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Influence of Preheating on the Grindability of Mono/Poli Mineral Ores

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Keywords

Comminution of preheated ores, preheating as an aid to comminution, Grinding of mono/poli mineral ores

Abstract

In grinding practice, heterogeneous poli-mineral systems are more common than homogeneous mono-mineral system. The heterogeneity of raw materials in mineral beneficiation grinding circuit results by virtue of the varying properties of mineral constituents in an ore. In this investigation the effect of particle size and preheating conditions on the grindability of quartz as a mono-mineral ore, and nepheline syenite as a poli-mineral one was studied. 2n Factorial method was applied to arrange the studied parameters affecting the preheating of each of the two studied ores according to the importance of their relative effect on its grindability. The results revealed that incremented percentage of -200 µm in the preheated ground poli-mineral ore was less than that of mono-mineral one by about 32.9%. This behavior was interpreted by containing nepheline syenite on more than one mineral, consequently, phase change and anisotropic thermal expansion or contraction of the grain boundaries have a markedly effect on the grindability of preheated rocks, especially those contain more than one mineral.

1. Introduction

Mechanical size reduction processes in the mineral processing industry are energy intensive. Therefore, most of the important developments in comminution have been aimed at reducing its high operating cost [1-2]. There are Two trends of research, those could potentially lead to a step change in comminution efficiency due to thermal treatment. They are preheating of the ore [3-14], and application of high voltage pulses [15-23] to improve the grindability of ores as well as the liberation of minerals. Pertaining to the preheating trend: Lytle et al [3] declared how grindability was affected by preheating. They used the population balance grinding models to interpret their results of coal grinding before and after the heat treatment on locked cycle tests and found that, approximately 40% increase in grindability of preheated coal. Ahmed and Rizk [4] and Ahmed et al

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[5] studied the effect of thermal treatments on grindability of feldspar. They used factorial method as an experimental design method to arrange the studied affecting parameters according to their relative importance on the comminution process. The obtained results showed a significant decrease up to 35% energy consumed on grinding of feldspar when it was preheated and quenched in water. Some investigators [6-7, 8-14] have studied the effect of heating and quenching on grindability of different minerals and ores such as quartzite, Cornish ten ore, iron ore, coal, fluorite, barite, marble, and wolframite. They found that heat treatment prior to comminution operation could reduce energy requirement up to 50% with extra benefits of having increased liberation. An example of the successful application of thermal assisted liberation for reclamation of copper/plastic scrap was preheated by Veasey and Wills [15]. Referring to the economic evaluation of the process, if cheaper fuel is used and moe efficient methods are employed, grinding costs would be reduced since mineral would liberate at coarse sizes [8, 11, 12, 14].

High voltage pulses trend has the ability to utilize both the electrical and mechanical properties of the ore to reduce the energy required for further breakage [16-17]. The microwave pretreatment technique has offered promising solution in pre-weakening of rocks and ores [18]. Parker et al [19] concluded that the mineral liberation of chalcopyrite due to electrical comminution was more than that of mechanical comminution noticeably in coarse size fractions. Hartlieb et al [20] studied the thermo-physical properties of granite, sandstone and basalt rocks and showed the effect of phase transitions (e.g., α-β quartz phase transition) on the texture and stability of these rocks. Hassani et al [21] reported that: establishing optimum electromagnetic heating conditions significantly improves microwave induced weakening. Breaking hard rocks by high voltage pulse discharge experiments were carried out by Che et al [22]. Their results showed that: the fragmentation effect of hard rocks is strongly dependent on electrode gab and rock type. Ore texture features distinctively influence particle fragmentation, mineral liberation and fracture energy [23]. Ji and Zhang [24] studied the effect of mechanical grinding and thermal treatment on the recovery of Rare Earth Elements (REEs) from kaolinite. They showed that mechanical grinding for 4 hours completely destroyed the crystal structure of the material, but recovery of the total REEs was less than 20%. On the other hand, thermal treatment of the same raw material at 600° c for two hours largely enhanced the total REEs recovery as 92%. They ascribed the improved recovery to the thermal decomposition of crystallized forecited into an amorphous phase, which was proved through Transition Electron Microscopy.

The main objective of this study is to compare between the effect of particle size and preheating conditions on the grindability of mono/poli mineral ores. El-Barameya [Egypt] quartz was chosen to represent mono-mineral and Abu-chorog (Egypt) nepheline syenite was chosen as a poli-mineral one. It is intended to study, particle size, heating temperature, duration time of heating and cooling medium as the most preheating factors affecting the grindability of the two studied ores. To arrange these factors according to the importance of their relative effect on the grindability, 2^n factorial method can be applied as experimental design method.

2. Importance and properties of the two Studied Ores

The two studied ores namely quartz and nepheline syenite are used in ceramics and glass making industries [25]. The low fusion point of nepheline syenite lowers the melting temperature which increases productivity and results in fuel saving in glass industry [25]. Nepheline syenite used for glass making should be sandy sized product falling within the range of 74 to 346 µm. Its iron content should not exceed than 0.1% Fe_2O_3. Finely ground nepheline syenite is also used in the manufacture of white ware ceramic products, particularly saintly ware, dinner ware, floor and wall tiles and various porcelain products for electrical, dental and chemical uses. For the ceramics industry it is finely ground typically >95% minus 43µm [25]. Silica sand and quartz are changeable in many different industries [26-27] as glass, ceramic, metallurgical and electronic, filler, foundry sand, abrasive, filtration media, engine sand, and electrical insulation. It is also used in ferrosilicon production. The physical specification of silica required for glass making is mainly concerned with particle size distribution. Glassmakers prefer a near uniform size to insure efficient melting. Generally, grain size range from 0.59 to 0.144 mm is preferable with angular grain shape [25-28].

3. Experimental Work

In this study two Egyptian ores were used. They are El-Baramey Quartz as a mono-mineral ore, and Abu-khorog Nephelin Syenite as a poli-mineral one. The chemical composition of each ore was appointed by using XRF and listed in Table 1. Some of their physical and mechanical properties were also measured as shown in Table 2.

Table 1: XRF chemical composition of the studied ores

Ore	Element%						
	Fe_2O_3	Al_2O_3	SiO_2	CaO	K_2O+Na_2O	LOI	Total
Quartz	0.01	0.87	98.43	0.00	0.40	0.15	99.50
Nepheline syenite	6.46	18.55	57.40	1.12	12.90	3.17	99.60

Table 2: Some physical and mechanical properties of the studied ores

Ore	Property				
	Abrasion constant	Hardness	Coeff.of plasticity	Sp. gravity (gm/cm^3)	Comp.strength (kg/cm^2)
Quartz	0.25	7.10	2.86	2.65	1302
Nepheline syenite	0.26	6.50	2.59	2.48	980

The head samples used in this study were stage crushed to -4 mm. The crushed product was sieved and -4+3.15 mm, and -1.6+0.8 mm size fractions were used in the study. Samples of 140 grams from each size fraction of the two ores were prepared by riffling to construct a monolayer on the bottom of the mortar of the stamp mill machine.

3.1. Equipment

A computerized muffle furnace was used in the heating process of the two studied materials. The tested samples were preheated in silica crucibles of 150 ml capacity. Grindability tests of the treated and untreated samples were carried out using a laboratory stamp mill shown in Fig. 1 [29] and 200 µm sieve was used as a test screen for measuring grindability. 2n factorial method [30] was applied in this study as an experimental design for experimentation.

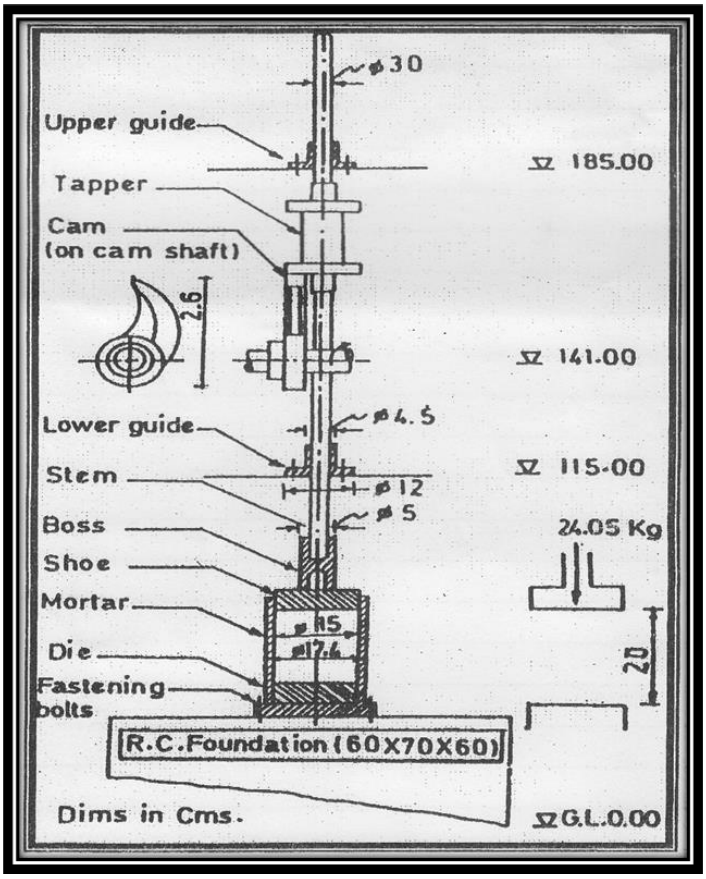

Fig. 1: A schematic diagram of the stamp mill [29]

3.2. Procedure

In addition to the two untreated head samples, sixteen experiments were carried out for each treated studied ore to execute the factorial program of four factors and two levels. Values of the lower and upper levels of the studied parameters were selected with the help of the previous investigations as listed in Table 3 [4-5, 7, 13-14].

Table 3: lower and upper levels of the studied parameters

Factor	Symbol	Levels		Units
		Lower	Upper	
Particle size	P.S	-1.6+0.8	-4+3.15	mm
Duration time	τ	18	60	min
Heating temperature	T	200	500	°c
Cooling medium	C	air	water	-

To follow the thermal treatment process, each sample was put inside the muffle furnace and heated from room temperature to the desired temperature with 40°c /min heating rate, and holder for a duration time at the desired temperature as planned in Table 4. The heated samples were then cooled by leaving it in open air or quenching it immediately in water. Subsequently, the quenched sample was filtered and dried. The treated and untreated samples were ground by using a laboratory stamp mill for 20 drops (943.24 Joules) and then sieved on the -200 µm sieve test.

Table 4: Matrix for the planning experimentation

Exp. No.	Factor			
	Particle size (P.S) (mm)	**Duration time (τ) (min.)**	**Heating temp. (T) (°c)**	**Cooling medium**
1	-1.6+0.8	18	200	air
2	-4+3.15	18	200	air
3	-1.6+0.8	60	200	air
4	-4+3.15	60	200	air
5	-1.6+0.8	18	500	air
6	-4+3.15	18	500	air
7	-1.6+0.8	60	500	air
8	-4+3.15	60	500	air
9	-1.6+0.8	18	200	water
10	-4+3.15	18	200	water
11	-1.6+0.8	60	200	water
12	-4+3.15	60	200	water
13	-1.6+0.8	18	500	water
14	-4+3.15	18	500	water
15	-1.6+0.8	60	500	water
16	-4+3.15	60	500	water

Energy consumed to grind each sample was kept constant at (943.24 Joule). It was calculated by using equation (1) [4, 5, 29].

E= W×L×F×2.7236×10-6 KWh……………………(1)

Where:

E: Energy consumed, KWh

W: The drop weight = 24.05 kg,

L: The free-falling distance = 0.2 m,

F: Number of drops (frequency).

Energy consumed was estimated in Joules by multiplying in 3.6×106 where 1 KWh= 3.6×106 J.

4. Results and Discussions

Table 5 shows the results of grinding of untreated -4+3.15 mm and -1.6+0.8 mm size fractions of quartz and nepheline syenite and Table 6 illustrates the percentage of increase of -200 μm in the ground preheated samples of the two studied ores.

Table 5: Weight of -200 μm in the untreated ground samples in grams

Ore	**Size fraction(mm)**	
	-4+3.15	**-1.6+0.8**
Quartz	18	36
Nepheline syenite	24	37

From Table 5 it is clear that untreated nepheline syenite is more grindable than untreated quartz with respect to the two studied size fractions. This behaviour can be attributed to its lower hardness as well as compressive strength than those of quartz as shown in Table 2. This interpretation agrees with that mentioned by Rizk [31]. The following regression models were estimated for the two preheated studied ores by applying the Yates's [32, 33] reduced method on the percentage of increase of -200 μm in the ground treated samples listed in Table 6:

For Quartz: $y = 15.89 + 6.86\ P.S + 1.87\ \tau + 3.40\ T + 1.37\ C$ …………….(2)

For Nepheline syenite: $y = 15.49 + 5.39\ P.S + 1.90\tau + 3.34\ T + 7.94\ C$ ………….……..(3)

Where y is the percentage of increase of -200 μm in the product due to preheating.

From the results of Table 6 and the previous regression models, it is clear that: preheating affects significantly on the grindability of both mono-mineral (quartz) and poli-mineral (nepheline syenite) ores, where it increases the percentage of -200 μm in the product of each of them. This increase is higher for quartz if compared with that for nepheline syenite. It is approximately evaluated by 1.33 times. This behaviour can be attributed to the difference in physical and mechanical properties of the constituents of these ores [31, 34].

From the predicted regression models, it is clear that: all the studied parameters have positive effect (direct proportionality). These findings agree with those obtained by Ahmed and Rizk [4] and Ahmed et al [5]. Table 7 shows the gradation of these parameters according to the importance of their relative effect on the grindability of the two studied ores.

Table 6: Percentage of increase of -200 µm in the ground preheated samples

Ore type / Exp.No.	Quartz				Nepheline syenite			
	feed (gm)	product (gm)	diff. (gm)	increase (%)	feed (gm)	product (gm)	diff. (gm)	increase (%)
1	36	38.00	2.00	5.56	37.00	37.51	0.51	1.38
2	18	20.00	2.00	11.11	24.00	24.84	0.84	3.50
3	36	39.00	3.00	8.33	37.00	38.67	1.67	4.51
4	18	21.00	3.00	16.67	24.00	25.67	1.67	6.96
5	36	40.00	4.00	11.11	37.00	39.50	2.50	6.76
6	18	22.00	4.00	22.22	24.00	26.51	2.51	10.46
7	36	41.00	5.00	13.89	37.00	40.34	3.34	9.03
8	18	22.91	4.91	27.28	24.00	28.17	4.17	17.38
9	36	42.00	6.00	16.67	37.00	41.17	4.17	11.27
10	18	23.99	5.99	33.28	24.00	29.85	5.85	24.38
11	36	43.00	7.00	19.44	37.00	42.00	5.00	13.51
12	18	25.00	7.00	38.89	24.00	31.52	7.52	31.33
13	36	44.00	8.00	22.22	37.00	42.85	5.85	15.81
14	18	25.20	7.20	40.00	24.00	32.35	8.35	34.79
15	36	45.00	9.00	25.00	37.00	43.68	6.68	18.05
16	18	25.58	7.58	42.11	24.00	33.19	9.19	38.29
Sum				311.67			209.12	
***Mean**				19.48			13.07	

*decrease% = $\frac{19.48-13.07}{19.48}$ = 32.9%

Table 7: Gradation of the studied preheating parameters according to their relative effect on the grindability of the studied ores

Ore	Gradation			
	1	2	3	4
Quartz	**P.S**	**T**	**τ**	**C**
Nepheline syenite	**C**	**P. S**	**T**	**τ**

From nepheline syenite model, it is clear that: cooling medium has the highest effect on its grindability. This result is logic and can be attributed to the anisotropic contraction of the boundaries of its metallic constituents during cooling process.

The obtained regression models showed only the trend of the effect of each studied factor on grindability, as each factor was tested only at two levels. Therefore, classical experimentation was applied to study the effect of the heating temperature on the grindability of each studied ore.

Batches of 140 gm each of -4+3.15 mm size fraction were heated in the muffle furnace for 60 minutes at varied temperature from 500 to 1000°c, followed by water quenching. The dried samples were subjected to grinding tests using the same stamp mill machine at the same condition. Table 8 and Fig. 2 illustrate the effect of heating temperature on the percentage of increase of -200 µm in the ground samples.

Table 8: % of -200 µm increase in the product of the preheated for 60 minutes and water quenched samples of the two studied ores

Heating temp. (°c)	Ore type	
	Quartz	Nepheline syenite
500	42.56	38.28
600	48.76	42.92
700	64.36	52.17
800	72.35	59.59
900	74.69	62.45
1000	75.14	63.45

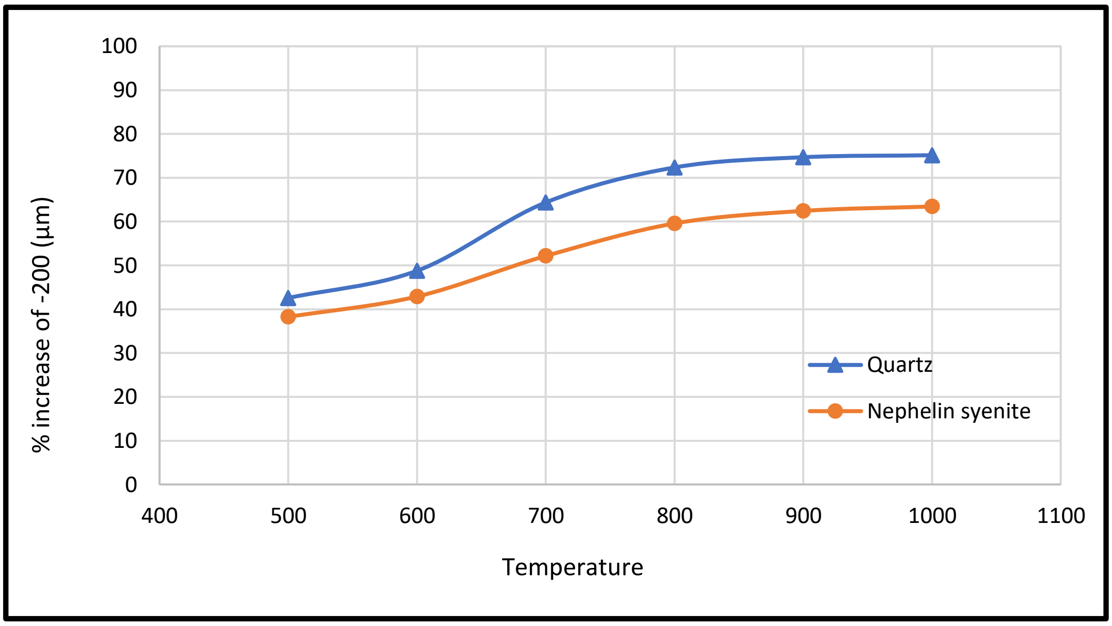

Fig. 2: Effect of heating temperature for 60 min. and water quenching on the percentage of increase of -200 µm in the product

Figure 2 illustrates that: the percentage of increase of -200 µm for quartz is slightly higher than that for nepheline syenite from 500 to approximately 650°c, then became higher up to 800°c, and above 800°c the two curves had a constant direction. This behavior may be due to the act of the higher heating temperature which induce weakening in grain boundaries between particles and causes numerous micro cracks and interstices throughout the structure which makes it easily grindable. This interpretation agrees with that suggested by Hariharan and Venkatachalam [14] and Pan et al [27]. Figure (2) illustrates also that increase of the percentage of -200 µm in the product of quartz is slightly higher than that of nepheline syenite from 500°c to 650°c. This behavior may be due to the phase transition of quartz from α to β as declared by Pan et al [27] and Martello et al [35].

5. Conclusions and Recommendations

From this study the following conclusions can be drawn:

- Preheating of either mono-mineral or poli-mineral ores increases the percentage of fine in the ground product. This increase is higher for mono-mineral more than that for poli-mineral one by about 32.9% under the same preheating conditions.
- Applying the 2^n factorial as experimental design method facilitates the gradation of the most affecting parameters on the preheating process on the grindability of each studied ore.
- The predicted regression models showed a direct proportionality between all the studied parameters and the increase of the percentage of fines in the product of the two studied ores.
- The obtained results illustrated that the cooling method of the preheated ore prior to grinding has a marked effect on the increase of the percentage of fine in the ground product.
- The percentage of fine in the product has been affected by phase transition, an-isotropic expansion or contraction and volume changes due to mineral inclusion accompanying phase transition.
- It is recommended to make an economic visibility study to compare between the costs of the consumed energy in heating process and that reserved in the grinding operation.

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تأثير التسخين المسبق على طحن الخامات وحيدة ومتعددة المعدن

الملخص العربى:

طحن الخامات متعددة المعدن أكثر تطبيقا من الخامات وحيدة المعدن فى أنظمة الطحن عمليا، حيث تتحكم خواص مكونات هذه الخامات فى درجة نعومة ناتج الطحن. فى هذا البحث تم دراسة تأثير حجم الحبيبات وظروف التسخين المسبق على درجة نعومة طحن كلا من الكوارتز والنيفلين سيانيت كل على حدة، فالكوارتز خام وحيد المعدن بينما النيفلين سيانيت خام متعدد المعادن. طبقت طريقة العوامل لتصميم التجارب على كل من الخامين على حده بهدف تصنيف العوامل المؤثرة على عملية التسخين طبقا لأهمية تأثيرها النسبى على عملية الطحن. وقد أوضحت الدراسة أن درجة نعومة طحن الخام متعدد المعادن سابق التسخين أقل منه بالنسبة للخام وحيد المعدن بمقدار ٣٢,٩٪ تقريبا، يعزى ذلك إلى فقد جزءا كبيرا من طاقة طحن الخام متعدد المعادن نظرا لتغير النظام البلورى والتمدد أو الانكماش الحرارى غير المتماثل لحدود الحبيبات المكونة لهذا الخام أثناء تسخينه.