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# Energy Factor-based Blast Design in Large Opencast Coal Mines

**Manish Sinha[1*] and A. K. Mishra[2]**

*[1]Indian Oil Corporation Limited, New Delhi, India*
*[2]Department of Mining Engineering, IIT(ISM), Dhanbad – 826004, Jharkhand, India*

## Abstract

Large surface coal mines in produce millions of tons of coal per annum, moving millions of cubic meters of overburden to mine the coal. Much of this volume is blasted in the form of benches, a common mining technique (Gustafsson, 1973). Blasting is a part of Large Opencast Coal Mine (LOCCM) operations, and is scheduled based on production requirements. With dragline pits, equipment size and operating parameters allow engineers to use tall benches and methods like cast blasting or production dozing to assist with moving blasted material. Changes in scale of equipment and speed of production scheduling have brought about a multi-dimensional shift in the planning process for drilling and blasting team at large surface coal mine operations. So, the problem is that while equipment scale and pace of planning have drastically changed over the last decade blast design and the explosive selection criteria has not changed significantly. Work done by eminent researchers such as Richard Ash and Calvin Konya set the standard for today's scientific bench blast design practices. Recently, the explosive's engineering community has largely occupied themselves with applying technology to subsets of the design problem – how to improve or measure fragmentation (M. Monjezi, 2009), how to use technologically advanced methods to design blasts (Y. Azimi, 2010) (P.D. Katsabani, 2005), the public's perception of mining (Hoffman, 2013). Explosives research for surface coal mining has essentially ignored bench blasting; the industry has not notably recognized the fundamental differences in scale and operational tempo that separate large surface mine blast from regular quarry-scale bench blasting. There is a vast scope of research in the field for explosive energy-based design for better fragmentation with less risk.

**Keywords:**

## 1. Background

Blasting the backbone of production in Large Opencast Coal Mine. Over the past thirty years, the present method of large-scale opencast coal mining has been developed which is dependent on the flexibility of large electric rope shovels to move between pre-strip operations for draglines and full dumper/shovel stripping mines. These large electric rope shovels can move well over 30,000 cubic meters of material in 24 hours, and some machines can approach 9 million cubic meters per year of material moved. Electric rope shovels can operate in a variety of conditions due to their relatively light weight compared to draglines, and have greatly increased mobility when

**Author for correspondence*

compared to draglines. Despite walking speeds of only a few km per hour, an electric rope shovel can move from bench to bench or across the mine from one pit to another in a matter of hours. This increased mobility significantly improves operational flexibility for capital expended when compared to a dragline. Although an interesting hybrid method of cast blasting and production dozing with rope shovel excavation has been developed in recent years, the great majority of electric rope shovels usually dig shorter benches where cast blasting and production dozing are not practical.

Blasting is a part of LOCCM operations, and is scheduled based on production requirements. With dragline pits and large sized shovels, the mine operating parameters allow configuration of tall benches, larger cut widths and methods like cast blasting or production dozing to assist with moving blasted material. Blast planning and design follows a measured pace because the dragline is committed to a particular cut in a specific pit until the coal is uncovered and work on the next cut begins, there is a rigidity of scheduling with draglines that contrasts the fluidity of electric rope shovels.

The use of electric rope shovels alongside draglines has created a paradigm shift in blast planning, since the efficiency of large opencast coal mines depend on well blasted material that can be easily dug without slowing down the mining process.

The increased flexibility in excavation has presented a major challenge to LOCCM operators: Accurate production scheduling is critical to fully utilize all equipment on the mine site. However, even with increased accuracy of production scheduling, physical challenges still intervene.

When investigating new processes or planning new methods, designers look for critical paths, the path most likely to cause problems and delay the desired result. If one uses a practiced eye view of LOCCM operations, the critical path that most often presents a bottleneck to production is the Drill and Blast (D&B) group.

The critical path for a successful bench blast includes:

1. Timely notification of plan changes
2. Cooperation between groups for bench preparation
3. Prompt drill moves
4. Pattern designs complete and available when needed
5. Teamwork within the D&B group to safely and successfully drill and blast the bench. These five steps present constant challenges to the D&B Manager. The D&B group is the tip of the whip for mine production, and must constantly stay a step ahead of the rest of the mine.

Large opencast coal mining operations are economically viable due to the large volumes mined and shipped every year. Relatively low profit margins dictate that to increase profits, either total output must be increased or costs must be cut.

Maintaining profitable production is difficult, and incremental savings represent huge benefits to the operation as a whole. Many companies foster Business Improvement groups whose sole purpose is to determine safer and more efficient ways to do business. LOCCM operators are generally technologically advanced, and open to new technologies to improve their businesses, as evidenced by the development of GPS based Operator Independent Dispatch System.

Essentially, to survive as a LOCCM operator, companies must be willing to continually re-examine their business methods to improve their safety and profitability.

The following chart, Figure 1, shows surface coal mining data in Northern Coalfields Limited (NCL) operating in Singrauli Coalfields from 1978-1979 to 2020-2021. In the forty-three years shown on the graph, one can see that the tons produced increased in a nearly-continuous fashion.

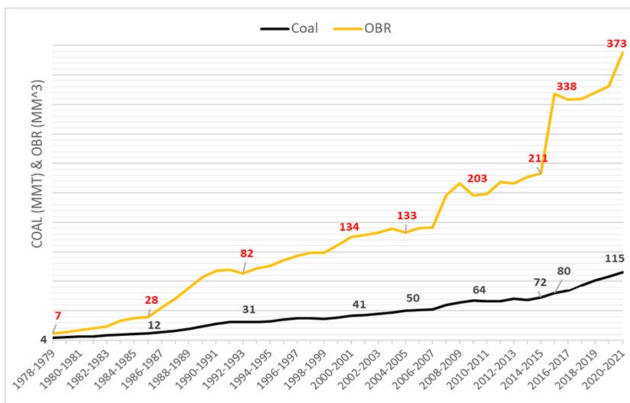



**Figure 1.** NCL Coal & OBR production 1978–1979 to 2020–2021.

Over the time period represented in the graph, the production has substantially increased through deployment of large sized excavators and tall benches, whereas, blast design practice witnessed minor improvements.

An important fact about surface coal mining is that mining always starts at the lowest strip ratio available, meaning that to maximize profits, companies will start mining where the cost per ton is lowest, which coincides with areas where less overburden is above the coal. The net present value of deposits will push mining companies to mine from low strip ratio to higher strip ratio coal.

The average strip ratio for the Singrauli Coalfields based on production of coal and overburden has increased from 1.65 to 3.25 cubic meter per ton from 1978-1979 to 2020-2021. As a general rule for surface coal mining, strip ratio always increases as shallower coal deposits are mined out.

Figure 1 shows coal and overburden produced; It is observed that coal and overburden production increased to 115 MMT from 4 MMT, i.e., 27 times and to373 $MM^3$ from 7 $MM^3$, i.e., 53 times respectively over the period of past forty-three years.

Thus, day by day the challenges before the D&B groups in Singrauli Coalfields has increased due to changes in equipment scale and quantity of production over past years.

## 2. Blast Design Practices

Bench blasting is fairly straightforward, breaking the material for digging. However, every blast has a few recognizable features and dimensions, regardless of where the blast takes place. The challenge of creating successful blast designs is not which dimensions are used, but how the designer determines the magnitude of those dimensions.

Usually, bench blasting at a specific site is done with some variation on a standard pattern. Standard patterns are exactly what they appear to be, a set of dimensions used everywhere for the same purpose. In Singrauli Coalfields, an example of a standard pattern would use an 8 m burden and 9 m spacing.

Drillers are given a pattern and a target elevation, and will drill whatever depth is required to reach the target elevation for the next lower bench.

Standard patterns work well where conditions meet the original design criteria. However, in shovel/dumper operations, the actual floor grade is often 1.0 m to2.5 m above or below the design floor grade due to strata of varying hardness or inattentive shovel operators.

This variation in elevation combined with an average planned bench height of 15m to 18 m leads to large swings in overall drilling depth and proportionally large changes in powder factor. These changes are not immediately a problem for pit operations if shot results do not hinder overall production, but problems arise when variations in powder factor make cost control difficult. A bright engineer could design individual patterns using existing major methods of blast design to maintain a fixed powder factor across shots of variable depth by repeated use of existing traditional design processes. However, such complex designs are unlikely to be completed in good times due to the quantity of time required for each pattern design, and will almost certainly not be completed during routine operations. Since cost control is essential element, it is vitally important that shots be designed to maintain powder factor within acceptable ranges. If the engineering staff is already over-utilized someone else must monitor bench blasts to maintain budgeted powder factors, and it is reasonable that those people should be drillers and/or blasters in the field. These employees will be most familiar with the challenges and applications of blasting at any specific site and would be most suited to control their own work.

In the LOCCM, it is common for mine operators to use average powder factors to project budgets for future years. If the D&B team has averaged a 2.0 $m^3$/kg powder factor for all pre-strip shots this year, and the budget calls for 20 million$m^3$ of pre-strip next year, the budget will include 10,000 ton of explosives for pre-strip shots. However, despite the use of powder factor to project costs and quantities for future mining practices; powder factor is not a part of the design process for bench blasting.

This contradiction adds an additional complication: maintaining an average powder factor that matches budgetary requirements while powder factor is not an integral part of the design of blasts.

For LOCCM bench blasting, where bench height is the dimension with the largest variability, powder factor and the efficiency of blasthole use i.e., Efficiency Index, defined as the percentage of the blasthole filled with explosive, are proportional when stemming is held constant. The efficiency index is a useful indicator of how much of the blasthole is being used for productive work?

As bench height increases, so does efficiency index, whereas, there is decrease in powder factor. 1-to-4-meter swing in bench height can create large changes in powder factor and efficiency index for individual shots; and over

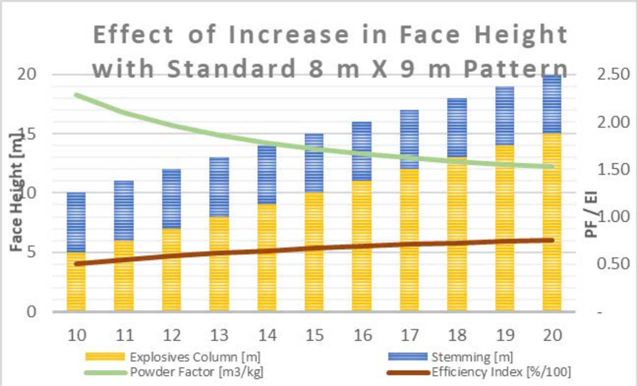



**Figure 2.** Shows the effects of increasing bench height for a common LOCCM bench blast scenario.

time similar incremental changes can have large impacts on budgets. It should be noted that in graphical form, the Efficiency Index is often represented as %/100, the decimal value being easier to show on a graph. In the case of Figure 2, the efficiency index ranges from about 50% to roughly 75%.

Similarly, blasthole diameter is also one of the major dimensions on which the explosives loading factor i.e., quantity of explosives packed per meter shall depend directly affecting the powder factor. Figure 3 shows the effect of increasing blasthole diameter over a constant bench height for a common LOCCM bench blast scenario.

As blasthole diameter increases, so does explosives loading factor, whereas, there is decrease in powder factor. 100-to-200-mm swing in blasthole diameter can create large changes in powder factor for individual shots; and over time similar incremental changes can have large impacts on budgets. In the case of Figure 3, the explosives loading factor efficiency index ranges from about 23kg/m to roughly 140 kg/m.

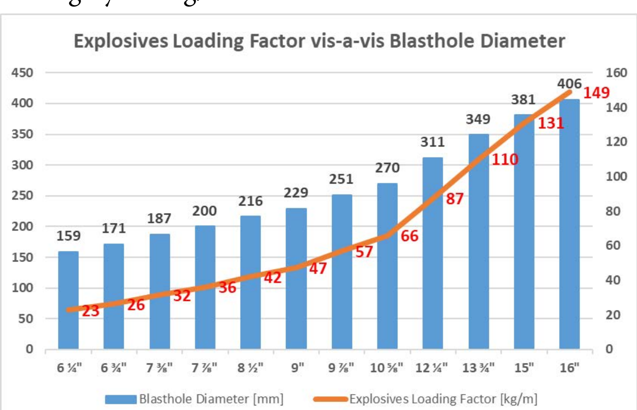



**Figure 3.** The effects of increasing bench height.

These factors provided a unique opportunity to add to the field of blasting knowledge by examining bench blasting at LOCCM operations and used evaluate the rock fragments size distribution, while maintaining all the controllable parameters unchanged for almost similar rock condition to improve the excavator's operational efficiency and reduce overall cost.

The question is whether the industry change the way it looks at bench blasting for Large Opencast Coal Mines? Large scale mining in Singrauli consumed 2,20,031 metric tons of bulk explosives in 2020–21, much more than as any other coalfield in country. This massive scale of explosive consumption indicates many millions of cubic meters of over burden are moved per annum in the process of mining coal. Increasing coal production dictate that the use of bench blasting will only increase over time as the greater depth to coal deposits limits the ability of dragline methods, requiring continual and increasing pre-strip volumes to be moved in benches. An efficient and effective blast design method tailored for LOCCM bench blasting applications will prove more useful in the future than it does today.

The efficiency of blast design is determined by the degree of matching the blast outcome and the required fragment size. In a LOCCM, requirement specifications are usually governed by loading equipment and hauling equipment. Fragmentation is one of the most important concepts of Explosives Engineering. Blasting is the first step of the size reduction in mining and it is followed by loading and hauling unit operations. The efficiency of these unit operations is directly related to the size distribution of muck pile. (Esen and Bilgin, 2000). Kazem and Bahareh (2006) stated that the outcome of a good blasting operation leads to the productiveness of the next stages of mining, such as loading and hauling process.

Thus, the explosives energy-based blast design is one of the key parameters for overall productivity of the LOCCM to achieve the desired degree of rock fragments for a particular loading equipment.

## 3. Assessment of Fragmentation

Jimeno *et al.*, (1995) observed that the outcome of blasting operations is determined by a number of indices or parameters, which can either, be controllable or uncontrollable. For the purposes of blast design, the controllable parameters are classified in the following groups: A- Geometric: Diameter, charge length, burden, spacing, etc. B-Physicochemical or pertaining to explosives: Types of explosives, strength, energy, priming systems, etc. C- Time: Delay timing and initiation sequence. The uncontrollable factors include but are not limited to: geology of the deposit, rock strength and properties, presence of water, joints, etc. (Hustrulid, 1999).

Methods to quantify the size distribution of fragmented rock after blasting are grouped as direct and indirect methods. Sieving analysis of fragments is the only technique in direct method. Though, the most accurate technique among others, but it is not practicable because it is expensive and time consuming. For this reason, indirect methods, which are observational, empirical and digital methods have been developed (Esen and Bilgin, 2000).

Observational method depends on expert's common sense is a widely used technique. An engineer assesses the fragmentation and other blasting results subjectively. This method is not a scientific method as it does not give any information about the size distribution (Jimeno *et al.*, 1995).

WipFrag™ Software is a Digital Image Processing Program (DIPP) for determining the size distribution of rock fragments and it has many features which overcomes the problem highlighted by Cunningham,1996. DIPP is one of the recognized methods for determination of fragmentation distributions resulting from blasting and in trend for more than thirty years now. Since 2000, many authors have cited the use of WipFrag™ for fragmentation analysis or used the software in blast fragmentation studies, citing fragmentation issues, measuring blast fragmentation for different rock types and characterizing the rocks and optimizing blasts.

The fragmentation distribution is expressed by the model provided by Rosin-Rammler distribution.

$$R = e^{-\left(x/x_m\right)^n}$$

where, x is the screen size, $x_m$ is the mean particle size, n is the uniformity index or slope of the curve and R is the proportion of material retained on screen opening x.

As reported, there are several issues with the digital image analysis approach such as problem with non-uniform lighting, shadows, noise and difficulty in delineating large range of fragment sizes obtained. To avoid or to minimize the effect of the issues while taking photographs, Franklin (1995) and Raina (2012) advised basic precaution to be taken into consideration while photography to get reliable results in image analysis. During the study the camera was operated using manual settings with tilt correction in sufficient day light conditions. Corrections were made while overlapping the fragments and high-resolution images were taken at different scale to incorporate the small and large size fraction from site for getting a final size distribution. To check the accuracy software-based system many calibration studies have been done in the past, in which rock fragments taken from the real field conditions were subjected to screening using traditional methods as well as to the software, and as per the results the error in estimating size distribution by WipFrag™ has been found to be less than 10%.

The blast design method will consider all the factors related to explosive energy. When beginning to work through blast geometry it is important to know the specific gravity of explosives, and it is fairly common to calculate the weight of explosive per meter of blasthole and overall quantity of explosive per blasthole. Then depending upon energy content of the type of explosives used will determine the available energy to do the work in blasting for a given set of drilling geometry and bench conditions.

Bench blasting at LOCCM operations involves large numbers of rows with occasionally hundreds of blastholes per shot and very little relief for material movement when the shot is fired. As a result of the geometric relationships of bench blasting in LOCCM operations the mechanism of breakage is similar to cratering as presented by Cooper (Cooper, 1996), except that the individual craters do not break the surface; instead, they appear to work together to lift a virtual mat of earth and create surface striations indicative of differential movement.

When viewing typical post-blast benches in Singrauli Coalfields, the great majority of the material does not move laterally away from the bench; rather it moves vertically, humping up and increasing height significantly.

## 4. Case study

Explosive use is driven around safety, low cost, and reliability. These dictate that bulk emulsion explosives, initiated by cast boosters using detonating fuse, non-electric or electronic detonators. Typically, blasting will take place using bulk emulsion explosives and depending upon blast requirements the energy ranges from 620–630 kcal/kg and densities from 1.10–1.25gm/cc.

Different types of explosives may have varying strengths within certain density ranges. Many factors contribute to the output of explosives, including detonation pressure and detonation velocity (Cooper & Kurowski, 1996). These relationships are complex, and in some cases, influenced within the blasthole based on water content and sleeping time in the blasthole. For the purpose of the experiment, varying explosive energy at nominal density will be considered. Attempt will be made to maintain a nominal density, as higher energy equates to more explosive energy in a given length of blasthole, and at the same time explosive density is a factor in both detonation pressure and detonation velocity (Cooper, 1996).

Energy of explosives being one of the important parameters, it is planned to use bulk explosives of various strength during the trial blasts.

In summation, for the purposes of the experiment, explosive types will be confined to bulk emulsions of four different energy levels with densities consistent with common uses.

Powder factor, on the other hand, is a simple ratio of material blasted to explosives used. Powder factor is calculated on either a per-blasthole or per-shot basis.

These three values define energy distribution, as the loading density states how much energy is available within a unit length of blasthole, and powder factor describes how much material that energy will break. Combining explosives energy, loading density and powder factor gives a single number that outlines the amount of work that can be done with a single meter of blasthole filled with explosive, providing a universal scale for design comparison, an extension of the original intent of powder factor. There are essentially three practical ways to combine the two numbers, multiplication or division. Adding or subtracting the values provides no benefit, while multiplication or division allows the use of dimensional analysis to complete the design process and will generate a ratio; and ratios are useful in blasting as evidenced by powder factor itself.

Examining the units of all three values, explosives energy in (Kcal/kg), loading density in (kg/m) and powder factor in ($m^3$/kg), indicates that explosives energy divided by powder factor results in units of (Kcal/$m^3$), which in context represents explosives energy available per unit volume of blasthole and, loading density multiplied by explosives energy results in units of (Kcal/m), which in context represents explosives energy available per meter of blasthole. Therefore, the above two ratios describe energy distribution for blasting. The ratio of Kcal/$m^3$ describes the amount of explosives energy being available to break per volume of material and Kcal/m the amount of explosives energy available per unit meter length of blasthole.

The field trials carried out in the top slice of the parting of 55 m to 60 m between Turra and Purewa Bottom Seam. The top slice of about 20 m being excavated by shovel dumper combination, whereas, the bottom slice of 30-35m being excavated by dragline.

## 4.1 Rock Parameters

The rock data included the Uniaxial Compressive strength, rock density, joint spacing and young's modulus to determine the Rock Mass Description (RMD), Joint Plane Spacing (JPS), Joint Plane Angle (JPA), Rock density influence (RDI) and the Hardness Factor (HF) to build the predictive models. Table V summarizes the rock parameters of Opencast Projects of Singrauli Coalfields.

| Sl No | Parameter | Unit | Value |
|---|---|---|---|
| 1 | Uniaxial Compressive Strength | MPa | 20 |
| 2 | Joint Plane Spacing (JPS) | m | > 1.0 |
| 3 | Joint Plane Orientation (JPO) | - | Horizontal = 10 |
| 4 | Specific Gravity | kg/$m^3$ | 1900-2200 |
| 5 | Protodyakonov hardness index | - | 2 |
| 6 | Rock Type | - | Sandstone |
| 7 | Rock Description | - | Fine grained strong sandstone; grey or white in colour |

The shovel bench is mainly of fine-grained strong sandstone, grey or white in colour, compressive strength 180–200 kg/$cm^2$, joint plane spacing >1.0 m, joint plane orientation horizontal, specific gravity of 2000 to 2200 kg/$m^3$ and Protodyakonov hardness index of 1.8–2.0.

## 4.2 Drilling Geometry

The blasts were carried out using vertical blastholes of 270mm diameter, 8 m burden, 9 m spacing in cuts from 45–55 m wide and face heights of 18–20 m.

## 4.3 Explosives

The field trials for blasting at opencast mines of Singrauli Coalfields was carried with the bulk emulsion explosive. The non-explosive ingredients/intermediates are mixed in the Mobile Manufacturing Unit (MMU) at the site and is pumped down the blasthole, where chemical gassing action takes place for a few minutes. The product acquires explosives properties only after the same is delivered into the blast hole, thus ensuring maximum possible safety. The programmable logic controller of MMU enables pre-determined quantity of explosives of different energies to be delivered in the same blasthole.

Blasting was carried out using bulk emulsion explosives with the energy range from 630–720 kcal/kg and average density of about 1.15 gm/cc.

### 4.4 Method

Bulk Emulsion explosives of varying energy content (kcal/kg) to be used while, the other parameters (a) drilling geometry – diameter of blasthole, burden, spacing and bench height, (b) explosives quantity, (c) stemming height, (d) powder factor, (e) cut width, (f) initiation sequence, and (g) rock mass characteristics were maintained unchanged to the extent possible without affecting the blasting sequence/frequency to adhere with the mine operation schedule.

The above method was planned to measure the degree of change on the fragmentation size vis-à-vis variation in the available energy to break the rock, while the remaining parameters being unchanged to determine the relationship between explosives energy and fragment size in LOCCM.

## 5. Blasts Details

During the field trials, about 25 blasts were carried out, with different energy level of bulk emulsion explosives ranging from 630 to 720 kcal/kg as detailed below:

| No of Blast | 6 | 6 | 6 | 7 |
|---|---|---|---|---|
| Bulk Emulsion Explosives | EMUL-W | EMUL-X | EMUL-Y | EMUL-Z |
| Energy (kcal/kg) | 630 | 650 | 690 | 720 |
| Nominal Density (gm/cc) | 1.15 | 1.15 | 1.15 | 1.15 |
| Blasthole Diameter (mm) | 269 | 269 | 269 | 269 |
| Average Depth (m) | 16.76 | 16.88 | 16.86 | 16.82 |
| Average Sub Grade (m) | 0.5 | 0.5 | 0.5 | 0.5 |
| Average Burden (m) | 8 | 8 | 8 | 8 |
| Average Spacing (m) | 9 | 9 | 9 | 9 |
| Stemming Height (m) | 5 | 5 | 5 | 5 |
| PF ($m^3$/kg) | 1.69 | 1.69 | 1.69 | 1.69 |

## 6. Fragmentation Analysis

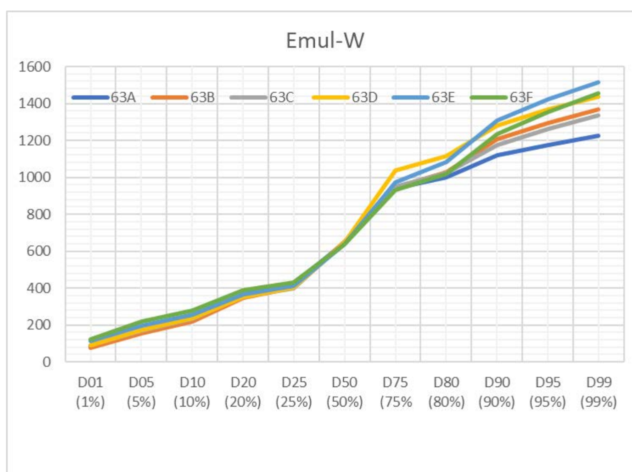
Random sampling strategy was used for capturing the digital images required for the fragmentation analysis. Photographs were taken at an interval of 2 hours from 0 to 10 hours period to consider the swelling property of the rock.

To determine the fragment size, 220–210 high resolution images with tilt correction and with manual setting were taken after all the trial blasts were conducted. The nature of the photographs used for the analysis to assess the fragmentation size of the resulting muck pile are shown below.

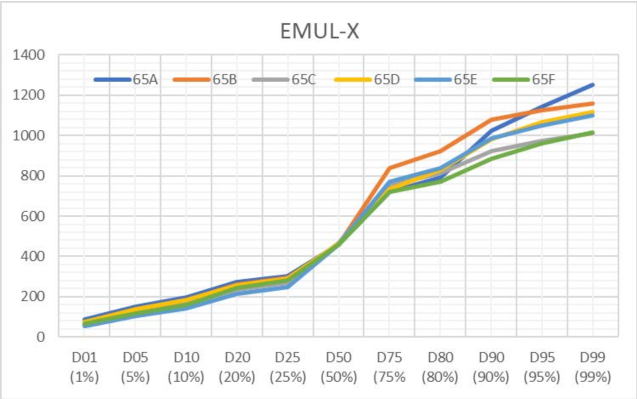
## 7. Result

The fragments depending upon their size, using the software, were categorized under 11 buckets in increasing order, namely, D01, D05, D10, D20, D25, D50, D75, D80, D90, D95 & D99 (11), representing smaller to larger fragments size.

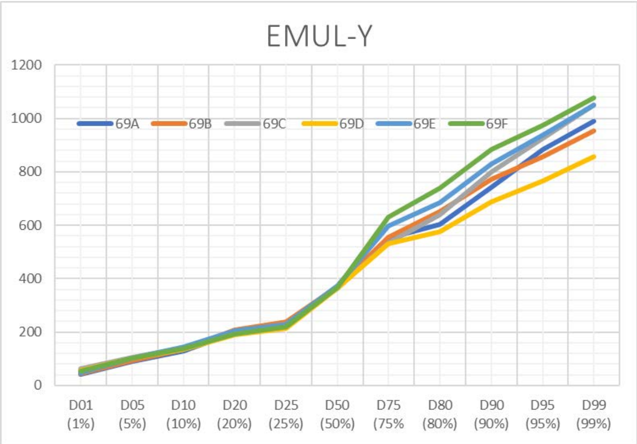
The fragment size,for 25 blasts carried out with bulk emulsion explosives of 4 different energy levels of 630, 650, 690 and 720, under 11 such buckets is represented below.



From the above, it is observed that the fragment size of 636 mm to 647 mm and, 1001 mm to 1115 mm constituted about 50% and 80% of the fragments respectively.




From the above, it is observed that the fragment size of 460 mm to 476 mm, 924 mm to 1078 mm constituted about 50% & 80% of the fragments respectively.

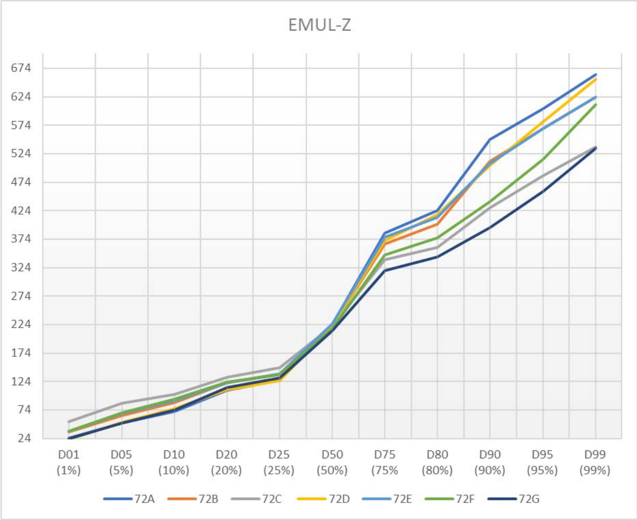



From the above, it is observed that the fragment size of 364 mm to 374 mm and 578 mm to 740 mm constituted about 50% & 80% of the fragments respectively.

From the above, it is observed that the fragment size of 213 mm to 225 mm and 343 mm to 480 mm constituted about 50% and 80% of the fragments respectively.

## 8. Conclusion

The blasts were carried out in coal mine, with similar rock conditions, with no major geological discontinuities




or structural deformations. All the trial blasts were fired with same initiation system and delay. The main influencing factor was energy content of bulk emulsion explosives ranging from 630, 650, 690 and 720 kcal/kg and formulated as EMUL-W, EMUL-X, EMUL-Y and EMUL-Z respectively. The blast performance of all the trial blasts were measured in terms of fragmentation which is obtained using Wipware software.

According to the results obtained from software, the average fragment reduction size from 644 mm to 220 mm, i.e., by about 1/3$^{rd}$has been obtained by using bulk emulsion explosives with higher energy levels as compared to original low energy emulsion explosives used by mine. The reduction in fragment size by 66% shall improve the excavator efficiency as well as related maintenance costs.

The higher strength of the explosives attributes to the improved fragmentation. The blasts were monitored, though it is no in the scope of the study, but the adverse effect of blasting were well under control. Although, in soft rocks, or in highly jointed strata, the negative implication increases with increase in energy levels.

The study shows that the change in energy of emulsion explosives, may induce greater degree of fragmentation, however, there is further scope to study the degree of change in fragments size by reducing to the extent possible, the variation in uncontrollable factors.

As fragmentation is the single largest factor, affecting the efficiency of the excavators, energy of emulsion explosives may be given due attention to overall reduction in mining cost.

## 9. References

1. Bond, F.C. 1952. The third theory of comminution. Trans. AIMM 193: 484.
2. Bond, F.C. & Whittney, B.B. 1959. The work index in blasting. Quarterly of the Colorado School of Mines 54(3): 77–82.
3. Central Electricity Authority, 2015. Growth of Electricity Sector in India from 1947-2015. Ministry of Power, India.
4. Cunningham CV. Keynote address—optical fragmentation assessment, a technical challenge. InMeasurement of Blast Fragmentation, Proceedings of the FRAGBLAST 1996 (Vol. 5, pp. 13-19).
5. Esen S, Bilgin HA, BoBo T. Effect of explosive on fragmentation. InThe 4th Drilling and Blasting Symposium, Ankara, Turkey 2000 (Vol. 6372).
6. Franklin, J.A., Kemeny, J.M. &Girdner, K.K. 1995. Evolution of measuring systems: A review. In J.A. Franklin & T. Katsabanis (eds.), Measurement of blast fragmentation: 47–52. Rotterdam: Balkema.
7. Kanchibotla SS, Morrell S, Valery W, O'Loughlin P. Exploring the effect of blast design on SAG mill throughput at KCGM. InMine to Mill. Conference. Brisbane 1998.
8. Kojovic T, Michaux S, McKenzie C. Impact of blast fragmentation on crushing and screening operations in quarrying. InProceedings of the EXPLO 1995 Conference, Brisbane, QLD 1995 (pp. 427-435).
9. Lizotte, Y., Scoble, M.J., Singh, A. &Mohanty, B. 1993. Prediction and assessment of fragmentation in underground mine. In H.P. Rossmanith (ed.), Proc. 4th Int. Symp. on Rock Fragmentation by Blasting, Vienna, 5–8 July, pp. 361–368. Rotterdam: Balkema.
10. Leung CS, Meisen P. How electricity consumption affects social and economic development by comparing low, medium and high human development countries. Retrieved November. 2005;10:2013.
11. Michaux S, Djordjevic N. Influence of explosive energy on the strength of the rock fragments and SAG mill throughput. Minerals engineering. 2005 Apr 30;18(4):439-48.
12. Monjezi M, Rezaei M, Yazdian A. Prediction of backbreak in open-pit blasting using fuzzy set theory. Expert Systems with Applications. 2010 Mar 15;37(3):2637-43.
13. Monjezi M, Ghafurikalajahi M, Bahrami A. Prediction of blast-induced ground vibration using artificial neural networks. Tunnelling and underground space technology. 2011 Jan 31;26(1):46-50.
14. Nielson, K. 1983. Optimisation of open-pit blasting. Proc. 1st Int. Symp. on Rock Fragmentation by Blasting, Lulea, Sweden, 22–26 August, pp. 653–664.
15. Raina AK. A history of digital image analysis technique for blast fragmentation assessment and some Indian contributions. Electrical Measuring Instruments and Measurements. 2012 Nov 5:3.
16. Raina AK, Ramulu M, Choudhury PB, Chakraborty AK, Sinha A, Ramesh-Kumar B, Fazal M. Productivity improvement in an opencast coal mine in India using digital image analysis technique. In Fragmentation by Blasting, Proceedings of the 9th Int. Symp. On Rock Fragmentation by Blasting—Fragblast 2010 Sep (Vol. 9, pp. 13-17).
17. Singh, S., 1993. Damage causing potential of different explosives. In: Proc. of the Ninth Annual Symposium on Explosives and Blasting Research, California USA, pp. 325–337.