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Influence of Operating Conditions of a Ball Mill on the Specific Surface Area of the Ground Alumina Oxide

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Abstract

The effect of mill diameter (D=74.3, 86.6, 99 and 112.5 mm), ratio of feed volume to mill volume (V_M=10,30,50,70 %), number of balls (N=2,3,4,5,6 and 7 balls), ball diameter(d=10,20,30 and 37.5 mm), mill speed (RPM=60,80,90 and 100% of max. mill speed), grinding time (T=10,20,30,40 and 50 min) and feed particle size (x_f=2000,1000,500 and 100 μ m) on the increase in specific surface area of the ground Alumina Oxide has been investigated. The ground materials were screened by using normal and micro sieves down to 45 micrometer to give a complete analysis of the ground product. The increases in specific surface area of the products were evaluated.

The results of the best operating conditions that achieve high increase in specific surface area of the ground Alumina Oxide with low energy consumptions were tabulated in table (3).

الخلاصة

يعتبر علم تكنولوجيا الدقائق (Powder Technology) احد العلوم التطبيقية للعديد من الصناعات ويعد تصغير الحجم الحبيبي (Particle Size Reduction) احد فروعه المهمة حيث يتم تكسير وتنعيم المواد الصلبة الداخلة في بداية العملية الصناعية أو لتحسين مواصفات المنتوج النهائي. مثل زيادة المساحة السطحية النوعية في عملية تحضير العوامل المساعدة.حيث إن الطاقة المصروفة في تصغير الحجم الحبيبي باستخدام الطاحونة ذات الكرات تكون عالية ولذلك فمن الضروري دراسة الظروف التشغيلية المؤثرة على عملية الطحن للحصول على أعلى كفاءة وباقل طاقة مصروفة.

تم في هذا البحث دراسة تاثير الظروف التشغيلية من حجم الطاحونة وعدد الكرات المستخدمة وحجم الكرات ونسبة حجم الداخل إلى حجم الطاحونة والسرعة الدورانية وزمن الطحن وحجم المساحيق الداخلة على المساحة السطحية النوعية لأوكسيد الألمنيوم المطحون . حيث تم استخدام اربع طاحونات ذات أحجام مختلفة (112.5,99,86.6,74.3) ملم وعدد كرات (7,6,5,4,3,2) كرة وحجم كرات مختلفة (37.5,30,20,10) ملم ونسبة حجم الداخل إلى حجم الطاحونة كانت (70,50,30,10) % وسرع دورانية متغيرة (100,90,80,60) % من السرعة القصوى وكان حجم الحبيبات الداخلة من اوكسيد الألمنيوم يتراوح بين (2000+1800-) و (1120+900-) و (560+450-) و (125+90-) مايكروميتر وزمن طحن (50,40,30,20,10) دقيقة. وبعد عملية الطحن تم تحليل الناتج المطحون بطريقة استخدام المناخل الاعتيادية والمناخل الدقيقة إلى اقل من ٤٥ مايكروميتر. كما تم حساب الزيادة في المساحة السطحية النوعية للناتج والتي تعتبر دليل النعومة وكفاءة عملية الطحن.

ومن خلال النتائج تم التوصل إلى أفضل الظروف التشغيلية للحصول على أعلى زيادة في المساحة السطحية النوعية لأوكسيد الألمنيوم وباقل طاقة مصروفة وكما مبين في الجدول(3).

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Nomenclature:-

D Mill diameter (mm)

d Ball diameter (mm)

N_B Number of balls

RPM Mill speed (% of max. mill speed)

ΔQ_i The weights fraction retained on sieve of size (i)

S The specific surface area (cm^2/gm)

Δs Increase in specific surface area (cm^2/gm)

T Grinding time (min)

V_M Ratio of volume of feed material to volume of mill

$\dot{X}_i$ The average particle size (μm)

X_i The size of ground product at the end of grinding (μm)

x_J Feed size (μm)

ρ_s The solid density of alumina oxide (=2.024 gm/cm^3)

ψ The sphericity of particles

$$(\psi = \frac{\min.\ particle\ diameter}{\max.\ particle\ diameter})$$

1-Introduction:-

Alumina oxide is extensively used as a catalyst, support and an adsorbent. For example the supports perform many functions, but most important is maintenance of high surface area of active components [1]. Grinding is usually carried out in order to increase the specific surface area because in the most operations involving solid particles, the rate of mass transfer and reactions are directly proportional to the surface area of contact with a second phase.Grinding is more a random process, and is subjected to the laws of probability [2]. The degree of grinding particles depends on the probability of their entering a zone between the medium and the probability of some occurrence taking place after entry [3]. The exact method by which the fracture occurs is not known. Pirt suggested that there is close similarity between the grinding operations and chemical reaction. In both cases a critical energy level must be exceeded before the start of the process and in both cases time is vital a variable [4]. The operating conditions of a ball mill are shown in the following empirical equations:

$$X_i = f(d, D, T, RPM, N_B, V_M, x_J) \quad \ldots\ldots\ldots\ldots\ldots (1)$$

It is important to study the operating conditions of a ball mill that gives a high surface area of the ground products and with low energy consumption in comminutions [5]. Also it is necessary first to describe the motion of a charge with mill speed. Cascading begins at low speed where the balls eventually roll over each other by which abrasive grinding occurs [6]. In the Cascading regime fine grinding takes place and hence greater wear and tear of the mill [7]. Cataracting regime occurs at higher speed. At this regime, the balls are projected into space and thereafter describe approximately parabolic paths before again meeting the balls mass [8]. In the Cataracting regime a coarse grinding takes place, that is due to the impact of the particles and hence less wear and tear on the mill [9]. There is hardly any breakage at very low speed and critical speed (where the balls would be against the shell thought cycle and so be carried around continuously with the mill shell) [10].

The best operation occurs when the balls between the linear radius of the charge and the radius of the mill go through their circular and parabolic paths without mutual interference [11].

Once of the most difficult question to answer in optimal design of a ball mill is the choice of mixture of ball size to be used in the mill [12]. Various formulas have been proposed for the required ratio of ball size to ore size [13], none of which are entirely satisfactory. An empirical rule which has been used for many years is [14]:

$$x_j = Kd^2 \quad \text{............ (2)}$$

Where $K = 10^{-3}$ to $0.7 * 10^{-3}$ for soft to hard material, d is the ball diameter in (mm) and x_j is the particle size in (mm). The above empirical rule gives a good basis for determining the ball size, but thereafter the correct size should be determined by trial and error. The effect of balls and mill diameter on the rate parameter (that required to evaluate a grinding process particularly for its initial grinding stage of various mill types) in dry and wet grinding operation have been discussed by many authors [15, 16, 17, 18]. Kotak et al [19] investigated the effect of ball diameter and feed size on the rate parameter for grinding of silica glass, limestone and gypsum, while Deniz [20] studied the effects of ball diameter and feed size on limestone, trass and clinker at batch grinding condition. Deniz developed an empirical equation to express the rate parameter of each material as a function of feed size and ball diameter. The optimum loading in a ball mill is also discussed by many authors [21,22] for dry and wet grinding in a laboratory experiments Deniz and onur [23], found that the 0.4 is a good powder-ball loading ratio to give an efficient breakage of pumice in a ball mill, while in many investigations, it has been found that this ratio a round from 0.6 to 1.1. Herbst et al [11] deals with great detail the movement of the charge in a ball mill and derives a technique to calculate optimum ball load as a function of rotational velocity.In the present investigation the effect of operating conditions such as number of balls, ball diameter, mill diameter, mill speed, feed particle size, volume of feed to the volume of mill and grinding time on the increase in specific surface area of the ground of Alumina Oxide were studied.

2-Experimental work and analysis:-

The experiments were preformed in a four steel mills of 74.3, 86.6, 99 and 112.5 mm internal diameter, using alloy steel balls of 10, 20, 30, and 37.5 mm diameter. The grinding stock employed was Alumina oxide (from Alcoa intentional company) of fractions 2000, 1000, 500, and 100 μm. These fractions are the nominal size of a narrow range distribution as shown in table (1).The operating conditions of five experimental groups for grinding of Alumina Oxide are tabulated in table (2).The ground products for each experiment were homogenized and divided into 8 equal samples by Riffler divider to have a proper amount of Alumina Oxide (15-20) gm.The analysis of the samples from the Riffler divider were carried out using normal and micro sieve (sieving machine) and the material retain on each sieves were weighted.

The specific surface area of Alumina Oxide before and after grinding process are calculated for each experiments using equation (1) as represented by Allen (1981) [2].

$$S = \frac{600}{\rho_S \psi} \sum_{i=1}^{n} \frac{\Delta Q_i}{X_i} \quad \text{.............. (3)}$$

Where the sphericities of each feed particles size were:

$(\psi_{2000} = 0.715, \psi_{1000} = 0.691,$
$\psi_{500} = 0.656, \psi_{100} = 0.588)$

For calculate the increase in specific surface area is calculated, using equation (4)

$$\Delta S = S_2 - S_1 \quad \text{.............(4)}$$

3-Results and Discussion:-

The increase in specific surface area of alumina oxide(1000 μm) were plotted versus the number of balls for two different mill diameter as shown in Fig (1). It can be shown that the increase in specific surface area increases with increasing the number of balls (i.e. increase the efficiency of grinding) to a maximum value and then decreases when the number of balls becomes greater than 5 balls. This could be due to that the increase the number of balls causes increase the impact force of balls on the material over the surface of the mill, while further increase in the number of balls makes increasing the probability to impact the balls between them (which causes the losses in the kinetic energy of balls) greater than ball- material. This probability is decreased when the mill diameter is increased. Because the free movement of the balls is increased, therefore the efficiency of grinding is increased when increasing the mill diameter as shown in Fig. (1).

Fig (2) shows the increase in specific surface area of Alumina Oxide (1000 μm) versus the ratio of feed volume to the mill volume (V_m) for two different mill diameters. It shows the behavior of grinding is similar to that observed by Von seebach (1972)[24] for grinding of cement clinker except for the range of mill charge. Fig(2) shows that the increase in specific surface area increases with increasing the ratio of volume of feed to volume of mill to a maximum value and then decrease when the ratio becomes greater than 30 % ,this may be due to the fact that the increase the volume of feed causes increase the probability of impact balls-material therefore the grinding efficiency increased but at same time when increase the feed volume, the abrasion between the material and mill surface increases too and this leads to increase the fine particles which covers the larger particles in the balk mass and hence reduce the chances of faster breakage. (Cushioning effect)[25] While the increase the mill diameter lead to increase the chance of separation between the fine and coarse particles (i.e. reduce the Cushioning effect) therefore the grinding increases when increase the mill diameter as shown in figs (1-2).

The increase in specific surface area versus mill diameter for various ball diameter for the feed particle size of 2000, 1000, 500, and 100 μm were plotted in Figs (3-6) respectively. Figs (3 and 4) show that the 20 mm ball diameter gives a greater increase in specific surface area than the other ball diameters that used for grinding of 2000 or 1000 μm feed size, while in Figs (5-6), 10 mm ball diameter gives a higher efficiency of grinding than the other ball diameters that used for grinding of 500 or 100 μm feed size. This may be due to the fact that the larger particles need larger balls to ground them, while the smaller particles need smaller balls so the balls that have 30 mm diameter, for example, break the particles to a given limit size therefore, its effect decrease since its size becomes larger in comparison with particle size of later stage.

The efficiency of grinding depends on the surface area of grinding media [26], thus balls should be as small as possible, and balls facilitate the production of fine material but do not deal so effectively with the larger particles in the feed.Also it can be seen from Figs (3-6) the increase in specific surface area increases when increase the mill diameter until the mill diameter becomes 99 and 90 mm the increase in specific surface area are slightly decreases or constant for the feed particle size of (2000, 1000 μm) and (500,100 μm) as shown in Figs (3-4) and Figs (5-6) respectively for all ball diameters used. This may be due to that when increase the mill diameter, the balls move more freely and the falling height of the balls is also increased therefore the impact force and compression effect are increased. Therefore the larger particles are broken to a stage when the abrasion effect comes into play, but the increase of mill diameter above a certain value the efficiency of grinding slight decrease or constant. This may be attributed to the wall effect.

The increases in specific surface area were plotted versus the percent of maximum mill speed for various feed particle size as shown in Fig (7) and the increases in specific surface area were plotted versus grinding time for various feed particle size as shown in Fig (8). Figs (7-8) show that the increases in specific surface area increase proportionally with increasing the mill speed and grinding time for all feed size. This may be attributed to fact that at low speed, Cascading take place, where the surface of the charge being inclined at approximately 30° to horizontal, in the Cascading regime, balls at the dynamic surface of the charge are subjected to mutual interference. The energy losses resulting from ball-ball contact (which increases when increase the number of balls) may be influence the breakage of particles by reducing the probability of breakage in a stress application event involving a stronger particle relative to corresponding probability of breakage for a weaker particle, this leads to the weaker particles are broken more rapidly leaving behind on increasing proportion of stronger particles. On the other hand the substantial proportion of the ball energy may be small to overcome the interfering influence of fine size (cushioning effect) in stress application event involving feed particles.At higher speed, cataracting regime occurs. In this case, the kinetics energy of the balls increases (i.e. increase the impact force) .on the other hand, the parabolic path will be given a chance to some of the separation between the fine particles and the large particles which is the result of the acceleration of gravity. Therefore the interfering influence of fine size is reduced i.e., the grinding increase at this stage. This occurs also when increasing the mill diameter as shown Figs (1-6).

Fig (7) shows that above 80% of maximum mill speed for the feed particles size of 2000 and 1000 μm and above 90% of maximum mill speed for the feed particle size of 500 and 100 μm, the grinding efficiency decreases or constant. Also fig(8) shows that above 40 min for the feed particle size of 2000 and 1000 μm and above 30 min for the feed particle size of 500 and 100 μm, the efficiency of grinding decreases or constant. This could be explained by the presence of fine particles (increases with increasing the mill speed, grinding time and feed particle size) which surrounds the large particles and this increases the choice of force distribution over a large number of force distribution over a large number of contact points and hence less impact intensity on the large particles, therefore in industrial application, the finer particles should be sieved out during the process of grinding. Also Figs (3-8) show the increasing in specific surface area for larger particles is greater than that of smaller particles due to the fact that the smaller particles are of greater hardness than the larger particles.

4-Conclusions:-

The following conclusions are drawn out from the present study:

1-The determination of the specific surface area of Alumina Oxide was based on the results of sieve analysis of the ground product. The results show that the increase in specific surface area increases proportionally with increasing the number of balls, the ratio of feed volume to the mill volume, mill diameter, mill speed, ball diameter, grinding time and feed particle size to a certain value and then the efficiency of grinding decreases.

2-Grinding efficiency decreases as grinding proceeds to fine size and it was found that the increase in specific surface area of larger particles are greater than that of smaller particles, i.e. less energy is consumed for the larger particles. Also it is important to take care in the determination of specific surface area of fine particles, since the small weight of these particles may alter the results completely.

3-The operating conditions of the ball mill are very important, since it governs the nature of the product and the best operating conditions that achieve high increase in specific surface area of alumina oxide and with low energy losses are tabulated in table (3).

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Table (1) Nominal of real of feed size

Nominal size (μ m)	Real size range (μ m)
2000	-2000+1800
1000	-1120+900
500	-560+450
100	-125+90

Table (2) operating conditions of experimental work

Group no.	No. of exp.	Feed size(μ m)	Grinding time (min)	RPM % of max. mill speed	Ball diam. (mm)	Mill diam. (mm)	No. of balls	Ratio % of $\frac{feed\ vol}{mill\ vol}$
1	12	1000 1000	10 10	80 80	20 20	74.3 86.6	{2,3,4,5, 6,7}	20 20
2	8	1000 1000	10 10	80 80	20 20	74.3 86.6	5 5	{10,30,50 , 70}
3	64	2000 1000 500 100	10 10 10 10	80 80 80 80	{10,20, 30,37.5}	{74.3, 86.6,99 ,112.5}	5 5 5 5	30 30 30 30
4	16	2000 1000 500 100	10 10 10 10	{60,80,90, 100}	20 20 20 20	99 99 99 99	5 5 5 5	30 30 30 30
5	20	2000 1000 500 100	{10,20,30, 40,50}	80 80 80 80	20 20 20 20	99 99 99 99	5 5 5 5	30 30 30 30

Total experimental work=120

Table (3) the best operating conditions of grinding of alumina oxide

Operation condition	Feed size (μ m)	
	2000 & 1000	500 &100
Mill diameter (mm)	99	90
Bill diameter (mm)	20	10
No. of balls	5	5
RPM % of max. mill speed	80	90
Ratio % of $\frac{feed\ volume}{mill\ volume}$	30	30
Grinding time (min)	40	30

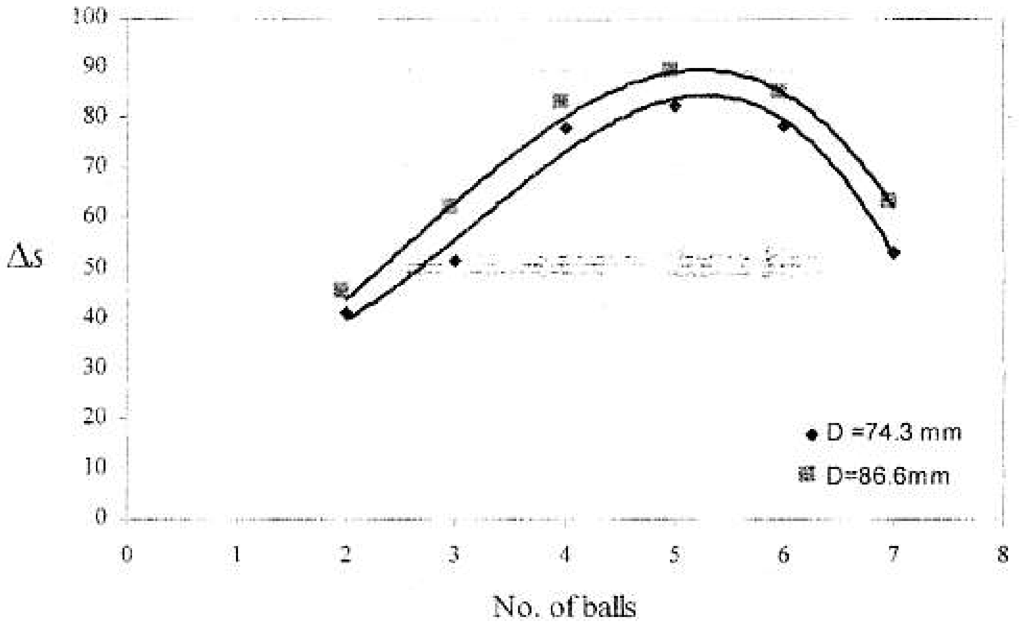

Fig (1) Increase in specific surface area (Δs) versus no. of balls for various mill diameter (feed size 1000 μm) of alumina oxide

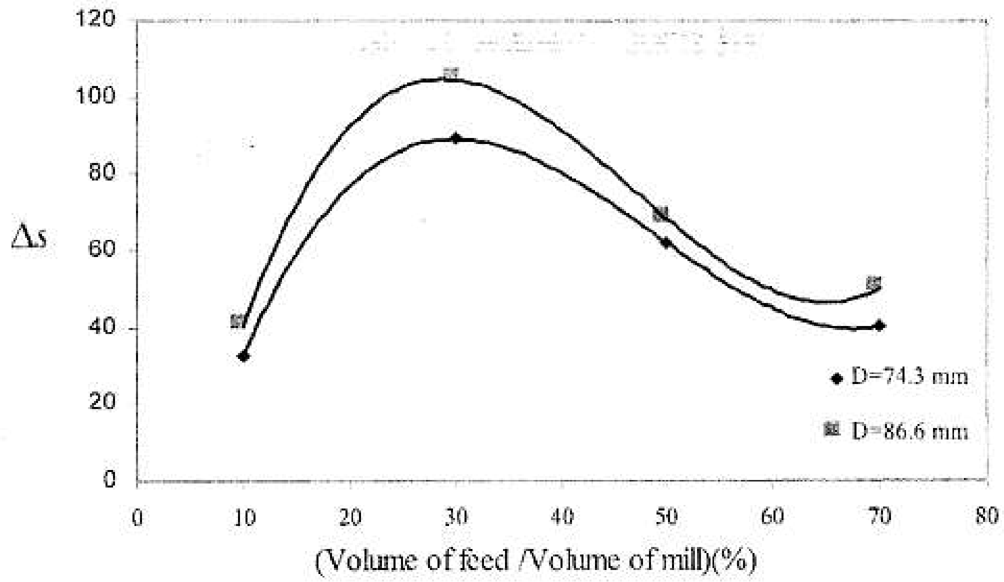

Fig (2) Increase in specific surface area (Δs) versus ratio of volume of feed to volume of mill for various mill diameter (feed size 1000 μm) of alumina oxide

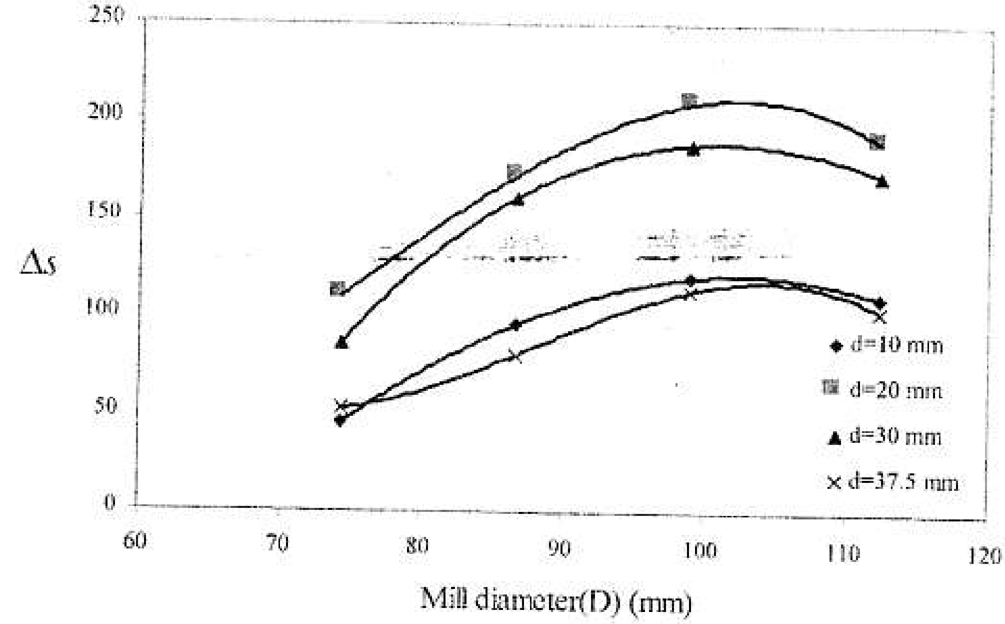

Fig (3) Increase in specific surface area (Δs) versus mill diameter for various ball diameter (feed size 2000 μm) of alumina oxide

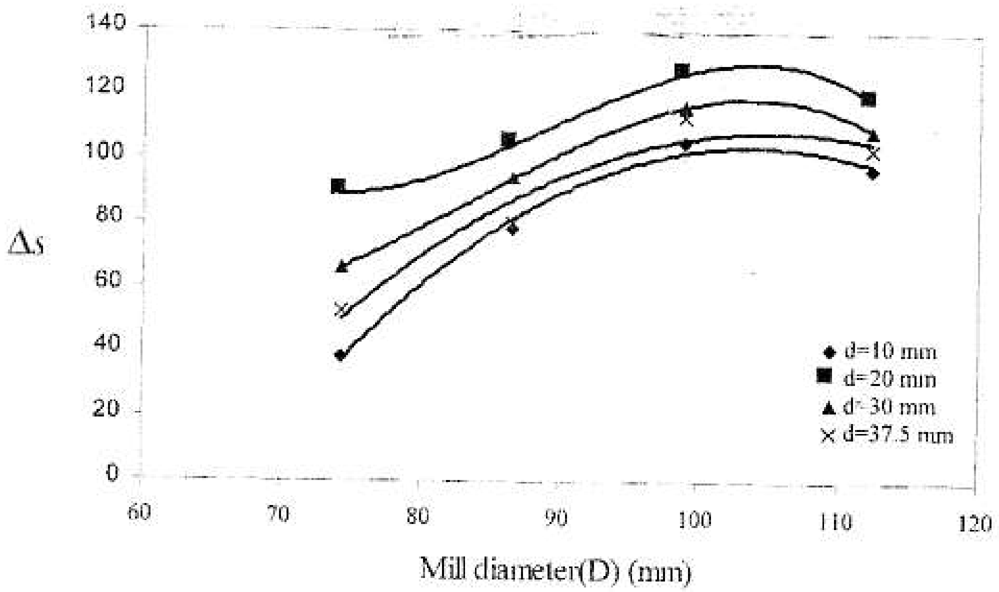

Fig (4) Increase in specific surface area (Δs) versus mill diameter for various ball diameter (feed size 1000 μm) of alumina oxide

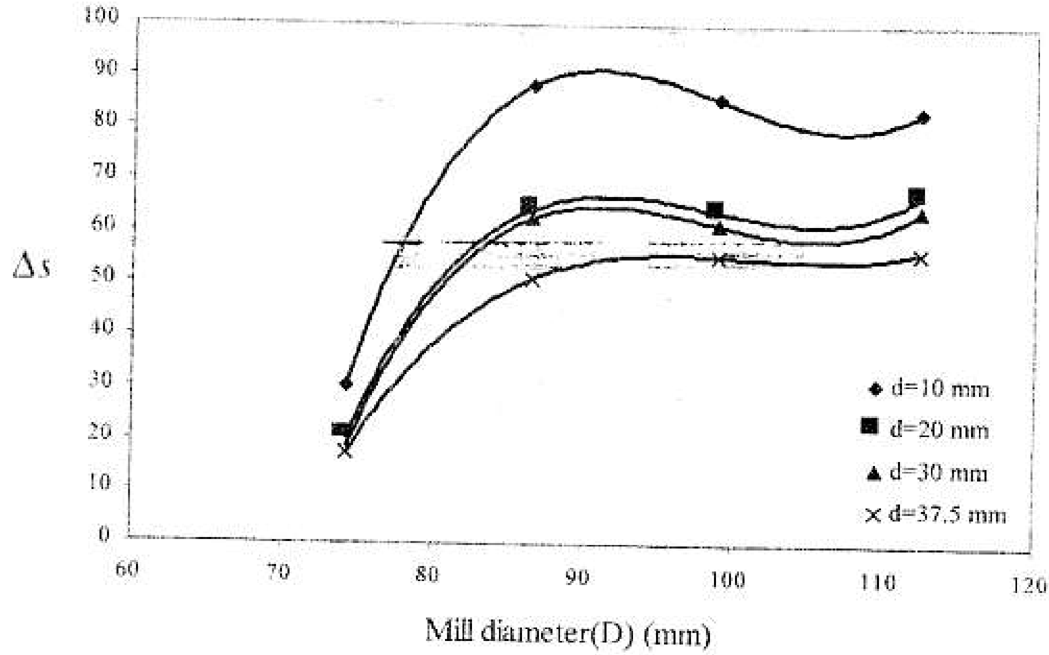

Fig (5) Increase in specific surface area (Δs) versus mill diameter for various ball diameter (feed size 500 μm) of alumina oxide

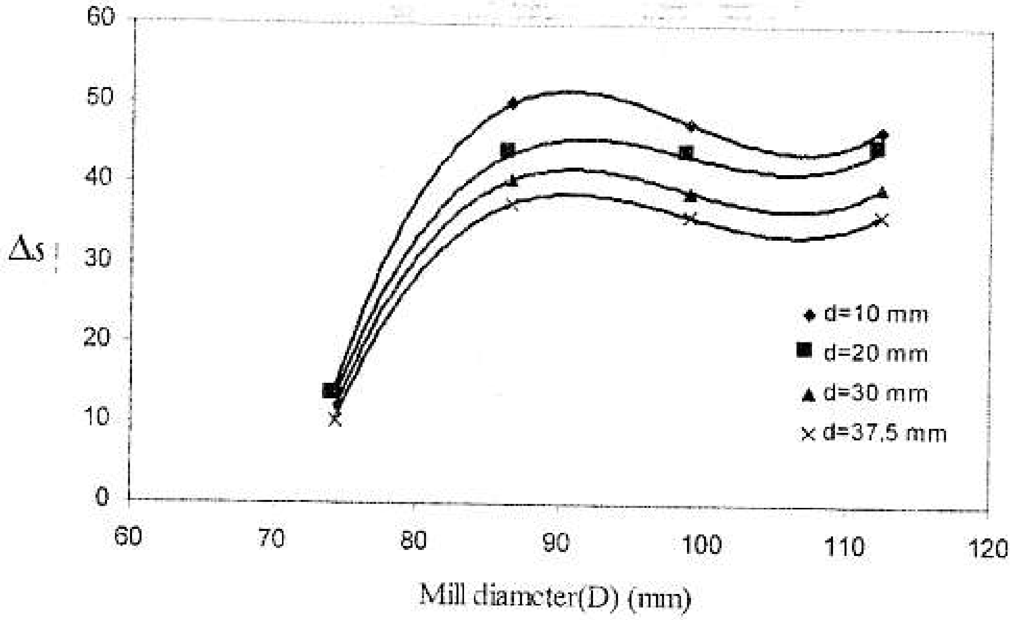

Fig (6) Increase in specific surface area (Δs) versus mill diameter for various ball diameter (feed size 100 μm) of alumina oxide

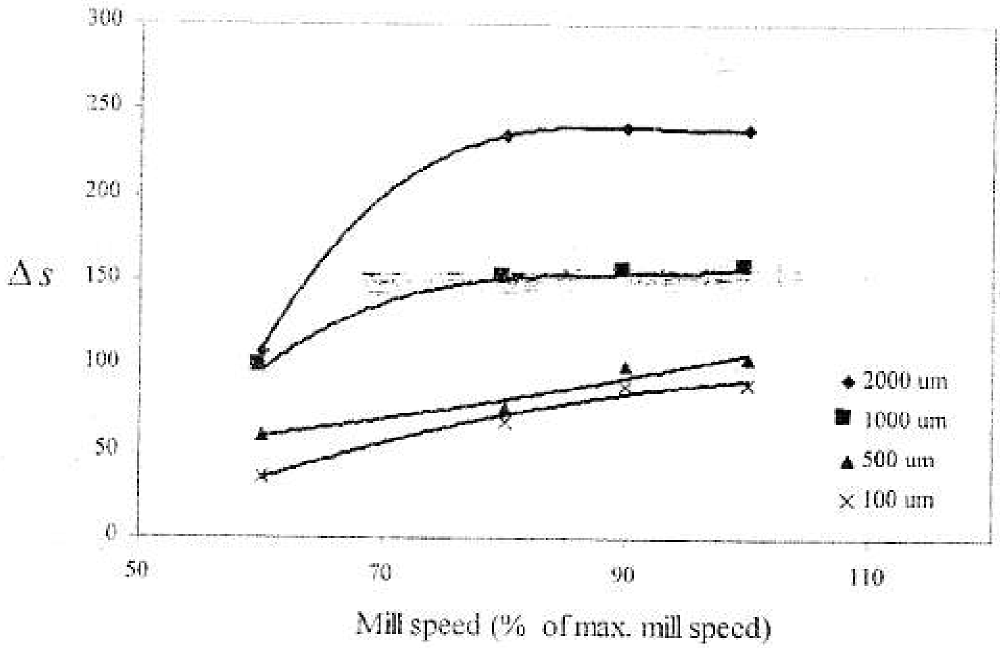

Fig (7) Increase in specific surface area (Δs) versus RPM % of max. Mill speed for various feed practical size of alumina oxide

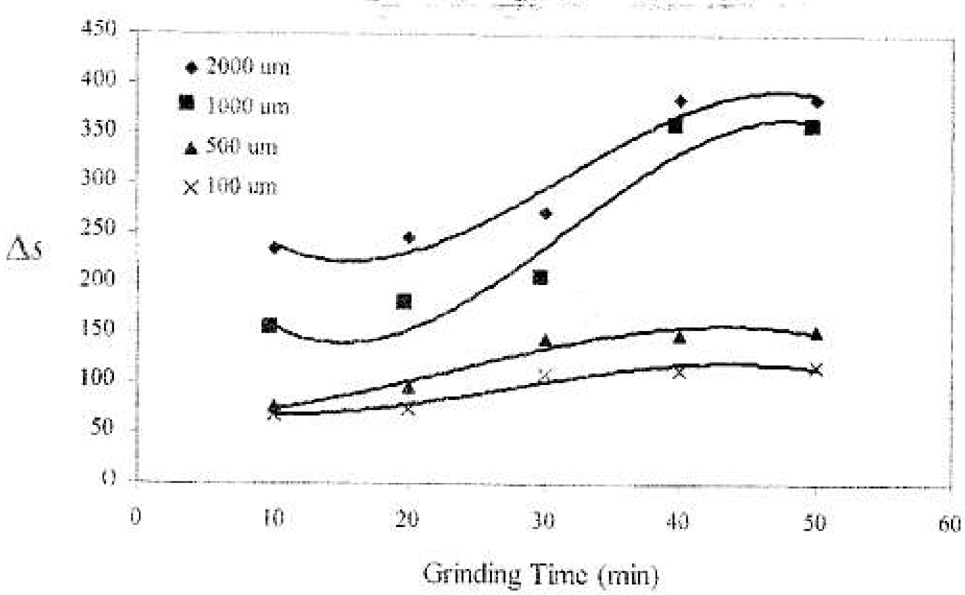

Fig (8) Increase in specific surface area (Δs) versus grinding time for various feed practical size of alumina oxide