STUDIES ON BATCH GRINDING CHARACTERISTICS OF LOCALLY AVAILABLE LIMESTONE ORE

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Abstract

The supply of common necessities has significantly increased as a result of recent population growth. Mineral processing offers numerous opportunities to enhance environmental and energy performance. The majority of industrial operations require some kind of reduction in size. It is now accepted that the size of the fineness achieved by a particular grinding method accounts for more than half of the total cost. This is true in any mineral beneficiation plant, regardless of the method used to enrich the total separation of one or more valuable species from natural ore. Limestone ore was used in this study for ball mill grinding tests. Five feed (ore) sizes and three ball sizes were used in the experiments. The upsides of selectivity capability for three arrangement of feed sizes with three different ball sizes have been assessed. Process optimization was also employed and analyzed for ANOVA and Regression analysis.

Keywords: : *Limestone, Ball Mill, XRD, Ore Microscopy, SEM, RSM*

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1. Introduction

With their exemplary service, the majority of researchers are working in various fields to improve society. Better research relies heavily on cost effectiveness. Mineral engineers play a crucial role in the processing of raw materials, which is why product development is so important. The fundamental size reduction is the primary operation of numerous research activities. Crushing and grinding are the natural steps in the mineral processing plant's comminution sequence **[1].** The primary goal of crushing, the first mechanical step in the comminution process, is to free the valuable minerals from the gangue. The ore is crushed either by being compressed against surfaces that are rigid or by being struck against surfaces in a motion path that is rigidly constrained **[2]** At some point during the manufacturing process, the final product or raw materials in many industries are powdered, and the cost-effective preparation of powdered materials is a significant economic factor **[3].** Experiments were carried out for the purpose of determining how the aforementioned parameters—time of grinding, feed size, feed quantity, and ball size—affect the specific surface area produced and the amount of energy required per unit surface area produced. Limestone sample for the research work has been collected from Jaggayyapeta Mining Zone, Krishna District, Andhra Pradesh, India.

2. Experimental Procedure

2.1 Description of The Equipment

The feed material that will be used in this study was prepared in the appropriate size range. In the Ball Mill's crushing rolls, the material was initially reduced to smaller sizes and further crushed. Using a set of sieves, the crushed material was thoroughly screened until the required size ranges of feed material were obtained. For the purpose of this experimental investigation, a total of three feed sizes—1 cm, 0.67 cm, and 0.475 cm—were chosen [4]. The batch grinding process was carried out with 50, 100, and 150 grams each. Half of these grams were fed to the ball mill as the grinding media, which consisted of 100 one-inch steel balls.

The material was sieved using the steps below. Each part of the sieving was tested on its own on a set of seven BSS sieves with mesh numbers 52, 60, 85, 100, 150, and 200, as well as a pan and lid for sieve analysis [5-6]. The sieving was divided into three equal parts. This approach was decided to try not to overload the strainers with material. Using a rotap sieve shaker was the method of sieving. Two minutes of sieving were applied to each component. Utilizing an automatic timer. The sieves were rotated 180 degrees and the shaker was stopped for gentle tapping every two minutes to ensure efficient screening. Before being discarded, the material was carefully removed from the sieves, collected, and weighed on a balance.

3. Results And Discussions

3.1 Effect of Time Of Milling

The effect of a scope of one to six minutes of crushing time in a ball factory has been examined. The mill was receiving 50 grams of feed in the sizes 1.0 cm, 0.67 cm, and 1.0 cm at 66 revolutions per minute. 100 balls with a diameter of one inch remained constant. Fig.1, 2 and 3 depict the specific surface area that was calculated for each run. The alteration in a specific surface over time depicted in Fig.1 demonstrates that the produced particular surface continues to rise over time. In Fig.2 time-varying energy consumption demonstrates an increase in energy consumption over time [7-8].

The introduction of coarse particles into the mill made it easier to grind, which is the reason for the increase. However, the cushioning effect of the formed fines and possibly the agglomeration of small particles caused by the generated heat slow down further division once the material reach certain fineness [9].

The variation of a specific surface's power consumption per unit over time is shown in the fig.3. The E/S esteem keeps on ascending over the long haul.

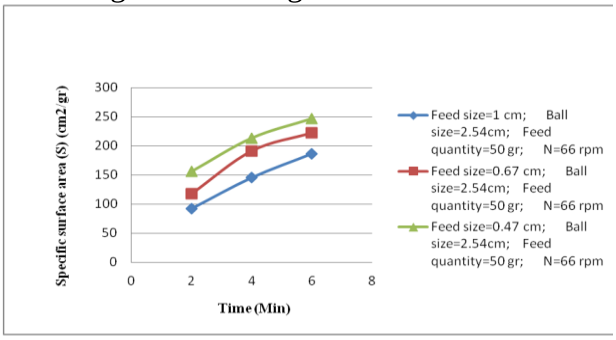

Fig.1 Variation of Specific Surface with Time

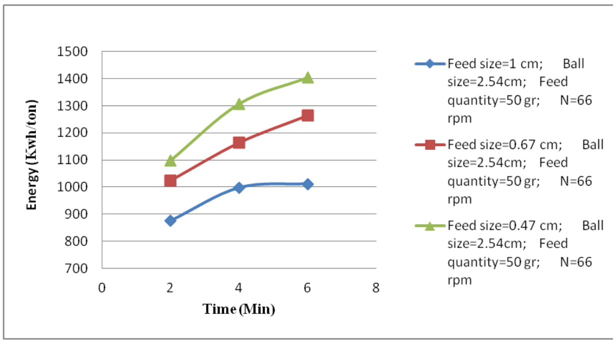

Fig.2 Variation of Energy Consumption with Time

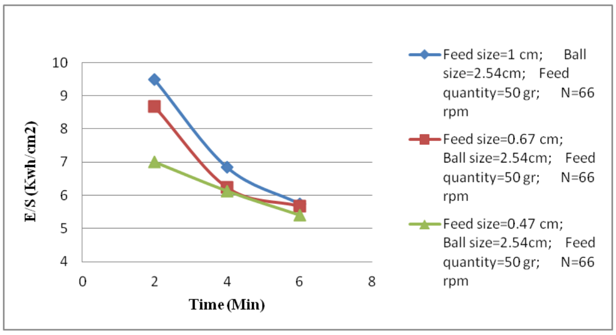

Fig.3 Variation of E/S with Time

3.2 Effect of feed amount

Three distinct examples of 50, 100, and 150g were taken in order to examine the effect of feed quantity on the estimated presentation of the ball plant in terms of created surface area and energy consumption. The feed was ground for 6 minutes using 1" steel balls at a mill speed of 66 rpm in this large number of frameworks[13-14].

The relationship between the specific surface and the amount of feed was depicted in the fig.4 it demonstrates that as the feed quantity rises, the specific surface area decreases. This is because the plant is being stifled by the increased feed quantity. The likelihood of balls moving closer to one another decreases with increasing feed amounts; consequently, the irritation caused by constant loss and effect is greatly reduced [11].

Fig.5 depicts the range of energy consumption based on feed quantity. As the quantity of feed increased, the amount of energy required decreased. Fig.6 depicts the amount of energy used per unit of feeding surface area. In addition, feed quantity decreases the E/S value [12].

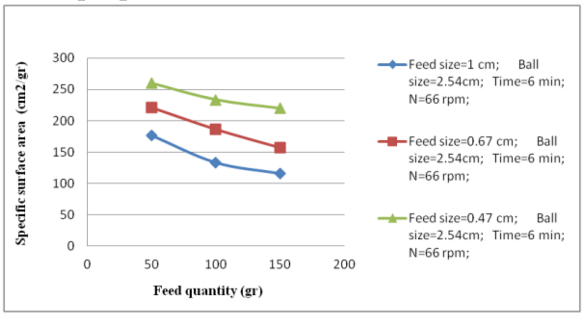

Fig.4 Variation Of Specific Surface With Feed Quantity

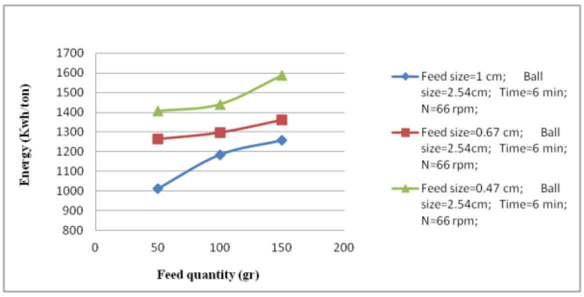

Fig.5 Variation Of Energy Consumption With Feed Quantity

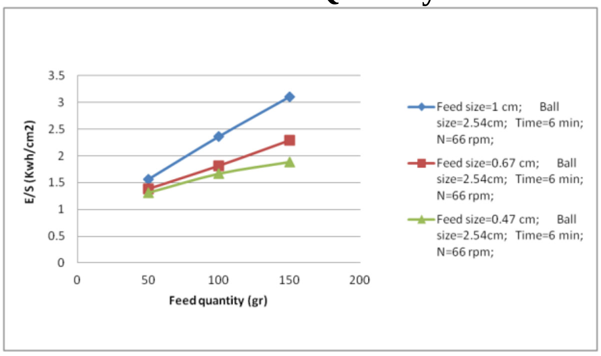

Fig.6 Variation Of E/S With Feed Quantity

3.3 Effect of Feed Size

Three distinct feed sizes—1.0 cm, 0.67 cm, and 0.47 cm—were utilized in order to focus on the impact of feed size on the estimated plant exhibition in terms of surface area produced and energy utilization. Using 1" steel balls and a mill speed of 66 rpm, the feed was ground for 6 minutes in this number of structures [15].

The connection between the particular surface and the feed size, as portrayed in Fig.7, demonstrates that the specific surface area decreases with feed size. The range of energy consumption based on feed size is shown in the fig.8. Energy consumption is always decreasing. Given that the size of the ball does not change, the effect on size reduction is significant [16]. However, as it grows in size, the feed's effect of size reduction diminishes. The handle size and the ball should be the same. Because there won't be any nipping, the particles won't be crushed if this isn't the case.

Fig.9 The graph that shows the relationship between the feed size and the amount of energy applied to the explicit surface shows that the feed size increased the amount of energy applied to the explicit surface [17].

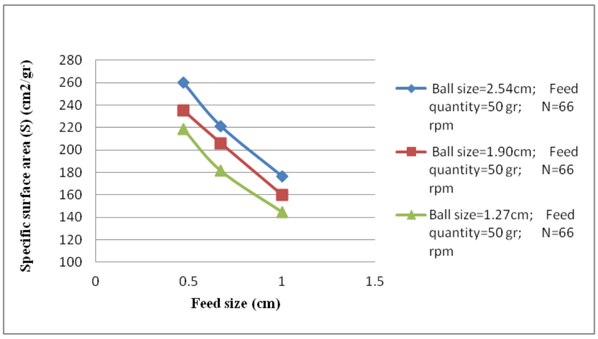

Fig.7 Variation Of Specific Surface With Feed Size

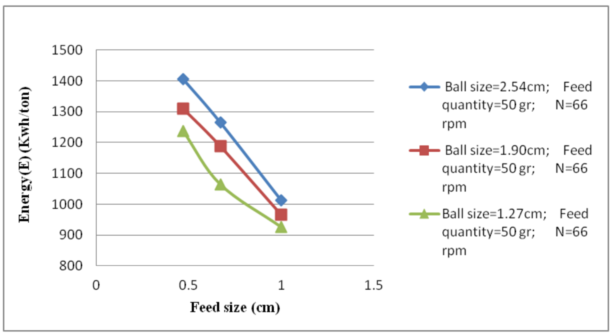

Fig.8 Variation Of Energy Consumption With Feed Size

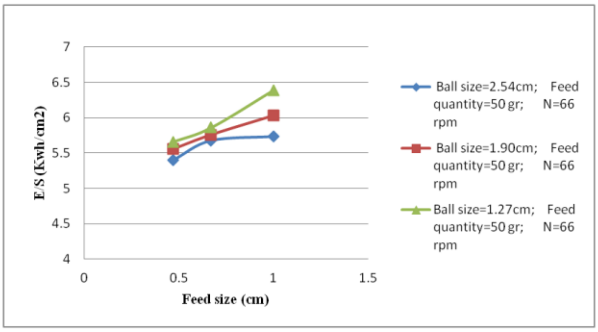

Fig.9 Variation Of E/S With Feed Size

3.4 Effect of ball size

The impact of the ball size limit on the introduction of the ball production line was evaluated taking into account the specific surface produced and energy consumed. Viz., three sizes of balls: the three options were 1.27 cm, 2.54 cm, and 1.90 cm. For a feed weight of 50 grams, the impact of ball size has been determined while maintaining a crushing time of 6 minutes and a plant speed of 66 revolutions per minute. The total weight of the balls remained constant at 6470g despite their varying diameters [18].

The various explicit surfaces and ball sizes were depicted on a chart, as shown in fig.10. As depicted in the figure, it could be argued that the surface area of the ball increases with its size. This is because there is now a larger void in the middle of the wider wads [15-17]. Fig.11 depicts the range of energy consumption based on ball size. The ball's increased size to 2.54 cm resulted in a greater expenditure of energy. The variety of e/s based on ball size is shown in fig.12 e/s expanded at the same rate as the ball's size [19].

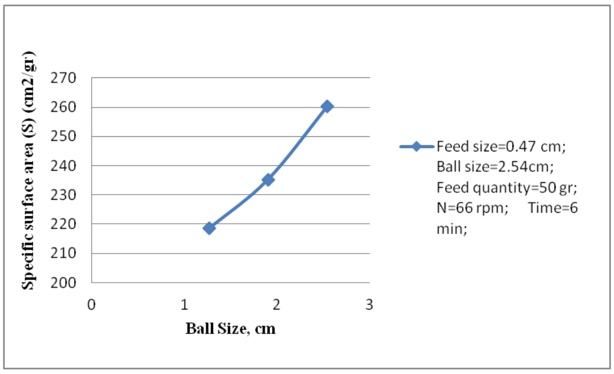

Fig.10 Variation Of Specific Surface Area With Ball Size

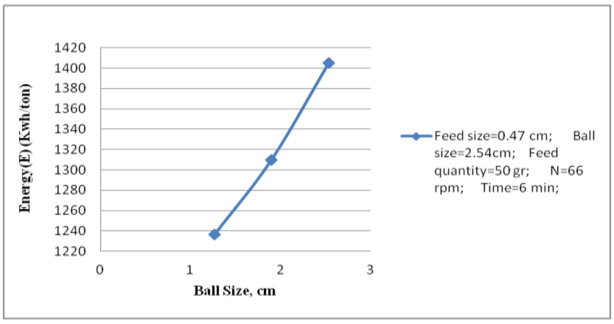

Fig.11 Variation Of Energy With Ball Size

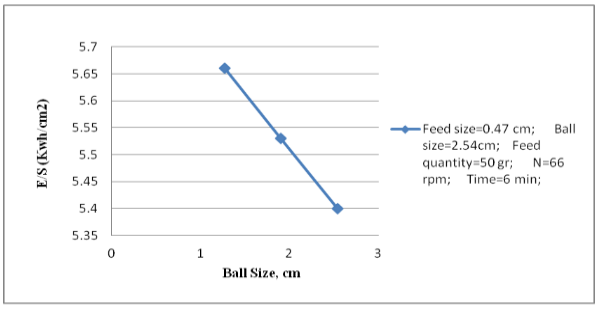

Fig.12 Variation Of E/S With Ball Size

3.5 Regression Analysis

According to the current study, the grinding time, ball size, feed quantity, and feed size all had a significant impact on the specific surface area produced by milling. As a result, the grinding rate factor is defined as "$S\rho D_m/(N\ t)$," which is a function of each of the variables listed below [20-22].

The findings of this study are correlated with the grinding rate factor and various dimensionless groups. The variables examined in this study render the groups dimensionless. Q/W_B, B_s/F_s, F_s/P_s, and (t/S_{ta}) are the dimensionless groups used for correlating the data. The equation that follows is obtained through regression analysis.

$$\mathbf{k = 2.3556\ (Q/Wb)^{-0.3806}(Bs/Fs)^{0.4931}(Fs/Ps)^{0.0165}}$$

Avg Deviation = +4.024
Std Deviation = +3.927

Correlation graphs for above equation are presented in Fig.13 to fig.16. This study's correlation is useful for predicting the size, size distribution, and surface area generated breakage function of the produced [23].

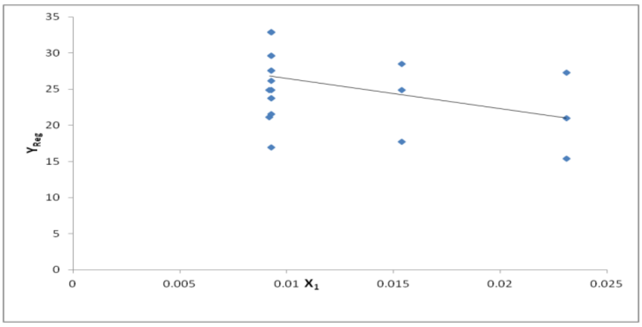

Fig.13 Correlation Plot For Rate Constant (X_1)

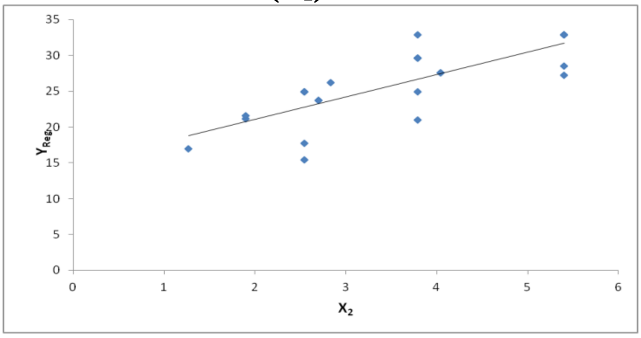

Fig.14 Correlation Plot For Rate Constant (X_2)

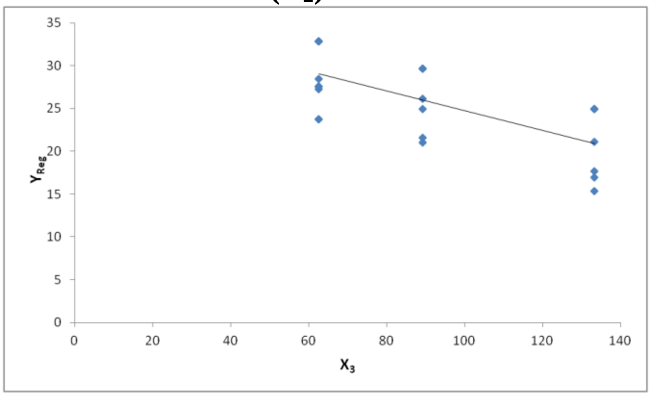

Fig.15 Correlation Plot For Rate Constant (X_3)

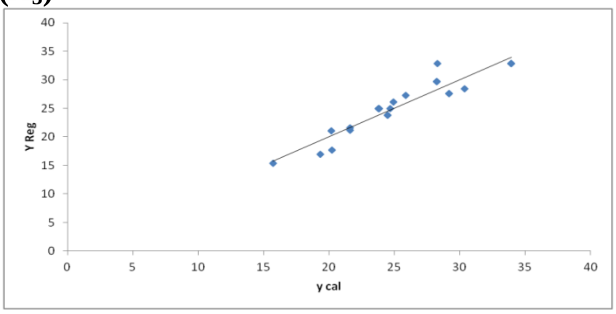

Fig.16 Correlation Plot For Rate Constant (Y_{cal})

4. Optimization using Response Surface Methodology (RSM):

From the results of preliminary experiments the following factor levels were selected as time of grinding(2-22 min),feed quantity (50-150gms), ball size (1.27-2.54cms), feed size(0.47-1.0cms) are listed in the following table.

Variable	Name	Range of Levels				
		-2	-1	0	1	2
X1	**Time of milling(min)**	**2**	**4**	**6**	**8**	**10**
X2	**Feed Quantity(gms)**	**10**	**30**	**50**	**70**	**90**
X3	**Feed Size(cms)**	**0.12**	**0.24**	**0.47**	**0.67**	**1.0**
X4	**Ball Size(cms)**	**1.2**	**1.9**	**2.54**	**3.38**	**3.81**

30 Trial runs were completed by central Composite Variable design, and the outcomes were summed up in table for the particular surface region and the energy utilization.

The following quadratic equation was fitted to the above data using multiple linear regressions on statistica.

$Y=b_0+b_1X_1+b_2X_2+b_3X_3+b_4X_4+b_{11}X_{12}+b_{22}X_{22}+b_{33}X_{32}+b_{44}X_{42}+b_{12}X_1X_2+b_{13}X_1X_3+b_{14}X_1X_4+b_{23}X_2X_3+b_{24}X_2X_4$ --------- (1)

The students'-test and the p-values, which are listed in the subsequent table, were used to determine the significance of each coefficient. The corresponding co-efficient is more significant when the t-values are larger in magnitude and the p-values are smaller.

Table Results from CCD for Energy consumption by the ball mill

S. No	Time	FQ	FS	BS	Energy consumption	
					Experimental	Predicted
1	4	30	0.24	1.9	1037.12	1036.57
2	4	30	0.24	3.38	1112.44	1111.47
3	4	30	0.67	1.9	1105.78	1106.87
4	4	30	0.67	3.38	1173.88	1174.08
5	4	70	0.24	1.9	973.22	972.68
6	4	70	0.24	3.38	1031.36	1030.39
7	4	70	0.67	1.9	1103.06	
8	4	70	0.67	3.38	1153.98	
9	8	30	0.24	1.9	1005.54	
10	8	30	0.24	3.38	1070.56	
11	8	30	0.67	1.9	1027.02	
12	8	30	0.67	3.38	1084.82	
13	8	70	0.24	1.9	991.64	
14	8	70	0.24	3.38	1039.46	
15	8	70	0.67	1.9	1074.24	
16	8	70	0.67	3.38	1114.82	
17	2	50	0.47	2.54	1098.92	
18	10	50	0.47	2.54	1026.32	
19	6	10	0.47	2.54	1078.82	
20	6	90	0.47	2.54	1051.48	
21	6	50	0.22	2.54	1156.62	
22	6	50	1	2.54	1011.86	
23	6	50	0.47	1.2	1001.92	
24	6	50	0.47	3.81	1219.56	
25	6	50	0.47	2.54	1404.96	
26	6	50	0.47	2.54	1404.96	
27	6	50	0.47	2.54	1404.96	
28	6	50	0.47	2.54	1404.96	
29	6	50	0.47	2.54	1404.96	
30	6	50	0.47	2.54	1404.96	

Table Estimated regression coefficients for the Energy consumption

	Regressn	**Std.Err.**	**t(15)**
Mean/Interc.	**-1504.33**	**10.10247**	**-148.907**
(1)Time, mins(L)	**248.87**	**1.35713**	**183.383**
Time, mins(Q)	**-21.35**	**0.07716**	**-276.719**
(2)feed quantity, gms(L)	**18.05**	**0.13012**	**138.690**
feed quantity, gms(Q)	**-0.21**	**0.00077**	**-274.670**

(3)feed size, cms(L)	**1677.24**	**11.74186**	**142.842**	**0.000000**
feed size, cms(Q)	**-1634.76**	**5.83829**	**-280.007**	**0.000000**
(4)ball size, cms(L)	**969.59**	**4.33413**	**223.701**	**0.000000**
ball size, cms(Q)	**-170.53**	**0.67964**	**-250.914**	**0.000000**
1L by 2L	**0.31**	**0.01015**	**30.747**	**0.000000**
1L by 3L	**-27.45**	**0.94384**	**-29.084**	**0.000000**
1L by 4L	**-1.74**	**0.27361**	**-6.368**	**0.000013**
2L by 3L	**3.55**	**0.09438**	**37.664**	**0.000000**
2L by 4L	**-0.29**	**0.02736**	**-10.613**	**0.000000**
3L by 4L	**-12.09**	**2.54504**	**-4.750**	**0.000258**

Table ANOVA table of the grinding

	SS	**df**	**MS**		
(1)Time, mins(L)	**7467.0**	**1**	**7467.0**		
Time, mins(Q)	**202127.9**	**1**	**202127.9**		
(2)feed quantity, gms(L)	**1714.5**	**1**	**1714.5**		
feed quantity, gms(Q)	**199145.3**	**1**	**199145.3**		
(3)feed size, cms(L)	**29516.0**	**1**	**29516.0**		
feed size, cms(Q)	**206959.6**	**1**	**206959.6**		
(4)ball size, cms(L)	**18184.5**	**1**	**18184.5**		
ball size, cms(Q)	**166187.6**	**1**	**166187.6**		
1L by 2L	**2495.5**	**1**	**2495.5**	**945.39**	**0.000000**
1L by 3L	**2232.9**	**1**	**2232.9**	**845.90**	**0.000000**
1L by 4L	**107.0**	**1**	**107.0**	**40.55**	**0.000013**
2L by 3L	**3744.5**	**1**	**3744.5**	**1418.55**	**0.000000**
2L by 4L	**297.3**	**1**	**297.3**	**112.64**	**0.000000**
3L by 4L	**59.6**	**1**	**59.6**	**22.56**	**0.000258**
Error	**39.6**	**15**	**2.6**		
Total SS	**620111.1**	**29**			

Df-degree of freedom; SS- sum of squares; F-factor; P-probability.

This data imply that first order main effects of time of grinding, feed quantity, ball size and feed size and their second order main effects of time of grinding, feed quantity and feed size are highly significant as is evident from their respective p – values.

The following equation represents multiple regression analysis of the experimental data for the Limestone Ore:

$$Y = -1504.33 + 248.87X_1 + 18.05X_2 + 1677.24X_3 + 969.59X_4 - 21.35X_1^2 - 0.21X_2^2 - 1634.76X_3^2 - 170.53X_4^2 - 0.31X_1X_2 - 27.45X_1X_3 - 1.74X_1X_4 + 3.55X_2X_3 - 0.29X_2X_4 - 12.09X_3X_4.$$

Interpretation of residual graphs:

The graphical method known as the normal probability plot (NPP) is used to determine whether a data set is more or less normally distributed. The term "residual" refers to the difference between the predicted and observed regression values. fig displays ordinary likelihood plot for the present data.it is clear that the trial information are sensibly adjusted suggesting typical conveyance.

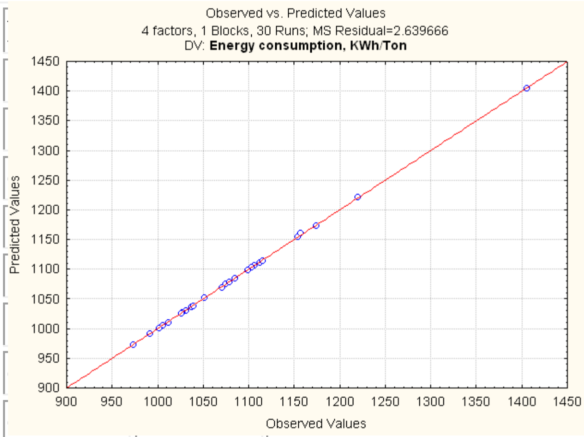

Fig Observed VS Predicted Values of Energy Consumption

Pareto Chart:

The pareto chart is shown in figure. The red line on the x-axis indicates that P is greater than 0.05, which indicates that the data are significant. Because their p-values are less than 0.05, the feed size (Q) and grinding time (L) are more significant than the linear, quadratic, and interaction terms.

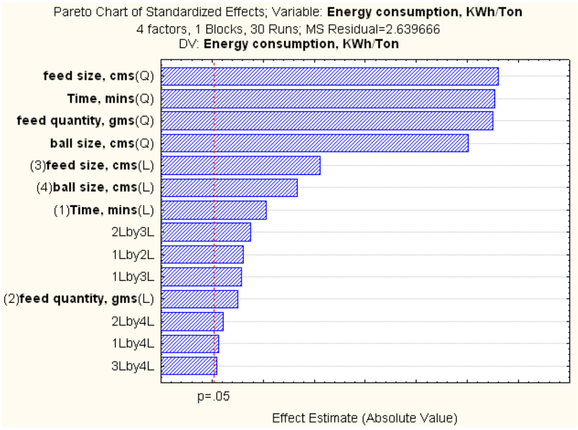

Fig pareto chart of the Energy consumption

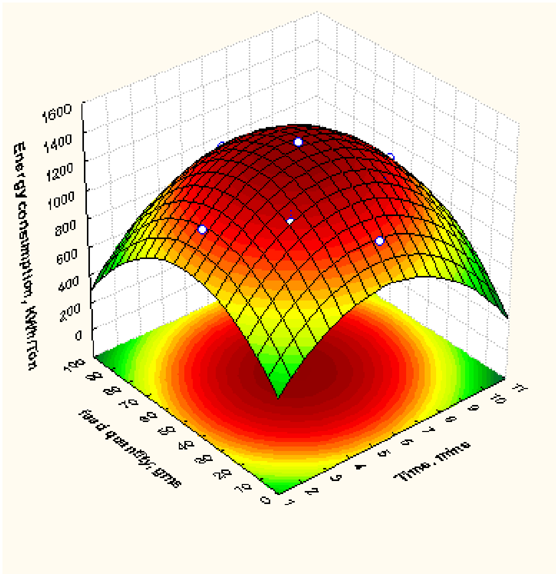

Fig Variation of Energy consumption with feed quantity and time.

Interaction effects of Energy consumption variables:

Three-layered perspective on reaction surface form plots show the new unambiguous region created by changing various mixes of ward factors.

This conduct adjusts that there is a presence of ideal for the info factors to accomplish the most extreme explicit surface region. As can be seen clearly from the plots, each variable plays a significant role in the specific surface area produced by grinding hematite ore.

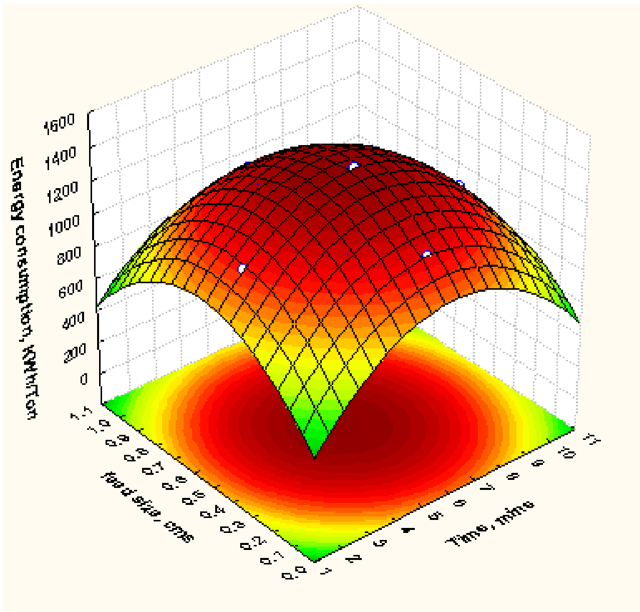

Fig Variation of Energy consumption with feed size and time.

Table Comparison between optimum values from CCD and experimentation

Variable	CCD	Experimental
Time of milling	5.74	22
Feed Quantity	49.18	50
Feed Size	0.50	0.47
Ball Size	2.75	2.54

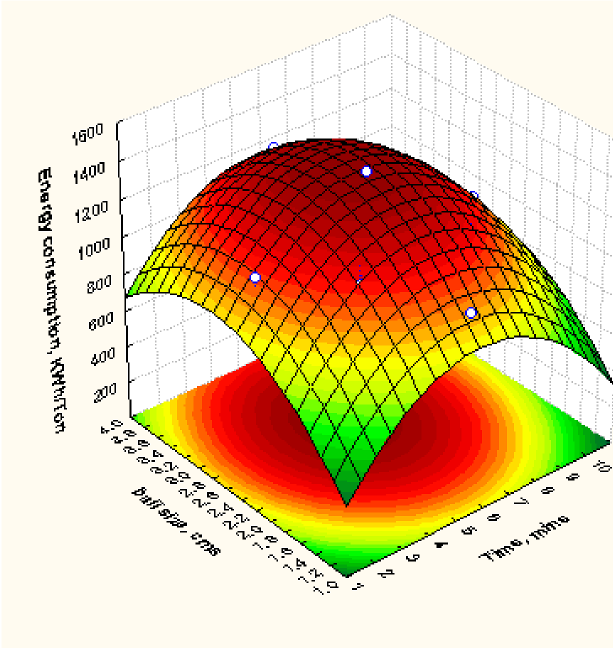

Fig Variation of Energy consumption with time and ball size.

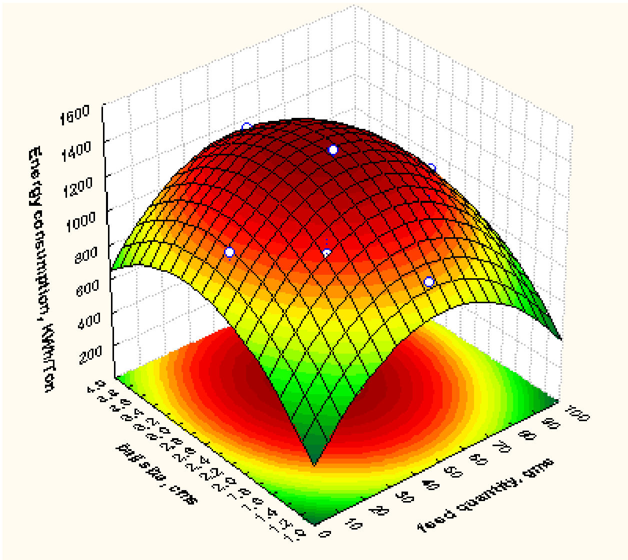

Fig Variation of Energy consumption with Feed Quantity and ball size.

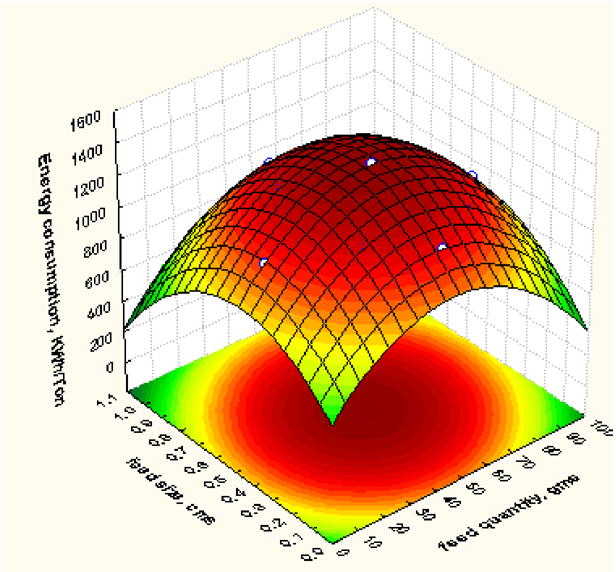

Fig Variation of Energy consumption with feed size and feed quantity.

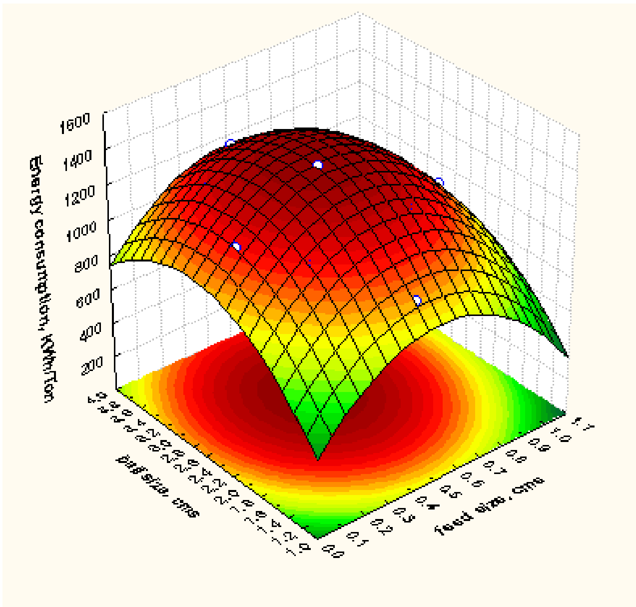

Fig Variation of Energy consumption with feed size and ball size.

Conclusions:

Milling time increases the specific surface. Energy consumption rises in tandem with the particular surface's expansion. As time elapsed, energy utilization per unit of explicit surface diminished. Both energy consumption and specific surface decreased as feed size increased, but E/S increased as feed size increased from 0.47 to 1.0 cm. The quantity of feed led to an increase in the feed's energy consumption. The new specific surface area that was created also decreased when there was more feed. The size of the ball uniformly increased the specific surface. As the size of the ball expanded, so did the feed's energy utilization. The corresponding relapse condition was found after the review.

$$k = 2.3556\ (Q/Wb)^{-0.3806} (Bs/Fs)^{0.4931} (Fs/Ps)^{0.0165}$$

Avg Deviation = +4.024
Std Deviation = +3.927

4. References

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