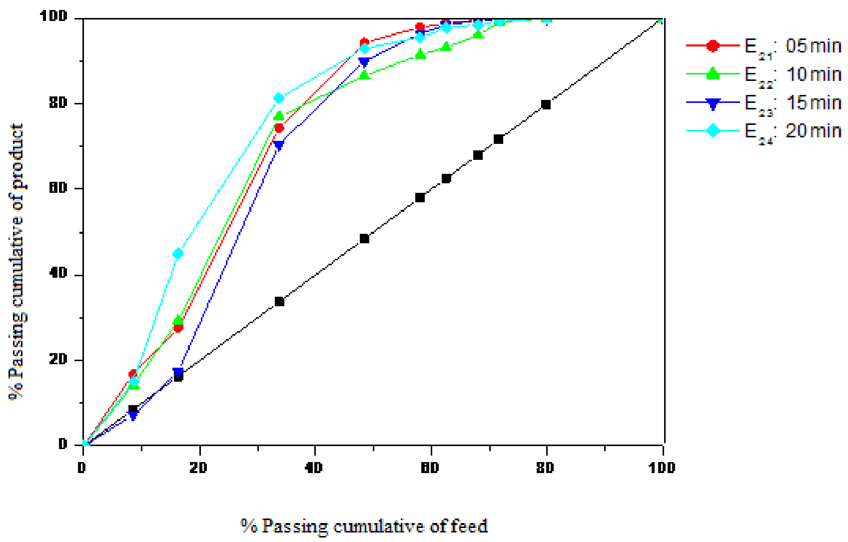


Fig. 4 Cumulative % change from product to% cumulative from feed to different milling times (V = 700 rpm)

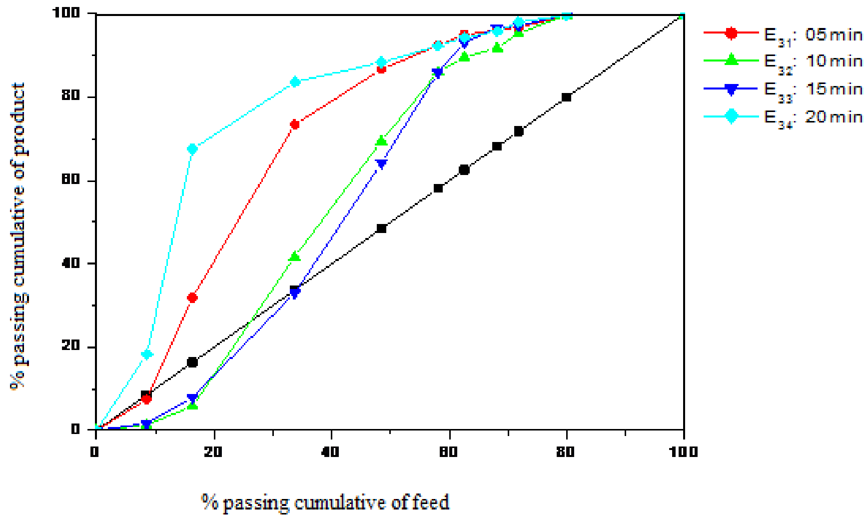


Fig. 5 Cumulative % change from product to% cumulative from feed to different milling times (V = 800 rpm)

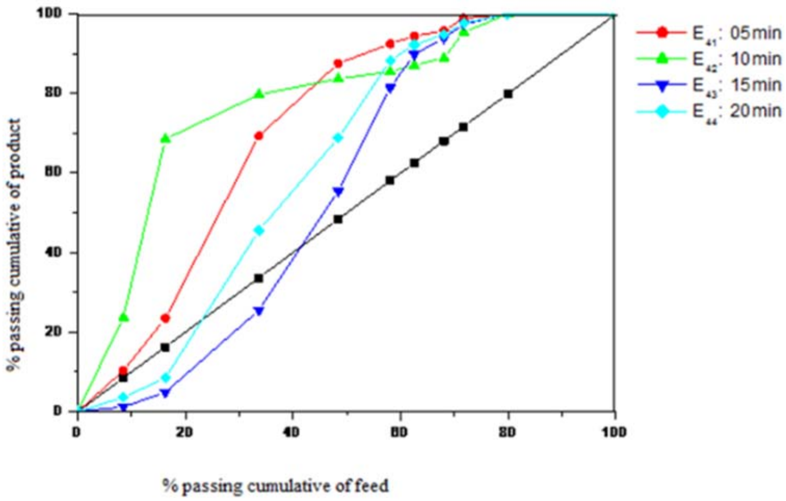


Fig. 6 Cumulative% change from product to% cumulative from feed to different milling times (V = 900 rpm)

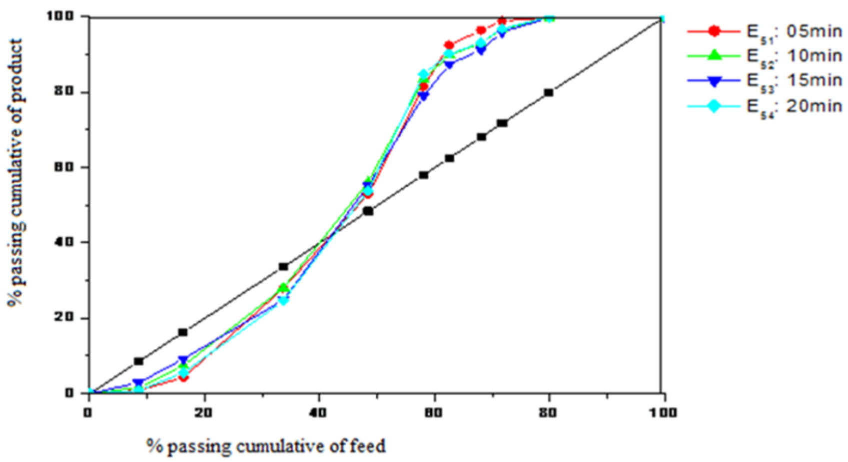


Fig. 7 Cumulative% change from product to% cumulative from feed to different milling times (V = 1000 rpm)

As shown on Fig. 3, the cumulative passing area of product is above the cumulative feed passing area (presented by the diagonal). Thus, the area between the curve and the diagonal is increasingly important that the grinding time is small.

However, the maximum area registered from 5 to 10 min shows the lowest grinding speed at 600 rpm.

The results obtained in Figs. 5-7 show a difference in the graphics layout mainly for the higher grinding time. This difference is observed by the displacement below the diagonal of a portion of the graph, which explains the agglomeration of cohesive fine particles which increases as a function of their residence time in the mill.

The characteristic diameters of the particle size and the reduction ratio for each ore grinding parameter are collected in Table I.

TABLE I
CHARACTERISTIC DIAMETERS OF ORE SIZE BEFORE AND AFTER GRINDING (V = 600 (RPM))

Grinding speed V (rpm)	Times (min)	Diameters					R
		D_{80}	D_{60}	D_{50}	D_{30}	D_{10}	
V=0	0	3.96	0.58	0.38	0.23	0.11	-
600	5	0.23	0 .19	0.16	0.15	< 0.11	17.21
	10	0.23	0.21	0.18	0.14	< 0.11	17.21
	15	0.25	0.21	0.17	0.11	< 0.11	15.84
	20	0.31	0.23	0.22	0.19	0.11	12.77
700	5	0.29	0.23	0.21	0.16	< 0.11	13.65
	10	0.29	0.22	0.21	0.18	< 0.11	13.65
	15	0.30	0.23	0.21	0.19	0.12	13.2
	20	0.25	0.21	0.19	0.15	< 0.11	15.84
800	5	0.30	0.23	0.20	0.16	0.14	13.2
	10	0.45	0.31	0.29	0.23	0.19	8.8
	15	0.46	0.34	0.30	0.25	0.18	8.60
	20	0.23	0.18	0.17	0.14	<0.11	17.21
900	5	0.31	0.23	0.22	0.19	0.11	12.77
	10	0. 25	0 .18	0.15	0.12	< 0.11	12.77
	15	0.49	0.38	0.33	0.26	0.19	8.08
	20	0.45	0.31	0.26	0.22	0.18	8.8
1000	5	0.49	0.39	0.34	0.25	0.19	8.08
	10	0.47	0.38	0.33	0.25	0.19	8.42
	15	0.53	0.38	0.33	0.26	0.16	7.47
	20	0.47	0.38	0.33	0.25	0.19	8.42

These results show that the optimum reduction ratio (R) greater than 17 is obtained for a residence time in the mill of 5 and 10 min operating at a speed of 600 rpm.

The values of the granular coefficients calculated as a function of the milling time at different speeds are summarized in Table II.

According to these results, the granulometry is tight and well distributed after 5 minutes grinding at a speed of 600 rpm. Beyond 10 min of grinding, a poor grain-size distribution appears due to the decrease of the coefficient Cu less than 2.5.

Therefore, the crushing of the particles by increasing the time is achieved. However, this disturbance is related to the agglomeration of the grains together, forming particles rather cohesive. In another point, the uniformity of the particles depends on the preponderance of the fine particles.

The uniformity and continuity of the distribution is poor after grinding at high speeds of 900 and 1000 rpm, caused by the strong deformation and rupture of the particles.

The evaluation of the energy consumption was determined after grinding each time and for each speed. The results obtained are illustrated in Figs. 8-10.

TABLE II
GRANULAR COEFFICIENTS AS FUNCTIONS OF GRINDING TIME AT DIFFERENT MILLING SPEEDS

Speed (rpm)	Times (min)	Cc (Befor/After)	Cu (Befor /After)
600	05	0.82/>1.07	5.27/> 1.72
	10	*0.82*/>0.84	5.27/> 1.90
	15	0.82/>0.52	5.27/> 1.90
	20	0.82/1.42	5.27/2.09
700	05	0.82/>1.01	5.27/> 2.09
	10	0.82/>1.33	5.27/> 2
	15	0.82/1.30	5.27/1.91
	20	0.82/0.97	5.27/> 1.90
800	05	0.82/0.79	5.27/1.64
	10	0.82/0.89	5.27/1.63
	15	0.82/1.02	5.27/1.88
	20	0.82/>0.98	5.27/> 1.63
900	05	0.82/1.42	5.27/2.09
	10	0.82/>0.72	5.27/> 1.63
	15	0.82/0.93	5.27/2
	20	0.82/0.86	5.27/1.72
1000	05	0.82/0.84	5.27/2.05
	10	0.82/0.86	5.27/2
	15	0.82/0.79	5.27/2.37
	20	0.82/0.69	5.27/2

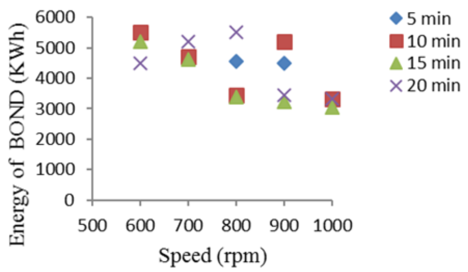


Fig. 8 Variation of energy of bond as function of the time and the speed of grinding

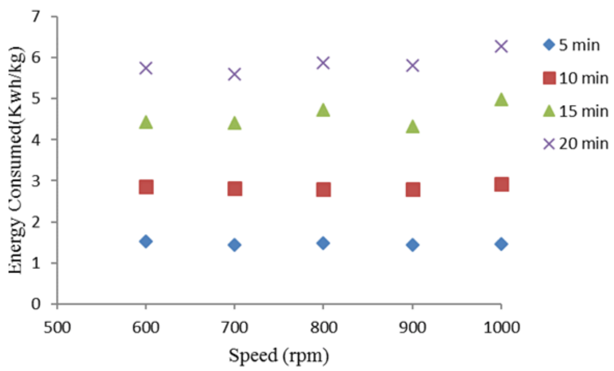


Fig. 9 Variation of energy consumed as function of the time and the speed of grinding

From these results, the variation of the energy is practically linear as a function of the speed and the slope increases slightly while increasing the time. This is confirmed by the equations on the right with the variation of the energy consumed (E in kWh / kg) as a function of the milling speed V (rpm) and as a function of the residence time of the ore in the chopper. Indeed, the lowest slope (lower value of energy) is obtained after 5 minutes of grinding and this energy remains almost constant (1582 kWh / kg). Thus, the increase in energy consumed is a function of the residence time of the particles in the chopper and the function of the operating speed of the chopper.

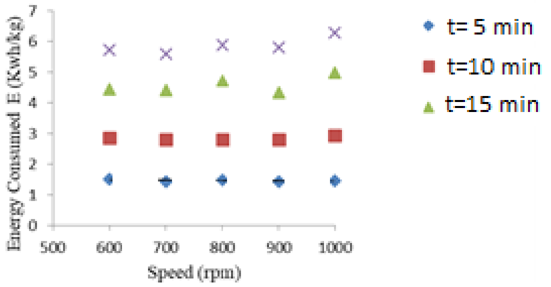


Fig. 10 Energy consumed as function of speed for different time of grinding

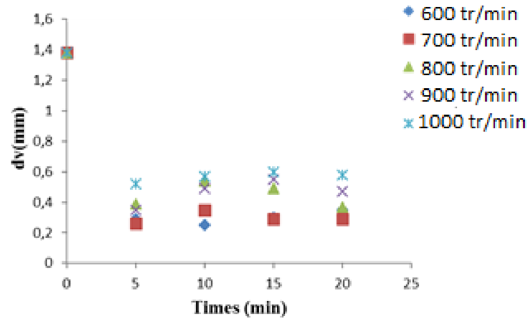


Fig. 11 Variation of equivalent diameter in volume as function of time grinding to different speed of grinding

The results of the equivalent diameters are shown in Fig. 11.

The mineralogical analysis of the crude phosphate (Fig. 12) shows that the raw material is mainly supposed by phosphate and its gangue.

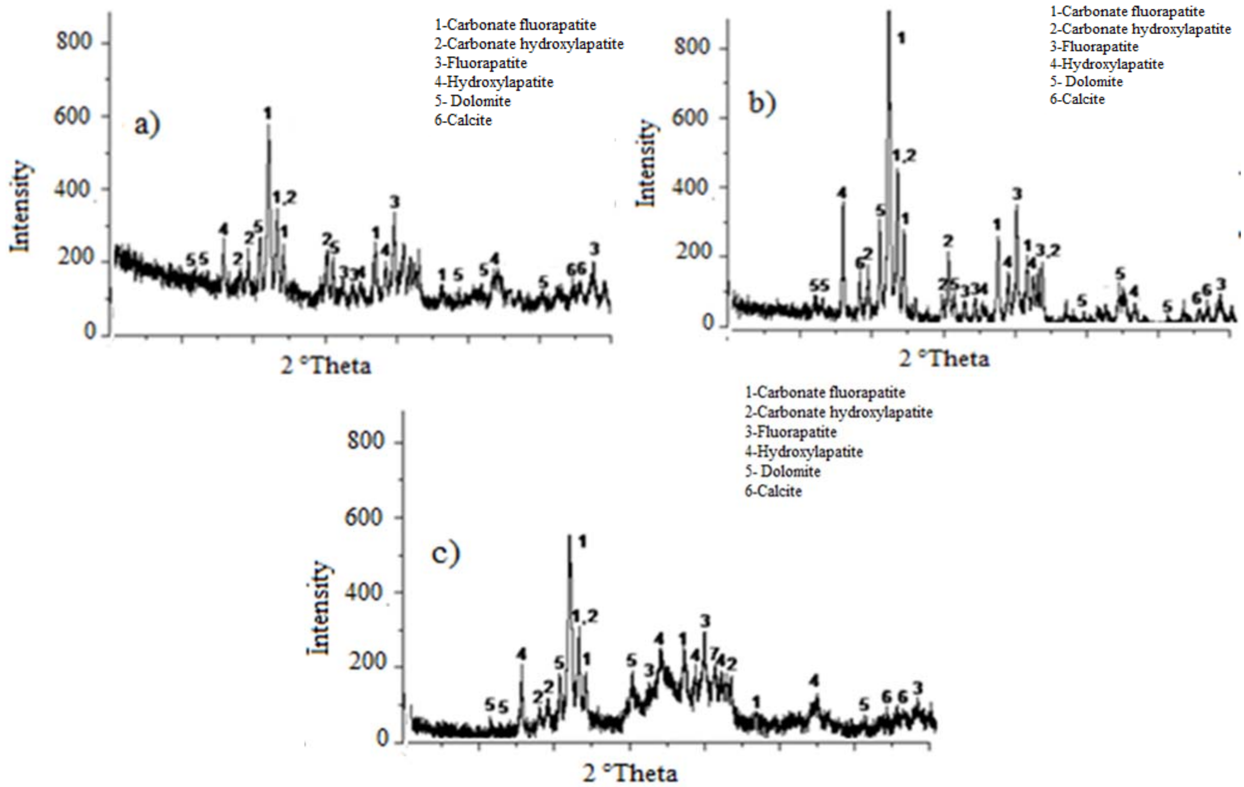


Fig. 12 Diffractogram X-RAYS: (a) Black phosphate gross (before grinding), (b) after grinding to v=600 rpm, t =5 min, (c) after grinding V=1000 rpm, t=20min

The diffractogram becomes more complex forming of the peaks of intensity lower bunk, which confirms the destruction of different particles constituents, the mineralogical phases present in the ores, and/or the agglomeration of the microfine material produced after grinding.

IV. Conclusion

The objective of this work is to show the effect of time and milling speed on the characteristics of Kef Es Sennoun phosphate ore (Djebel Onk-Tebessa). The time of 5 to 10 min and the speed of 600 rpm can be chosen as the optimal time and optimal grinding speed of kef Es Sennoun phosphate ore in a disc mill, thus giving an optimal reduction rate of about 17. In fact, the particle size is tight and well distributed after 5 minutes of grinding at a speed of 600 (rpm), beyond 10 minutes of grinding, a poor distribution and graduation of grains appear by the decrease of the coefficient of uniformity (Cu) less than 2.5 because of the crushing of the particles and /

or related to the strong agglomeration of grains between them which form rather cohesive particles.

A release of apatitic particles (hydroxylapatite, fluorapatite, fluorapatite carbonate) is obtained after grinding under optimal conditions (V = 600 rpm, t = 5 min). This work allowed us to provide some answers in the understanding of the mechanisms involved during grinding to obtain a quality phosphate powder by performing sieving - grinding circuits for each experimental parameter.

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