

Batch Grinding of Dolomite Using Box-Behnken Design

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Abstract

The aim of our research paper was to apply response surface methodology for modeling of grinding Dolomite ore using ball mill with the parameter considering;

1. Time of Grinding.
2. Ball Size.
3. Feed Quantity.
4. Feed Size.

Specific energy consumption also decreases with feed quantity at all ball sizes. Energy savings, expressed as a percentage of the energy consumption. Using these set of experimental data obtained, the models are developed to show the effect of each parameter and their interactions on the product. Maximum Specific surface is obtained at higher speed of the mill (66 rpm in our case). This also correspondence to the speed at which we have minimum energy consumption per unit surface area generated. As the grinding time increases specific surface increases. As the specific surface increases, power consumption also increases.

Keywords: Response surface methodology; Modeling; Box-Behnken design; Dolomite ore; Ball mill

Introduction

Yet grinding operations ought to be carried out for the effective processing of minerals, either to liberate mineral values or to prepare a suitable feed for separating processes like flotation, gravity concentration, classification, magnetic or electric separations etc. It is now widely understood that grinding to definite sizes must be economical [1]. The cost of energy consumption is a major factor in the crushing and grinding processes that influence the viability of a mineral processing operation [2]. In batch grinding, the particle size is continuously reduced with time but minerals of various complexities behave differently. In view of the fact, grinding studies of each mineral is to be studied to predict the product size with other influencing parameters [3]. The present study is contemplated to know the comminution parameters for Dolomite ore (Provided by RRL-Bhubaneswar).

Description

The ball mill used for the studies is an ordinary cylindrical type vessel with 8"×8" size, closed permanently at one end and with a provision to close the other end by using a lid [4,5]. The lid in turn is provided with a groove and gasket around the periphery and can be fixed to the mill by means of a suitable nut and bolt mechanism such that material does not leak out of the mill while in operation. The inside surface of the mill is smooth except that it is provided with three baffles of square cross section of 0.5"×0.5" size, along the length of the mill fixed firmly and evenly around the periphery.

The essential dimensions of the mill are given below

Inside diameter-8"=and length -8"

Thickness of the mill wall=0.38"

Theoretical critical speed of the mill-100rpm

Ball sizes and weight: 2.54 cm (1"), 64.7g.(100No.); 1.27 cm (1/2"), 28.75g.(225no.); 0.8467 cm (1/3"), 18.86g.(343no.); 0.635 cm (1/4"), 8.55g.(756no.); Width of the groove-2.54 cm.

A stepped pulley framework is connected at one end of the mill by means of the shafts through toothed wheel reduction gear system, which

enables the mill to rotate on its horizontal axis. AV-belt connecting the motor and pulley frame work in turn enables the mill to rotate. The stepped pulley framework is provided with four steps and hence the mill can be run at four different speeds namely 23, 41, 66 & 82 rpm. The mill is supplied with 100 balls of 2.54 cm diameter, 225 balls of 1.27 cm diameter, 343 balls of 0.8467 cm diameter and 756 balls of 0.635 cm diameter. With this arrangement the mill can be charged with the required amount of feed and the required size of the balls, lid placed in position, tightened to leak proof and run for a specified period of time at a selected speed. The other accessories used for conducting the experiment include a rotap sieve shaker with an automatic time switch, a set of BSS sieves with mesh numbers 10, 16, 30, 52, 60, 85 & 100 with lid and pan, a specific gravity bottle for measuring the density of Dolomite and a stop watch to note the time (Table 1).

Experimental Procedure

The feed material was prepared in the required size range to be used

SI No	Parameters	Range of Variables
1	Time of grinding	2, 3, 4, 5 and 6
2	Mill speed	23, 41, 66 and 82 rpm
3	Size of balls	1", 1/2", 1/3" and 1/4"
4	Quantity of feed	50, 100, 150, 200, and 300
5	Feed size	-1/2" + 1/4" -1/4" + 1/8" -1/8" + 1/16" -1/16" + 1/32"

Table 1: Range of variables considered.

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in the contemplated study. The material was initially reduced to lower sizes and further crushed in crushing rolls. The crushed material was thoroughly screened using a set of sieves until the feed material of required size ranges was obtained. Totally four feed sizes (-1/2"+1/4", -3/8"+1/4", -1/4"+1/8", -1/8"+1/16") were selected for the present experimental study. The charge material was procured from the hills of sabbavaram village of vizag district, A.P. Experimental work is carried out to establish relationships for specific surface area generated and energy consumption for both the cases with and without additive and also to determine the specific breakage rate. It was also planned to establish the effect of several operating variables viz.,

1. Time of grinding in the mill (t, min.)
2. Speed of the mill (N, rpm)
3. Size of the balls (keeping the total weight of the balls constant) (B_s , "cm")
4. Quantity of feed (Q, gms)
5. Feed size (Fs, cm)
6. Dosage of Additive

Estimation of the specific surface and energy consumption

The batch grinding operation was carried out with the selected quantities of 50, 100, 150, 200 & 300 g. respectively and fed to the ball mill half filled with the grinding media of one inch steel balls counting 100 in number [6]. The open end of the mill was closed by clamping the lid tightly to the mill so that no leakage of the material takes place during grinding operation. Then the mill was run for a period of 2 min. and the reading of energy meter was noted. In the present study the whole experiment was conducted by running the mill at a constant speed of 66 rpm. The material was discharged from the mill using a brush after unclamping the lid.

The material was allowed to fall on a meshed tray placed on a cubical container. When the material was discharged on to the meshed tray, the balls would remain on the wired mesh while the grounded material will pass through the mesh and was collected in the container. Adequate measures were taken every where to prevent the loss of the material. The material was subjected to sieving as follows. It was divided into three equal fractions and then each part was subjected to sieve analysis independently on the set of seven BSS sieves with mesh numbers 10, 16, 30, 52, 60, 85 & 100 with a pan and lid. This method was adopted to prevent the overloading of the material on the sieves. A rotap sieve shaker was used for the purpose of sieving. Each part was subjected to sieving for a period of 6 min. using an automatic timer. All necessary steps for effective screening, like stopping the shaker for every 2 min. for gentle tapping and rotating the sieves by 180 degrees were taken. The material was carefully brushed from the sieves, collected and weighed on a balance and finally the material was discarded. The specific surface of the product at the end of the experiment was calculated from the sieve analysis data for each run of the mill using the formula,

$$S = (K_s / \rho W) / (\sum w d P^{-1})$$

Where, K_s = specific surface factor of the ground particles (6 for spherical particles),

w = weight of the product collected on a Particular sieve, g

W = weight of the total feed taken, g

d_p = mean size of the product retained on a sieve under consideration, cm

ρ = density of the material (g/cc).

Time of milling was studied at regular intervals of time with four different feed sizes and keeping 100 balls of 2.54 cm size, the speed of the mill at 66 rpm and weight of feed 200 gms [7].

To evaluate the effect of ball size, balls of same material of 0.635 cm, 0.8467 cm, 1.27 cm and 2.54 cm sizes were used by keeping total ball weight constant at 6470 g. The effect of the ball size was investigated at feed quantities of 50, 100, 150, 200 & 300 g. respectively, at a speed of 66 rpm and a milling time of 2 min. for four different feed sizes. The effect of feed quantity on specific surface area and energy consumption is studied with feed quantities of 100, 300, 500, 700 & 900 g. as charge material. The other parameters were maintained as 2 min. milling time at a mill speed of 66 rpm with 1.0" steel balls.

Results and Discussion

In this chapter the important variables which affect the performance of ball mill are studied [8]. The study consists in terms of the following factors: Surface area, size distribution of the product & power consumption and the following parameters:

1. Effect of time of milling
2. Effect of the size of balls
3. Effect of feed quantity
4. Effect of feed size

Effect of time of milling

The effect of time of grinding in a ball mill has been studied covering a range of 2 minutes to 6 minutes. 200 gms of feed of the size -1/2"+1/4" was fed to the mill and the mill was run at the speed of 66 rpm. The number of balls of one inch size kept as constant at 100. The specific surface area per each run is calculated and the results are shown in Figure 1. The Figure 1 shows the variation of specific surface with time, which shows that the specific surface produced, continues to increase with time. The variation of energy consumption with specific surface which reveals that power consumption increases with specific surface. The reason for increase is due to the fact that coarse particles were being introduced to the mill is easily ground. But after attaining a certain degree of fineness, further division becomes a slower due to the cushioning action of the fines formed, and may also due to small particles agglomeration, due to generated heat. Similar observations have been made by Datta and Nandi.

Effect of ball size

To study the ball size parameter on the performance of the ball mill measured in terms of the specific surface generated and energy consumed. Four sizes of ball viz., 2.54 cm (1"), 1.27 cm (1/2"), 0.8467 cm (1/3") and 0.6350 (1/4") are chosen. The effect of ball size has been found for a feed quantity of 200 g and keeping the time of grinding at 2 min and speed of the mill at 66 rpm. Even though the sizes of the balls are changed, the total weight of the balls was kept constant at 6470 g. A graph is drawn to show the variation of specific surface with the size of the balls. From the figure it can be concluded that the specific surface area increases with ball size and shows a downtrend after a size of 1.27 cm. This is because of the increased void spaces in between the balls of larger diameter. Similar observations have been made by

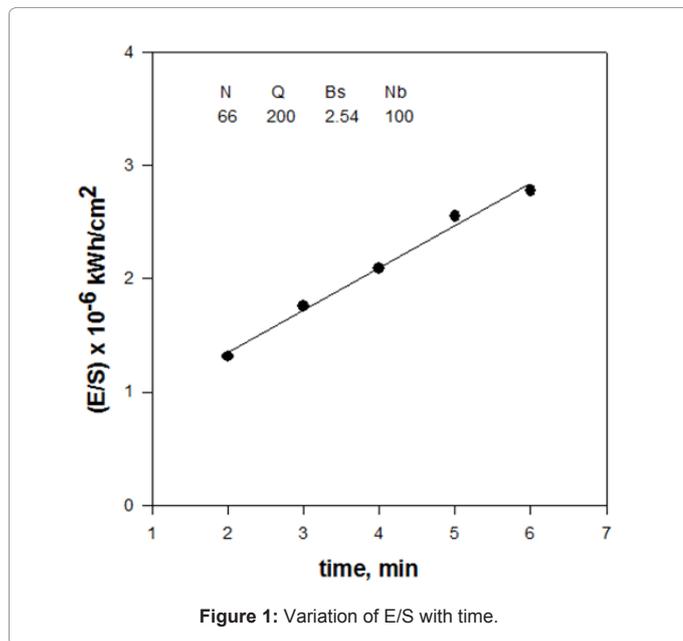


Figure 1: Variation of E/S with time.

Murthy and Arun Kumar. The variation of energy consumption with the ball size. The energy consumption is constant in the early stages and then increases with the further increase in ball size up to 1.27 cms. The variation of specific surface with energy consumption. E/S is constant in the beginning for initial small sizes of balls and then increases with increase in ball size. Figure 2 shows the variation of E/S with ball size. E/S decreases with increase in ball size.

Effect of feed quantity

To study the effect of feed quantity on the performance of the ball mill measured in terms of the surface area generated and the energy consumption, five samples of 50, 100, 150, 200 and 300 g respectively were taken. In all these systems the feed was ground for a grinding time of 2 min, at a mill speed of 66 rpm using 1” steel balls.

A graph was drawn between the quantity of feed and the specific surface; it reveals that the specific surface area decreases with increase in feed quantity. This is attributed to the choking of the mill with the increased feed quantity. At larger feed quantities, the chances of balls coming closer are meager; as a result combination by attrition and impact is greatly reduced and reveals the variation of energy consumption with the quantity of feed. The energy consumption decreased with an increase in feed quantity also reveals the variation of energy consumption with the specific surface. The energy consumption increased with an increase in specific surface. Figure 3 shows the variation of energy consumed per unit surface area produced with the quantity of feed. The E/S value is constant in the beginning upto 100 gms and then increased with the increase in feed quantities.

Effect of feed size

To study the effect of feed size on the performance of the mill measured in terms of the surface area generated and the energy consumption, five samples of sizes $-1/2'' + 1/4''$, $-1/4'' + 1/8''$, $-1/8'' + 1/16''$ and $-1/16'' + 1/32''$ respectively were taken. In all these systems the feed was ground for a grinding time of 2 min, at a mill speed of 66 rpm using 1” steel balls. A graph was drawn between the feed size and the specific surface as it reveals that the specific surface area decreases with increase in feed size and reveals the variation of energy consumption

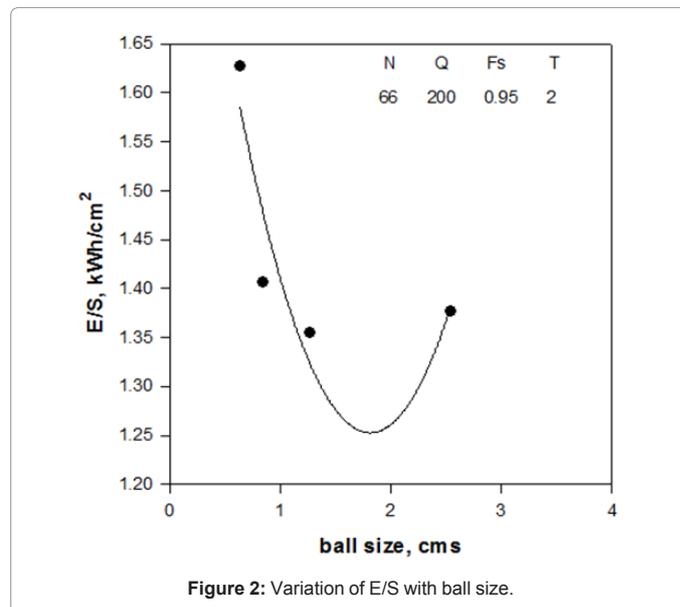


Figure 2: Variation of E/S with ball size.

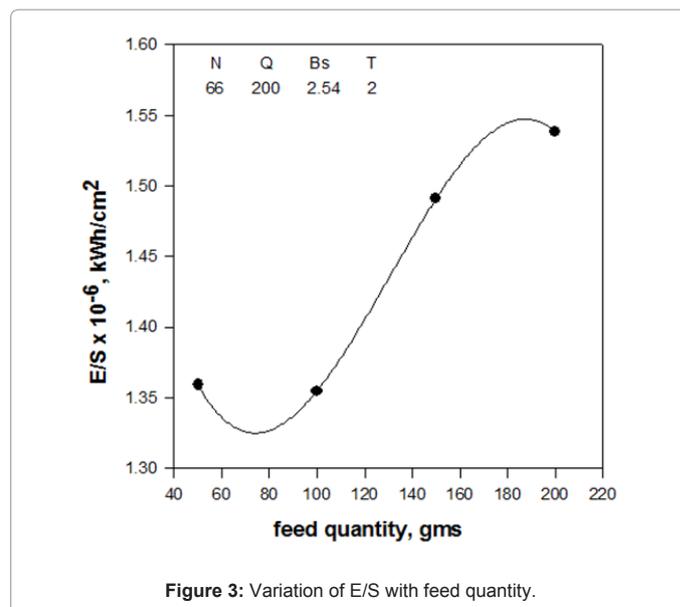


Figure 3: Variation of E/S with feed quantity.

with the feed size. The energy consumption is continuously increasing and after attaining a maximum value at a feed size of 0.65 cms it starts getting decreased and it shows the variation of energy consumed with surface area. The energy gets decreased with the increase in the specific surface. Figure 4 shows the variation of energy consumed per unit surface area produced with the feed size. The E/S values increased with the increase in feed size.

Response Surface Methodology is used with Fractional Factorial Design

From the results of preliminary experiments the following factor levels were selected as Time of grinding (2-6min), feed quantity (50-200gms), ball size (.635-2.54 cm), feed size (.24-.95 cm) as listed in Table 2. 27 experimental runs were carried out according to Box-Behnken variable design with 3 additional runs at centre point to check

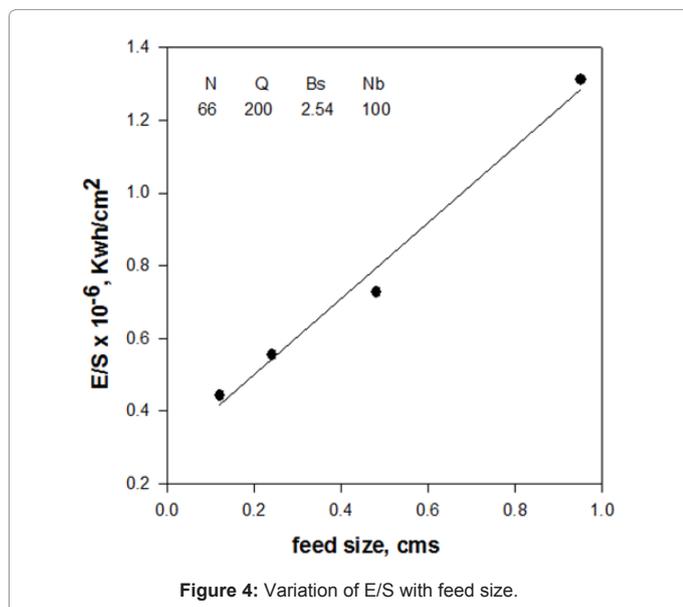


Figure 4: Variation of E/S with feed size.

the reproducibility. And the results were summarized in table.

The following quadratic equation was fitted to the above data using multiple linear regressions on statistical version 6.

$$Y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_4 x_4 + b_{11} x_1^2 + b_{22} x_2^2 + b_{33} x_3^2 + b_{44} x_4^2 + b_{12} x_1 x_2 + b_{13} x_1 x_3 + b_{23} x_2 x_3 + b_{14} x_1 x_4 + b_{24} x_2 x_4 + b_{34} x_3 x_4 \quad (1)$$

The significance of each co-efficient was determined by students t-test and p-values, which are listed in Table 3. The larger the magnitude of the t-value and smaller the p-value, the more significant is the corresponding co-efficient. 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 ($p_{x_1} < 0.00001$, $p_{x_2} < 0.006$, $p_{x_3} < 0.077$, $p_{x_4} < 0.00001$, $p_{x_1^2} < 0.006$, $p_{x_2^2} < 0.002$, $p_{x_3^2} < 0.02$, $p_{x_4^2} < 0.00008$). The best model for minimizing energy consumption by a surface analysis was the quadratic polynomial model [9]. The fitted equation is

$$\text{Energy consumption} = 103.02 + 25.82 x_1 - 10.08 x_2 - 17.81 x_3 - 59.97 x_4 - 8.03 x_1^2 - 9.18 x_2^2 - 20.32 x_3^2 + 0.60 x_1 x_2 + 7.77 x_1 x_3 - 1.40 x_2 x_3 + 19.81 x_4^2 + 2.06 x_1 x_4 - 0.34 x_2 x_4 - 3.64 x_3 x_4$$

The fit of the model was checked by the co-efficient of determination R^2 , which was calculated to be 0.9506 indicating that 95.06% of the variability in the response could be explained by the model. The optimal conditions for the four factors were calculated to be 2.4559 min, 143.8056 gms, 1.6261 cm and 0.3407 cm for time of grinding, feed quantity, ball size and feed size respectively [10-12]. The model predicts the minimum response of 94.88 kw hr/ton for this point. The excellent correlation between predicted and measured values of these experiments justifies the validity of response model and the existence of minimum energy consumption.

Surface Area

Different surface areas are shown in the form of Response Surface Methodology (RSM) with Fractional Factorial Design (Figures 5-7).

Energy

Different energy fields are shown in the form of Response Surface Methodology (RSM) with Fractional Factorial Design (Figures 8-10).

Factors	Lower limit	Center Point	Upper Limit
Time of grinding (min)	2	4	6
Feed Quantity (gms)	50	100	200
Ball Size(cm)	0.635	1.27	2.54
Feed Size(cm)	0.24	0.48	0.95

Table 2: Range of factors.

	Std. Err.	t(21)	p	Coeff.
intercept	6.02331	17.1237	0.000000	103.1412
(1)time of grinding(L)	6.50329	7.5859	0.000000	24.6667
time of grinding(Q)	5.30991	-3.0342	0.006309	-8.0556
(2)feed quantity(L)	6.50329	-3.0412	0.006208	-9.8889
feed quantity(Q)	5.41941	-3.3966	0.002720	-9.2037
(3)ball size(L)	18.67928	-1.8559	0.077559	-17.3333
ball size(Q)	16.25822	-2.5081	0.020416	-20.3889
(4)feed size(L)	9.40588	-12.6522	0.000000	-59.5024
feed size(Q)	8.17766	4.8376	0.000088	19.7801

Table 3: Values of p and t.

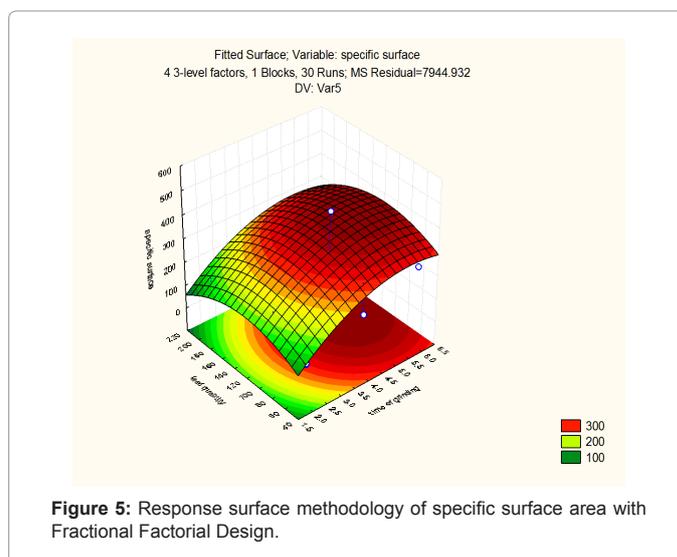


Figure 5: Response surface methodology of specific surface area with Fractional Factorial Design.

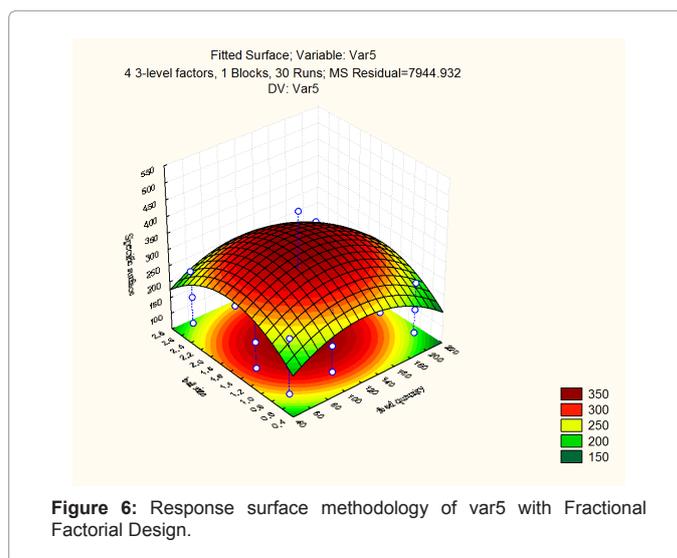


Figure 6: Response surface methodology of var5 with Fractional Factorial Design.

Conclusions

- As the grinding time increases, specific surface increases. As the specific surface increases, power consumption also increases. Power consumption per unit specific surface increases with time.

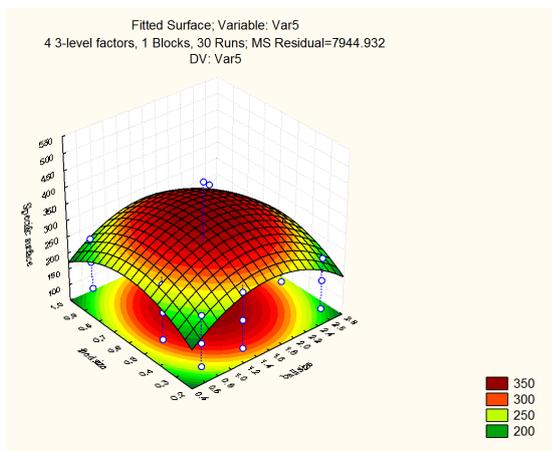


Figure 7: Response surface methodology of var5 with Fractional Factorial Design.

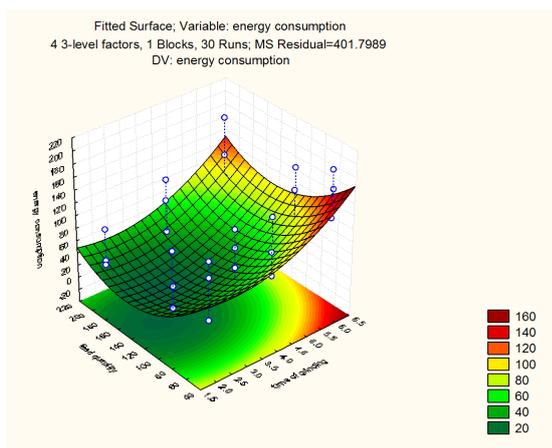


Figure 8: Response surface methodology of Energy consumption with Fractional Factorial Design.

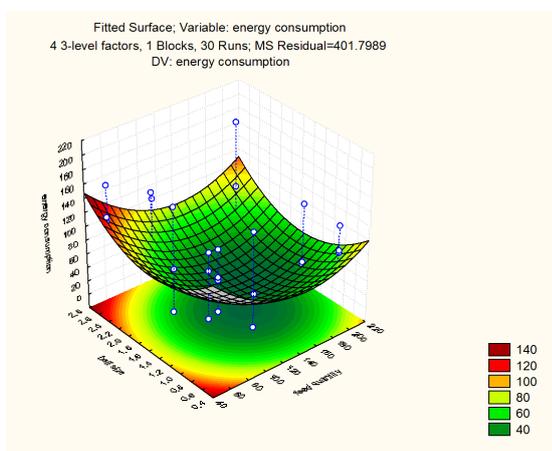


Figure 9: Response surface methodology of Energy consumption.

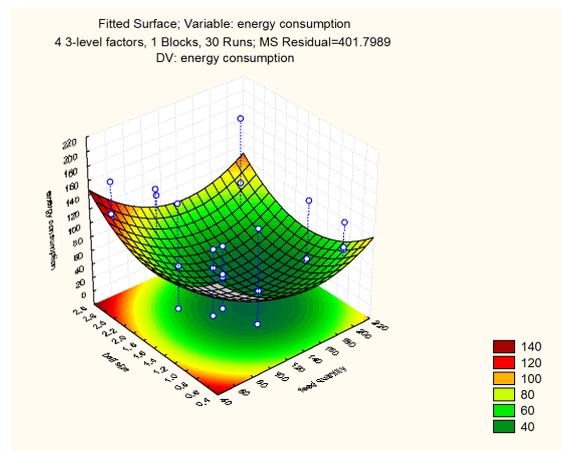


Figure 10: Response surface methodology of variable energy points.

2. As the size of the ball increases specific surface increases up to a certain value of Bs and then decreases.
3. Power consumption is almost same for all ball sizes for a particular amount of feed.
4. Power consumption per unit specific surface area of feed decreases up to certain ball size and then increases.
5. Power consumption of feed decreases with quantity of feed. The new specific surface generated also decreases with increase in feed quantity.
6. The power consumption per unit specific surface of the feed is first decreases and then increases.

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