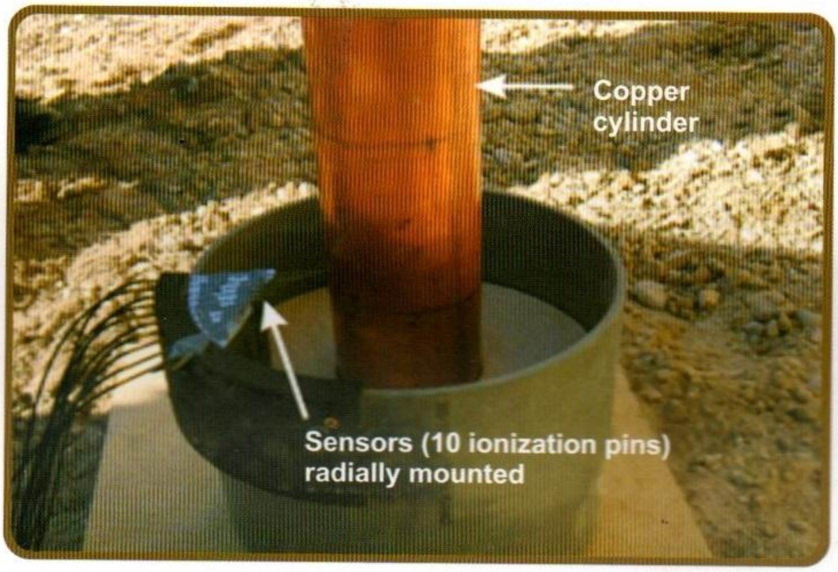
Vol. No.10 : December 2016

ISSN : 0976-4070

Visfotak®

JOURNAL OF THE EXPLOSIVES SAFETY AND TECHNOLOGY SOCIETY (VISFOTAK) INDIA, DEALING WITH SAFETY AND TECHNOLOGICAL ASPECTS OF THE EXPLOSIVES INDUSTRY



The 'cylinder expansion test', illustrated above, is popularly used to provide empirical data characterizing the adiabatic expansion of the detonation products, by measuring the motion of the cylinder wall as it is expanded by the detonation products of the explosive charge inside. The expansion energy function of the volume obtained in the cylinder test is commonly used to derive the detonation products equation of state, for which the JWL (Jones-Wilkins-Lee) detonation code is the most widely used.

Cover Feature : The 'Non-Ideal' Detonation Conundrum of Ammonium Nitrate mixture Explosives (ANEs)

(The need for developing a separate 'Standardized Protocol of Test Criteria and Methods' for Technical specifications of ANEs)

MISSION STATEMENT

"To proactively establish a sustainable interface between all major constituents of the Explosives Industry : The Users, the Regulatory Bodies, the Manufacturers, the Academic and Research Institutions, et.al., in order to foster and promote modern concepts and practices, relating to Safety and Technology of Explosives."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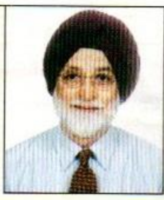
Editorial...

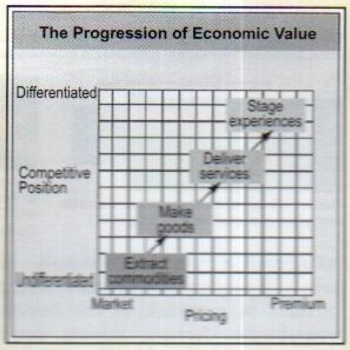


"We are what we repeatedly do. Excellence then is not an act but a habit - Aristotle"

This is the 10th edition of Visfotak Journal since the inaugural publication in 2006; a modest milestone, though I would hasten to add that we started with high hopes of contributing bi-annual publications and that remains our cherished goal : a task clearly requiring fullest cooperation from every constituent of the explosive industry which we fervently seek !

Every edition is distinguishable by its 'Cover Feature', an in-house contribution, where we deliberate upon an important contemporary 'Issue of Concern' relevant to safety and technology of the explosives industry - "not to see what lies dimly at a distance, but to do what lies clearly at hand" - and in that context, highlighting global developments with a fond hope that the industry would take due cognizance and initiate appropriate steps in order to match up with best global practices. Being the 10th edition, as many issues have been covered through the medium of this Journal; and indeed, a compendium of these deliberations provides a unique widow into the state of the explosives industry in the country (@ www.visfotak.org).

Looking back over the years, whereas, the growth trajectory of the explosives industry in India has been very impressive, currently ranked amongst the top five in the world, and that the industry is seemingly possessed of the full range of modern genre of explosive blasting systems, but, unfortunately, the economic values potentially deliverable by the industry in full measure, have not quite matched the global trend. I dare say, a state of 'laissez-faire' - the more things change the more they stay the same - without direction, with serious economic implications of 'Opportunity Cost' to the economy, as a measure of prospective financial benefits forgone by not allocating resources towards superior technical specifications and operating procedures with supportive R&D services that fully take on board the best global practices. This important issue forms the thematic burden of the cover feature in this edition.



"Harvard Business Review (July-Aug 1998), nearly two decades ago", 'dwelt upon the history of "How do Economies change?, and pointedly referred to the emerging 'Experience Economy' on the premise that "as 'Services' like 'Goods' before them, increasingly become commoditized and fungible, the leading edge companies whether they sell to customers or businesses-would be compelled to upgrade their economic offerings to the next differentiable economic value (see illustration). "The question, then, isn't whether, but when and how to enter the emerging experience economy".

The explosives business worldwide is witnessing a similar trend by virtue of the unique attributes of technology and safety deliverable with the modern genre of bulk Ammonium Nitrate mixture Explosives (ANEs) and Electronic initiating systems. The most prominent example of the changing paradigm is provided by M/s Orica Ltd., a major global player in explosives business, by upgrading their offerings of manufactured explosive products to the next level of economic value through their new business entity of 'Orica Mining Services', by engaging the customers with an open-ended value added business offerings of 'Product Systems and Engineering Services', supported with requisite blast design soft-wares and computing capabilities including measurement of detonics properties in-situ in a blast hole, that creates a distinctively differentiable and experiential economic value of quality solutions that the customer wants : *Welcome to the emerging digital age of superior 'virtual reality' experiential economic value of commercial explosives business!*

It's about time the explosives industry and all its constituents collaboratively switch to 'fast forward' mode and promptly address this issue . In this context, in all our past deliberations on various issues of concern through this Journal, we have been pleading for revival of 'Explosives Development Council', in the Ministry of Industries, long moribund for years , duly restructured and given a permanent tenure as a 'Nodal Agency', for stewardship of the development and growth of the explosives industry.

Greetings and very happy 2017.

Ardaman Singh

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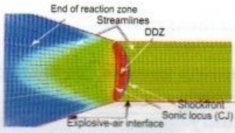
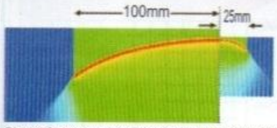
COVER FEATURE & SUPPLEMENTS

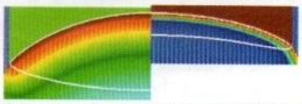
The over-arching fundamental characteristic of non-ideal detonation process, strongly bearing on performance, is the time-dependent 'Curved Detonation Front' and consequently, the detonation pressure sustaining the detonation front, would vary across the curvature - highest at the central point and progressively decreasing towards the periphery.



Density contour plot for a hypothetical explosive showing streamlines, the detonation driving zone, the end of the reaction zone and the explosive-air interface (adapted from Schoch, 2012



Shock front curvature increases as diameter decreases (adapted from Schoch, 2011).



Contours of the extent of reaction and the limits of the detonation driving zone (while line) for ANFO (right) and EM120D (left). Charge diameter is 80 mm (Schoch, 2012)

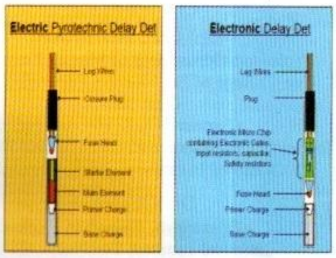
As a result, a situation seriously impacting performance, would arise with decrease in diameter of an explosive charge and the resultant increase in curvature of the detonation front (see illustrations), whereby the forward - driving detonation pressure steeply falls at the periphery; and if the diameter is low enough, the detonation would fail to progress any further..

Therefore, importantly, every ANE is differentiable by its 'Critical Diameter (CD)', as an important criteria, for performance.

Supplements :

TECHNOLOGY ABSTRACTS / PATENTS/ SPECIAL REPORTS

SCIENTIFIC / TECHNICAL PAPERS



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COVER FEATURE & SUPPLEMENT

COVER FEATURE

The 'Non-Ideal' Detonation Conundrum of Ammonium Nitrate mixture Explosives (ANEs)

(The need for developing a separate 'Standardized Protocol of Test Criteria and Methods' for Technical specifications of ANEs)

1.0 Prelude :

1.1 This subject was first mooted in the 'Cover Feature' of the 2nd edition of this Journal in 2006, presented in the back drop of an anachronistic dispensation of statutory test criteria and methods prescribed for ANEs, fixated in the NG explosives era, and failing to take cognizance of the fundamental disconnect between the detonation behavior of the two classes of commercial explosives. The full text of the 'cover feature' can be viewed at www.visfotak.org. The recommendations then made for developing a suitable modality of test criteria and methods, are briefly provided in Box-1 for ready reference.

Cover Feature - "Energy Audit of Commercial Explosives", 2nd Edition (2006) : Box - 1

"An institutional arrangement was proposed with the following 'Terms of Reference' :-

(i) To adopt and develop an appropriate thermo-chemical-hydrodynamic Detonation Code', capable of predicting Equation of State (EOS) of products of detonation of one dimensional 'Ideal' state, detonation behavior (1D) and also, of time-dependant Two/Three Dimensional detonation behavior (2-3D), respectively.

(ii) To validate the 'Code' with extensive experimental data on VOD vs Diameter (unconfined), as well as with 'Energy Profile / Partitioning' data by Under Water Test Procedure, respectively.

(iii) To Develop norms for measure of 'Ideality' by generating data as follows :

Computed data :

- Energy Density and Velocity of Detonation in Ideal State:
- VOD vs. Diameter vide Two/Three dimensional detonation code unconfined.
- Energy Density in the Primary Zone by the 2-3D code vs Energy Density by the 1D code

Experimental data :

- VOD vs. Diameter, unconfined.
- Max. VOD, unconfined, and corresponding relationship with 'Ideal' VOD.
- In-hole VOD measurement in a standardized blasthole geometry and rock type, for a measure of Relative Ideality of explosives in confinement.
- Under Water Test data on Energy Profile / Partitioning, and Completion of Primary Reaction on a time scale.

(iv) To analyze and devise a uniform basis for rating of explosives in terms of 'Ideality', relative to the two designated basic energy parameters, viz, Velocity of Detonation, and Energy density, respectively".

1.2 Unfortunately, thus far, the explosives industry hasn't shown any degree of due diligence towards resolving this important issue, which is also affirmed by the following two examples:-

a) The revised specifications for power of ANEs prescribed vide IS 15447 (Part 2), by the Bureau of Indian Standard Institution (BIS), as late as 2008, continue to be based on Ballistic Mortar Method and Trauzel Lead Block Method, respectively, despite the glaring limitations of these methods, by virtue of the fact that the size of the test sample is too small (10g) to be fully representative since these explosives typically react fully in relatively much larger quantity (see Annexure I).

b) The Tender Document issued by Coal India Ltd for the requirement of explosives during the period 2015-2017 is the most recent example, wherein, the technical specifications prescribed for ANEs, packaged and bulk, grossly omit consideration of the reality of 'Non-Ideal' detonation behavior of these explosives. The consequential techno-economic ramifications, are discussed later.

1.3 This 'cover feature' revisits the subject in the context of the global developments since 2006, in the hope that the industry, notably the regulatory authorities, would take due cognizance and initiate appropriate steps soon enough in collaboration with other major constituents of the industry, viz, the manufacturers , the users and the R&D institutions, in the country .

2.0 Discussions :

2.1 Transition to Non-Ideal Detonating Blasting Systems : A paradigm shift.

The phenomena of detonation of condensed chemical explosives was first recognized around the turn of the last century; and over the past 100 years or so, a number of detonation theories / models and codes, have been developed (Annexure - II), firstly dealing with near instantaneous, Ideal detonation of NG sensitized explosives; and later from around the 1950s, having to contend with a profound paradigm shift to non-ideal detonation regime of the emerging ANEs, collectively categorized as Nitrate mixture Class 2 high explosives, which over time replaced NG explosives, by virtue of unique advances in technology and safety deliverable by ANEs (see Box - 2).

(The "Cover Feature" is an 'In-House' contribution, as part of the running serial on "Challenges and Issues" of the Explosives Industry - Editor)

2.2 Influence of Non-ideality on performance:

The cap-sensitive, water-in-oil, emulsified ANFO and the booster - sensitive dry ANFO mixture, respectively, represents two ends of the non-ideality spectrum of ANEs : the total reaction times range from around one millisecond of the former, to 50-100 millisecond of the later; and all other blasting agents, viz, emulsion blends with dry ANFO, Water Gels, etc., fall between these two extremes.

Advances in Technology and Safety Deliverable by ANEs

(Abstract from the 'cover feature' of the 6th Edition, titled "Emerging Dividends from the 'Technology-Safety Interface' of Modern Industrial Explosives)"

Box - 2

1. *Simplicity of manufacture and Inherent Safety :*

   The unique rheology of AN based formulations has enabled modular designs for bulk product processes and systems in a continuous flow at high speeds, easily adaptable for automation and digital control systems for optimization of processes.

2. *Amenability Mobile Production and Down-the-Hole Delivery Units (MPDU), at the blasting sites:*

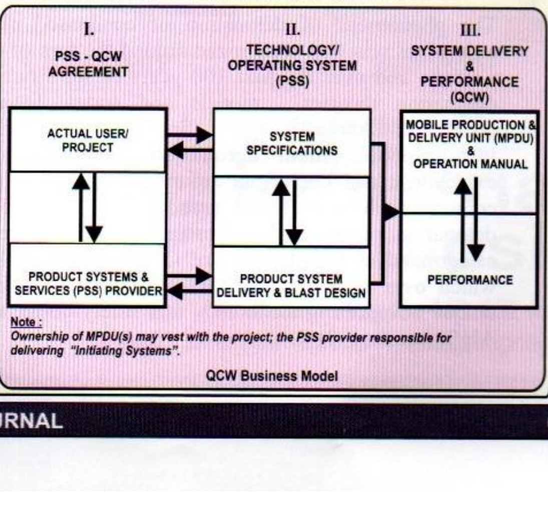
   The system typically comprise truck mounted configuration of modular storage and processing equipments, powered through a power-takeoff mechanism, ranging from 5-15 t capacities, carrying ingredients from a 'Base Plant' close by; the ingredients including additives such as sensitizers, gassing agents, etc, are mixed at site of blasting with options to modify formulations, their sensitization, etc, on-line, to match specific field requirements, and directly pumped down the blast hole.

   A number of variants of the three basic formulations, viz, ANFO, Water Gels, and Emulsions, provide a wide range of options for best results:-

   - Dry Conditions: 100% ANFO, or blends with Emulsions.
   - Mild Wet Conditions: Heavy ANFO; Emulsion Matrix blended with AN prille / ANFO as necessary.
   - Very Wet Conditions: 100% Emulsion or Water Gels.

3. *'Product Systems and Services (PSS)' tailored to provide Quality solutions that the Customer Wants (QCW):*

   Aside from the huge gains in 'public safety' by the elimination , in one stroke, of all the risks and hazards associated with handling, storage and transportation of packaged explosive products , the new dispensation has also for ever unshackled and transformed the landscape of the explosives business , to an open- ended, customer driven model illustrated below that provides quality optimal solutions to specific blasting environment .



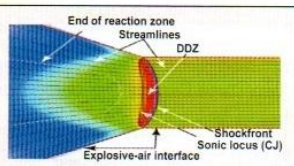
Note : Ownership of MPDU(s) may vest with the project; the PSS provider responsible for delivering "Initiating Systems".

QCW Business Model

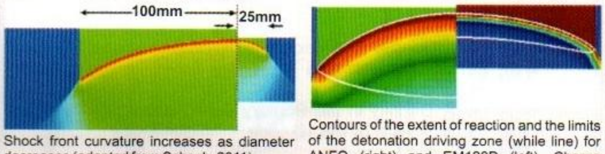
Fortuitously, relatively longer reaction zone and rarefaction wave of non-ideal detonation (Annexure II), is a welcome phenomena from the stand point of rock blasting, because the peak detonation pressure is relatively lower with longer pressure pulse duration, thereby avoiding un-necessary pulverization of rock around the bore hole and maximum energy is released for useful work of fracturing and moving the rock mass during the rarefaction phase of detonation.

The above benefits are, however, subject to an important caveat, and that is that the full potential is only realized if the detonation process is sustainable through the entire cylindrical charge column; and there lies the crux of the challenges of non-ideality, briefly discussed below :-

a) The over-arching fundamental characteristic, strongly bearing on performance, is the 'curved detonation front' (Annexure II), and commensurately, the detonation pressure that sustains the detonation wave, would vary across the curved front - highest at the central point of the curvature and progressively decreasing towards the periphery of a cylindrical charge. As a result, a serious situation impacting performance would arise with decrease in diameter when the curvature of the front correspondingly increases and the forward detonation driving pressure steeply falls towards the periphery, and therefore, if the diameter is low enough, the detonation would fail to progress, as illustrated below :



Density contour plot for a hypothetical explosive showing stramlines, the detonation driving zone, the end of the reaction zone and the explosive-air interface (adapted from Schoch, 2012



Shock front curvature increases as diameter decreases (adapted from Schoch, 2011).

Contours of the extent of reaction and the limits of the detonation driving zone (while line) for ANFO (right) and EM120D (left). Charge diameter is 80 mm (Schoch, 2012)

(Source : "On the influence of fundamental detonics on Blasting Practice, by A. Minchinton)"

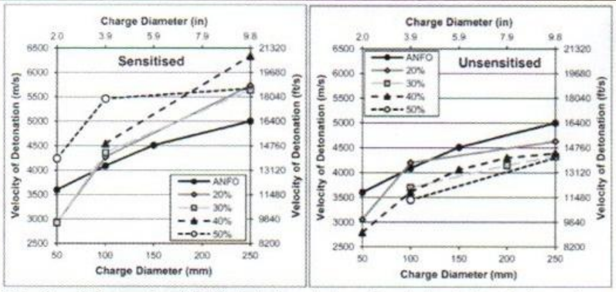
b) Therefore, importantly, every non-ideal formulation/ blasting system is characterized by its 'Critical Diameter (CD)', which is influenced by the density and sensitization of a formulation, below which detonation failure will occur : an important criteria differentiating various types of ANEs, from the stand point of sustainability of detonation.

The gamut of variability across a range of Sensitized and Un-Sensitized formulations, w.r.t. 'velocity of detonation' (VOD) Vs. Sensitization process Vs. Density, etc., and consequently the impact on relative available energy / work capacity, is presented in Box - 3 .

Relative Detonics of Emulsions, Bulk ANFO, and Emulsion-ANFO Blends

Box - 3

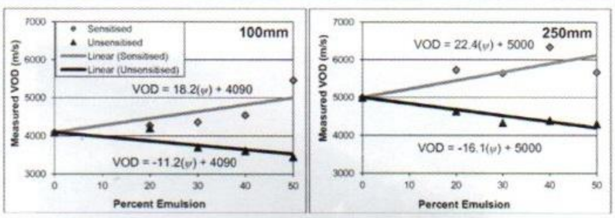
1. Measured VOD of Sensitized and Unsensitized ANFO- Emulsion Blends



Velocity of Detonation (VOD) data for steel-confined pipe tests of glass micro-balloon (GMB) sensitized (left) and un-sensitized (right) emulsion-ANFO blends (after Bauer et al., 1984).

The data clearly indicates different relationships between the measured VODs and percent emulsions for the sensitized and un-sensitized blends relative to plain ANFO. The data of the sensitized emulsion blends are close to what would be expected, with increasing VODs observed for higher percent emulsion blends. The data for the un-sensitized emulsion blends is opposite to that of the sensitized blends, suggesting a loss of performance relative to ANFO for increased emulsion percentages. The VODs for the un-sensitized blends of the most common blend percentages (between 30 and 50 emulsion) were up to 15 lower than plain ANFO and up to 37 lower than the sensitized blend over the range in diameters.

2. Sensitized and Un-sensitized blend VODs relative to ANFO for a single diameter



Measured VOD values for steel pipe confined tests of sensitized and un-sensitized emulsion-ANFO blends in 100 mm (left) and 250mm (right) diameters.

The observed differences between the sensitized and un-sensitized emulsion blend VODs should be considered when selecting a suitable emulsion for a blended product, especially in intermediate hole diameters where increased sensitivity may be required due to wet holes, long sleep times or poor product quality from repeated cycling or excessive storage times.

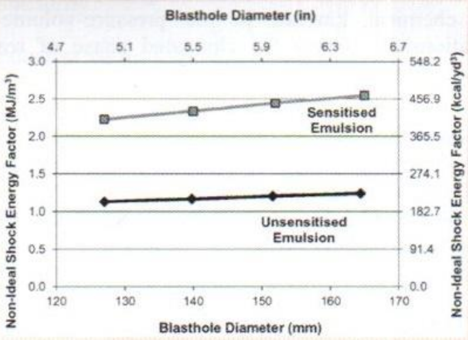
3. Comparison of 'Non-Ideal Shock Energy Factors (NSEF)', for equal Powder Factor(PF) : and the irrelevance of PF as a viable 'energy factor'

The implications of the reduced in-hole VODs and available shock energies on the estimated blast performance for the sensitized and un-sensitized ANFO-Emulsion blends were further investigated by comparing a series of theoretical blasting patterns in limestone. The theoretical sensitivities of each product to blasthole diameter were also compared using four examples of equal PF blasting patterns, charged with either sensitized or un-sensitized formulations . The four compared patterns were designed using existing rules of thumb for burden, spacing, sub-drill and stemming length and representative bench heights used in quarry blasting. The reference design powder factor was 0.84 kg/m³ for the four intermediate hole diameters of 127-165mm . The shock energy values were then used to calculate the Non-Ideal Shock Energy Factors (NSEF) for each theoretical pattern, as charged with un-sensitized or sensitized ANFO-Emulsion blends. The resulting pattern dimensions and NSEF values are illustrated below, which clearly demonstrate the irrelevance of PF as a viable energy factor for blast design .

a) Pattern Dimensions and NSEF Values Calculated for Equal PF Blast Patterns in Limestone

Diameter (mm)	Burden (m)	Spacing (m)	Powder Factor (Kg/m³)	Un-sensitized NSEF (*MJ/m³*)	Sensitized NSEF (*MJ/m³*)
127	3.3	4.5	0.84	1.13	2.23
140	3.6	5.0	0.84	1.17	2.33
152	3.8	5.5	0.84	1.20	2.44
165	4.1	5.9	0.84	1.24	2.55

b) Plot of Blasthole Diameter and NSEF for 30 Unsensitized and Sensitize Emulsion Blends in Equal Powder Factor Patterns in Limestone.

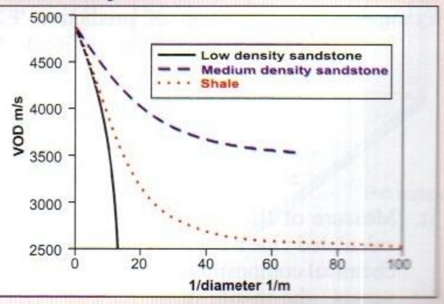


The NSEF values for the un-sensitized emulsion blends are approximately half of that for the sensitized emulsion blends in patterns of equal powder factor. The increase in available shock energy to perform rock breakage would suggest that the pattern loaded with the sensitized emulsion would result in better fragmentation; and significantly therefore, by matching the NSEF values for both explosive products would require the pattern charged with the un-sensitized emulsion blend to be reduced or alternately spreading of the sensitized emulsion blend pattern, to achieve equal energy concentrations.

The NSEF could therefore, be a preferred option in place of PF as a blast design parameter to assess probable blasting outcomes from different explosive products.

4) Influence of the strength of 'Rock Confinement'

Yet another very significant factor which further accentuates the influence of 'Non-Ideality'on performance, is the strength of rock confinement, illustrated below, relating to ANFO :-



Source- "Comparison of the Non-Ideal Shock Energies of Sensitised and Unsensitised Bulk ANFO-Emulsion Blends in Intermediate Blasthole Diameters" by K.G. Fleetwood, E. Villaescusa and J. Eloranta (2012)

2.3 *Determining 'Relative Ideality (RI)' of a non-ideal explosive system :*

2.3.1 The NG era was well served by the applicability of detonation codes based on PJ postulate. Therefore, given an empirical measure of VOD, it was feasible to determine physical energy parameters of the equation of state (EOS) of the products of detonation, viz detonation pressure (P) as a function of the density (D) and the square of the measured VOD of a given explosive, i.e., $P=DxV^2$, a simplified version of the theoretical equation of detonation pressure as a product of the density (D), the detonation rate (V), and the particle velocity (VP) of gaseous products or fumes (assumed equal to rate of detonation in the simplified equation above).

However, the 'one size-fit all' solution feasible with NG explosives breaks down whilst dealing with a wide spectrum of variable detonics / EOS of products of detonation of ANEs, not discounting the unpredictable role of chemical kinetics in the pressure-volume-energy relationships during the elongated phase of reaction / rarefaction wave.

2.3.2 A number of researchers / technologists are working towards developing 'Predictive Detonation Codes / Programs', appropriate for non-ideal explosive, a work-in-progress, as of now.

These developments broadly, signify two approaches, briefly discussed below:-

- Traditional Theoretical Approach :

The traditional approach of firstly developing a thermo-chemical detonation code capable of theoretical determination of detonics properties, viz, VOD, detonation pressure, and EOS for one-dimension ideal state detonation as well as two/three dimensional representation of non-ideal detonation which are compared with field measurements of VOD and detonation pressure in a blast hole, as a reasonably credible basis for estimating 'Relative Ideality' of various non-ideal explosive formulations / systems, i.e. the departure from Ideal state detonates for rating of ANEs.

Two examples in this regard were cited in the 2nd edition of 2006, summarized below for ready reference :-

Example - I: Application of predictive 'EXTRINCT Code' (an Explosive Rock Interaction 'one dimensional' and 'two-dimensional' detonation theory calculations/ program) in conjunction field measurements conducted, to provide a model for estimate of RI, as follows :-

i) Measure of RI, as the ratio of CJ value of VOD calculated vide I-D Ideal Code with reference to the chemical composition of an explosive formulation, versus the in-situ measurement VOD inside the blast hole by a VOD recorder;

ii) Measure of RI as the Ratio of the CJ value of energy released in the primary zone, versus the value of the energy calculated per the 2-D detonation theory modeled in the EXTRINCT Code.

Example -2 : Application of DeNE Code (De tonic of N on-ideal Explosive) developed to predict the non-ideal behavior of commercial explosives :

The performance of several commercial explosives, viz, ANFO, Heavy ANFO, Emulsions, in different blasting environments, is analyzed and compared with the properties determined vide the detonation code, to indicate the sensitivity of the code to charge diameter, explosive type and variation of in-hole explosive density. It is interesting to note that the results showed ANFO, Heavy ANFO and Emulsion explosives approaching ideal detonation at 360, 330,and 140 mm, respectively, and The non-ideality gets more pronounced when the bore-hole diameter is decreased from 250 mm to 152 mm.

- Modern Empirical Approach :

A new empirical approach is gaining ground in recent years, post 2006, whereby a non-ideal Detonation Code is modified by using empirical test data of 'pressure - volume - energy' relationship of EOS of a detonating explosive, generated by conducting 'Cylinder Wall Expansion Test with a non-ideal formulation / explosive, illustrated below :-

Figure 1 - Cylinder Expansion Test Set-up

The Cylinder Test owes its origin to the Gurney Model of mathematical formulas defining the 'equation of state' of a detonating explosive within a metallic shell or other solid shells, to relate how fast the surrounding shell is accelerated both by the initial detonation shock wave and by the expansion of the detonation gas products contained by the outer shell, to provide a history of pressure volume energy relationship of the detonation phenomena of a particular explosive. The Gurney Model was later adapted for military explosives at Lawrence Livermore National Laboratory in 1965, and much later, following this development, Swedish Blasting Research Centre (SWEBREC) pioneered this methodology for commercial explosives. (See Box 4).

Box - 4

Swedish Blasting Research Centre (SWEBREC) Report : Determination of the Energetic Characteristics of Commercial Explosives using the Cylinder Expansion Test Technique

The cylinder expansion test technique has been a principal testing technique for the determination of energetics of commercial explosives at Swebrec. The aims of this project are to evaluate the work capacity of commercial explosives, compare the products, judge the addition of Aluminum into ANFO and emulsion explosives, assess the addition of ANFO into emulsion explosives, compare the test results with the underwater test and full-scale results as well as determine the usefulness of the cylinder test in the mining and quarrying industry.

This report presents the comprehensive cylinder expansion tests collected to date. 58 cylinder tests were carried out during the period from January 2002 to January 2005. A total of 11 commercial type explosives have been tested during this period at charge diameters between 40 and 100 mm in copper pipes. The explosives ranged from pure ANFO to pure emulsions and covered the majority of the commercial explosive types used in today's production blasting operations. In addition to the previous in-house data, 9 more cylinder tests were conducted between August 2005 and November 2005.

The major conclusions drawn from this project are as follows:

- Because of the issues (mainly experimental) with the old data, a detailed analysis was undertaken in this study by analyzing the data for each explosive type; charge diameter; raw cylinder expansion, kinetic and JWL expansion data; making consistent analysis; doing JWL fitting for each experimental data; eliminating faulty data (due to e.g. moisture, insufficient pin data, etc); and including elaborate statistics for data analysis. All data collected/analysed to date are placed in a consistent electronic format.
- JWL fitting for each experimental data resulted in the determination of the full expansion (pressure and energy) curve as well as the detonics properties (detonation pressure, specific volume, internal energy) of the explosive. This was a key extension of the previous Gurney analysis technique, which gives only a limited value.

The usefulness of the cylinder test in blasting:

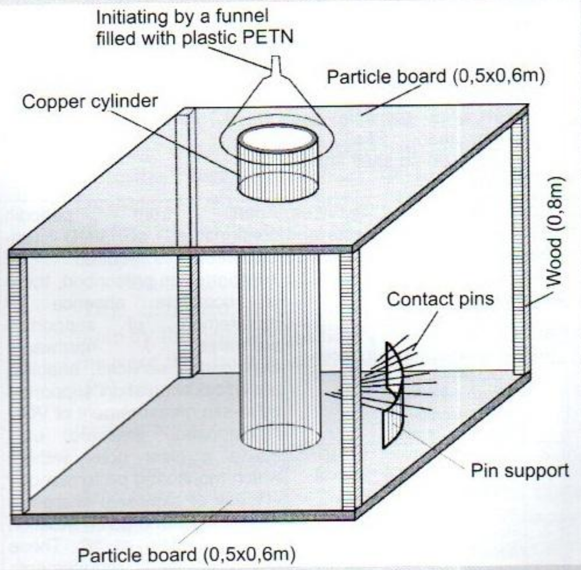
The following uses were identified for the current cylinder testing technique which includes the new JWL evaluation;

- It can be used to determine the detonics properties (VOD, detonation pressure and specific volume) of explosives, and the pressure-volume and energy expansion curves to a pre-defined cut-off pressure level under a reasonably realistic confinement type.
- The test can be used to compare or rate explosive formulations and new explosive products. The effect of aluminum or any other solid energetic ingredients, ANFO addition into emulsion, changes in the emulsion formulation, etc can be assessed.
- This is the only technique, which plots the full expansion energy (work done to the surroundings) curve under real, i.e. non-ideal conditions. Non-ideal detonation modeling is also promising; however, it has not been developed satisfactorily.

The cylinder test has the following limitations:

- The results do not measure any direct blasting results (fragmentation, heave, damage) but nor does any other indirect tests.
- The results are valid for the charge diameter (100 mm) and confinement (copper) conditions. Reactions may become more complete at larger diameters for some highly non-ideal explosives such as ANFO or aluminized ANFO.

The Disposable Rig with Copper Tube and Contact Pins (Nie, 2001)



3.0 Conclusion / Recommendations :

3.1 Techno-economic Ramifications :

3.1.1 The 'Tender Document' of Coal India Ltd (CIL) for the requirement of explosives and accessories during the period 2015-17, makes an interesting 'Test Case'.

Coal mining constitutes around 70% of the total explosives demand in India; and CIL is the major constituent, and therefore, the techno-economic specifications prescribed by CIL in the Tender Document, would reflect the currently prevalent 'state of the art' in India, discussed below :-

a) Technical Specifications prescribed in the Tender :

Sr. No.	Specifications	Remarks
i)	VOD (Unconfined) (fresh and after sleepage)	Corresponding "Diameter' not specified nor its relationship with critical diameter, which are critically relevant factors of non-ideal detonation behavior.
ii)	Density (fresh and after sleepage)	
iii)	Absolute Weight Strength; Relative Weight Strength; Absolute Bulk Strength, Relative Bulk Strength.	These energy factors at best, if at all, are deemed to be relevant only for cap-sensitive explosives. Even here, there is an open question mark (?) whether the small test sample of 10 g is adequate enough to truly reflect the actual EOS of the cap-sensitive formulation, let alone the booster sensitive ANEs.
iv)	Booster Sensitivity (fresh and sleepage),	
v)	Water proof-ness, and applicability for explosives	
vi)	Powder Factor (PF) (kg / cu.m) as the prescribed energy factor for blast design: • Mine-wise 'bench mark' powder factors, separately for coal and over burden, prescribed for acceptance by the bidders. • Bidders shall confirm that the explosives supplied by them shall achieve the bench mark PFs, and failure to do so shall attract penalty.	As illustrated in Box -3, PF as a defining energy factor is a retrograde consideration, to say the least, for blast design with ANEs.
vii)	Supportive Technical Services, viz, Random sample tests and Delivery performance, during the pendency of the contract, as follows:-	Apart from periodic confirmation of VOD (un-confined) required of supplier(s) as prescribed, there is complete absence of requirement of supportive softwares / hardwares engineering services, enabling analytical simulation supported by in-situ measurement of VOD / detonation pressure, etc., inside a blast hole, without which monitoring performance / efficacy of explosive charge in a blast hole for a given situation is not feasible at all. These are given basic requirements as per the best global practices.

Sr. No.	Tests to be conducted	Limiting ranges
1.	VOD (m/sec) (Fresh sample, & after sleepage in water for 24 hrs.)	4000±500 (m/s)
2.	Density (gm/cc) (Fresh sample, & after sleepage in water for 24 hrs.)	1.15±0.05 (gm/cc)
3.	Booster sensitivity (fresh sample, and after sleepage in water for 24 hrs.)	Sample should fire with 100g cast booster.

b) Value of explosives and accessories tendered for two years (2015-2017) :

Sl. No.	Type	Underground Mining. Rs. (crores) (Approx.)	Open-cast Mining. Rs.(crore) (Approx.)
1.	Packaged Explosives	140	370
2.	Bulk Explosives	nil	2740
3.	Blasting Accessories	75	150
	Total	215	3260
	Av. Per year	110	1600

Thus, the value of explosives and accessories, averaged for one year, is around Rs.1700 crores, of which, the 'Bulk Explosives Systems' for open cast mining constitute the majority share (approx. 95 %) and therefore, the focus here.

c) Opportunity Cost (OC) :

OC is an implied financial cost as a measure of prospective financial benefits forgone by not allocating resources towards superior technical specifications / operating procedures that fully take on board the entire gamut of variability of non-ideal detonation behavior, (see Box-3).

A 'back of an envelop' estimate vis-à-vis the CIL Tender, factoring an expenditure of Rs 1600 crores on account of explosives and accessories in one year, implies servicing an 'Operating Cost' towards drilling, blasting and evacuation, of the order of Rs.30,000 crores; and correspondingly, assuming a nominal one percentage point saving achieved in the operating cost @ Rs.300 crores, by virtue of due diligence and allocating appropriate resources towards ensuring superior operating technical specifications including supportive engineering services, represents a very substantial order of financial benefits forgone.

d) Factors deserving due diligence via-a-vis formulation of technical specifications :

i) The empirical test criteria and methods which are proven for NG explosives must be validated for non-ideal detonating explosives;

ii) Significance of 'Sensitization Process' ensuring continuity of detonation at an optimal rate; and in this regard, the relationship between critical diameter (CD) of a formulation vis-à-vis the blast hole diameter, providing adequate margin of safety against failure to deliver optimal VOD / detonation pressure, is extremely important. Correspondingly, the sensitization of the formulation may need to be modified as required.

iii) Matching impedance of the explosive charge (Density x VOD), as configured in a blast hole, closely with that of the rock impedance as far as practically feasible, for maximizing useful utilization of explosive energy towards rock breakage / fragmentation to follow.

3.2 Developing a separate protocol of 'Test Criteria / Methods' for technical Specifications of ANEs

3.2.1 Indian Explosives Rules, 2008

a) A very significant development in recent years is the adoption of UN Model of Classification of Hazardous Goods and the 'Test Criteria and Methods' prescribed in this regard, made effective from 2014 for all commercial explosives under the perview of the Indian Explosives Rules 2008. Under the new dispensation, all high commercial explosives are collectively categorized as UN Class 1 Explosives ; and further sub-classified into six Divisions, depending upon sensitivity and hazard of mass explosion. Important to note in this regard, is that ANEs have been assigned to two distinctive divisions, as follows :-

- Division 1.1 (UN Class 1, Division 1 : Cap-sensitive Emulsions / Water Gel explosives (in the same category as Nitro-compound explosives) which have mass explosion hazard.
- Division 1.5 (UN Class 1, Division 5) : all non cap-sensitive blasting agents which have mass explosion hazard.

Correspondingly, the standard 'Test criteria and Methods' prescribed for determining which of the two classifications would apply are shown in Table below. See Annexure III for more details.

UN Class 1, Division 1	UN Class 1, Division 5
Test Series 1	**Test Series 8**
Test type 1(a) - UN Gap Test (for determining propagation of detonation). **Test type 1(b)** - for determining the effect of heating. **Test type 1(c)** - for determining the effect of under confinement.	**Test type 8(a)** - Thermal stability test for **ANE** **Test type 8(b)** - ANE Gap Test (a shock test to determine sensitivity to intense shock). **Test type 8 (c)** - Koenen test (a test to determine the effect of heating under confinement). **Test type 8 (d)** - Vented pipe tests (to evaluate the suitability for the transport in tanks).

3.2.2 Proposed empirical Test Criteria and Methods towards evolving operational technical specifications of ANEs within the frame work of UN Classification :

a) From the stand point of resolution of the 'non-ideality conundrum' of ANE blasting systems, what is very significant about the prescriptive UN Test Criteria and Methods designed for classification of ANEs, is that the procedure takes a definitive cognizance of the reality of the 'time-dependent' detonation behavior of ANEs, strongly influenced by sensitization process / sensitivity, diameter and confinement of the explosive charge, etc. Upon a closer examination of the prescribed Gap Tests vide Test Series 1 and 8 respectively, and the Koenen Test vide Test Series 8, it appears eminently feasible to adapt these tests for developing an empirical basis for evaluation of 'Relative Ideality (RI)' in terms of performance parameters of various ANE formulations.

b) Following up on the recommendations made in the 2nd edition of this Journal, a two stage modality of procedure is proposed, duly factoring the global developments post-2006, as already discussed

STAGE-I :

It comprises the following phases of evaluation, which are quickly implementable by the Bureau of Indian Standards Institution (BISI), and duly incorporated as a separate chapter in IS 15477 (Part 2) 2008.

Phase-I : Adopt a proven 'Ideal Detonation Code / Program' to simulate Ideal State Detonation of every ANE test sample, on the basis of its physical-chemical composition; that is to say, provide calculated CJ values of VOD (Vcj), Detonation Pressure (Pcj), etc., to serve as 'bench marks' against which to measure RI of ANE formulations.

Phase-II : Adaptation of UN Gap Test and UN Koenen Test protocols, respectively, with provision for continuous measurement of VOD (V) and Detonation Pressure (P) of the detonating explosive charge, and duly conduct a series of tests with Cap-Sensitive and Booster Sensitive formulations, as follows:-

- *Cap-Sensitive ANEs :*

Determining propagation of detonation by following tests vide UN Gap Test, type 1(a).

Test series 1 :

The diameter of the steel tube is altered / varied, whilst keeping constant other physical parameters of the prescribed Test type 1(a) set up, to determine 'Critical Diameter (CD)' representative of the Sensitization Process / Sensitivity, of the specific ANE test sample, indicated by 'no impression' on the witness plate .

Simultaneously, determine threshold charge diameter (Dt), indicated by 'first-time' perforation of the witness plate by the detonating charge, and correspondingly, also measure threshold velocity (Vt) and detonation pressure (Pt), respectively.

Test Series 2 :

Progressively increase diameter of the steel tube to determine charge diameter corresponding to maximum velocity and detonation pressure achieved, viz, measure of V(max), P(max) and matching diameter D(Vmax) for every ANE test sample.

- *Booster Sensitive ANEs :*

  Determining sensitivity to intense shock vide UN Gap Test Type 8(b).

  Test series 1:

  Same test procedure as proposed for cap-sensitive ANEs above, to determine Critical Diameter (CD) and corresponding threshold measure of velocity (Vt) and detonation pressure (Pt), in respect of various ANE formulations.

  Test Series 2 :

  The Test series 1 above, is repeated by adopting the specifications of the steel tube prescribed vide UN Koenen Test, Type 8 (c), in order to simulate 'high strength' confinement condition; the confinement strength of the steel tubing in the regular Gap test is around 30Mpa whilst that of the steel tubing in the Koenen Test is 420Mp. This test series would generate another set of comparable empirical data, viz, CD, threshold velocity (Vt) and pressure (Pt), respectively, in respect of every type of booster sensitive ANE formulations

Phase III:

Finally, to draw up Technical Specifications of ANEs based on relative measure of non-ideality of detonation or RI as the departure from CJ values of Ideal State detonation, indicated below :-

i) Differentiating Technical Specifications :

- Critical diameter (CD); Threshold VOD (Vt) and Diameter (Dt)
- Maximum VOD-Max and Diameter combination, i.e, Vmax and D(Vmax)
- Ratio of CD and D(Vmax)

ii) Differentiating Measure of RI provided by the following ratios with corresponding calculated CJ values :

- Vt)/Vcj x 100(%)
- Pt/Pcj x 100(%)
- Vt/Vmax x 100(%), Vt/Vcj x 100(%)

STAGE-II

Whilst the empirical data generated vide Stage-I does provide a reasonably credible set of differentiating technical specifications useful for selection of ANES appropriate for a given blasting environment, it does, however suffer from an infirmity in that the CJ values of booster sensitive ANEs used for determining RI, are not accurately representative of the non-ideal detonation behavior of relatively less-sensitized formulations/blends; and therefore, consideration of a suitable non-ideal detonation code / program for evaluation of booster sensitive / non-sensitized formulation would be required. The work done at the Swedish Blasting Research Center (SWEBREC) in conjunction with JWL Detonation Code duly incorporating empirical Cylinder Expansion Test data (Figure 1), provides an excellent template for a similar study in India under the aegis of the office of Chief Controller of Explosives in collaboration with BISI, involving all the major constituents of the explosives industry. Visfotak would be keen to offer its services in whichever manner necessary.

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4) 'Predicting detonation velocity of ideal and less ideal explosives via specific impulse' by M H Keshavarz & H R Pouretedal, 2004.

5) 'Gurney Equations' from Wikipedia.

6) 'Determination of the energetic characteristics of commercial explosives using the cylinder expansion test technique' by Sedatr Essen, et al. Swedish Blasting Research Centre (Swebrec) Report 2005.

7) 'Jones-Wilkins Lee Parameters for Civil Explosives', by R Castedo, et al, 2015.

8) 'Kinetic Modeling of Non-Ideal Explosives with Cheeta', by W. Michale Howard, et al.

9) 'Detonation Modelling for the Mining and Quarrying Industries : Use of the NAG Fortran Library', by Martin Braithwaite, 2009.

10) Determination of the JWL Constants for ANFO and Emulsion Explosives from Cylinder Test Data', by Jose A. Sanchidrian, et al, 2015.

11) 'Determination of Detonation Products Equation of State from Cylinder Test : Analytical Model and Numerical Analysis', by Predrag M. ELEK, et al, 2015.

12) 'Controlling Fragmentation ' by Stuart Thomson, 2012.

13) 'A new theory of rock-explosive matching based on the reasonable control of crushed zone', by Leng Zhendong, et al, 2014.

14) 'Design and Implementation of Sensor for Velocity of Detonation Measurement', by Arun D. Tete, et al, 2014.

15) Chapters on 'Theory of Detonation' and 'Single Hole Blasting', respectively, vide book - "Rock Fracture and Blasting by Zong-Xian Zhong".

16) 'Prediction of Detonation Pressure and Velocity of Explosives with Micrometer Aluminium Powders', by Qi Zhang and Yan Chang, 2012.

17) 'The Science of Industrial Explosives', by Melvin A. Cook (1974).

Indian Standard IS15447 (Part-2) 2008
Commercial Blasting Explosives
Part 2, Slurry/Emulsion Explosives - Specification

Annexure - I

- **Requirements of Slurry/Emulsion-Based Commercial Blasting Explosives**

Sl No. (1)	Characteristic (2)	Requirement (3)	Method of Test, Ref to (4)
i)	Air gap sensitivity	For small diameter cartridges (20-32 mm) a) Permitted explosives - Not less than 2cm b) Non-permitted explosives - Not less than 2cm	Clause 3.6 of IS 6609 (Part 2/Sec. 1)
ii)	Velocity of detonation (VOO) (Unconfined) at $25^0C \pm 5^0C$ ambient temp	Permitted – 2.800 m/s. Min Non-permitted – 3.000 m/s. Min	Clauses 3.7 to 3.9 of IS 6609 (Part 2/Sec I) (Micro meter or Dautriche test)
iii)	Power percent *Max*	Non-permitted – 50 - 90 percentage As agreed to between the purchaser and the manufacturer Permitted – P1 : 50 and above P3 : 40 and above P5 : 35 and above	Clause 3.11 of IS 6609 (Part 2/Sec. 1)
iv)	Water proofness test (Small dia and large dial)	To pass the test (when tested at 24 h)	Annex. A
v)	Impact sensitivity with 10 kg load from a Distance of 1.1 m	No detonation in 10 tests	Clause 3.4 of IS 6609 (Part 2/Sec. 1)
vi)	Thermal stability test	To pass the test at 75^0C for 48 h	Annex. B
vii)	Sensitivity to initiation	No.6/8 Detonator (for permitted explosives) Detonator/Booster (for non-permitted explosives)	Clause 4.0 of IS 6609 (part 21 Sec. 3)
viii)	Gallery test	a) PI : Series I - 13/26 Series II - Nil/5 Series III - Nil/5 b) P3 : Series 1-13/26 Series II - Nil/5 Series III - Nil /5 c) P5 : Series I - Nil/20 Series II - Nil/5 Series III - Nil/5	IS 6609 (Part 2/Sec. 2)
ix)	Continuity of detonation (COD) [small dial]	To pass the test	IS 6609 (Part 2/Sec 2)
x)	Density g/cm^2	0.8 - 1.35	Annex. C
xi)	Size of cartridges	± 2 percent tolerance	
xii)	Shelf life *Min*	6 months	Clause 3.6 of IS 6609 (Part 2/Sec. 1)
xiii)	Deflagration for P5 permitted explosives	Not more than 1 cm	IS 6609 (Part 2/Sec. 2)

- **General Tests Procedures for Strength (Power) of Explosives vide IS6607 (Part-2) 1973**

Ballistic Mortar Method

General - The strength or power of a high explosive is determined by measuring the angle of recoil produced by a 10g charge of the explosive fired in a Dupont ballistic mortar and is expressed as a percentage of polar blasting gelatine.

Trauzl Lead Block Method

General - The lead block test is carried out by firing a weighed quantity of an explosive in an axial cavity made in a cylindrical lead block. The increase in the volume of the cavity is measured and the result of the test is expressed as millilitre enlargement per gram of the explosive.

Detonator Insensitive Explosive (Ballistic Mortar Method)

General - In case of detonator insensitive explosives: the method of power measurement consists of mixing different proportion of sensitizer such as PETN, polar blasting gelatine, etc., with the explosive and firing 10g charges of the mixed explosive in the ballistic mortar. The angle of recoil of the mortar obtained with different proportions of sensitizer in the explosive or the corresponding power values are plotted on a graph paper and the plot (angle of recoil or power values *versus* percentage of sensitizer) is extrapolated to zero sensitizer. From this, the power of the explosive without sensitizer can be determined.

Detonation Phenomena of Commercial Explosives

Annexure - II

CHRONOLOGY

1930's: Thermo hydrodynamic theory of detonation or Chapman-Jouget (CJ) 'Ideal State' postulate of detonation.

1940/1950's: Generalization of the CJ postulate for condensed explosives :

- Zeldovic, Von Neuman and Doring (ZND), 1940's
- Melvin A Cook, 1950's

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1981: Steady State two - dimensional detonation: a generalization of WK analysis .Bdzil J.B.

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1998/2001: Howard W.M, Fried L.E, Souers P.C,: Kinetic Modelling of Non-Ideal explosives with CHEETAH:, and Calculation of Chemical Detonation waves with Hydrodynamics and Thermo-chemical Equation of State.

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2005: Swedish Blasting Research Centre (Swebrec) Report - 2005 : Determination of the Energetic Characteristics of Commercial Explosives using the Cylinder Expansion Test techniques.

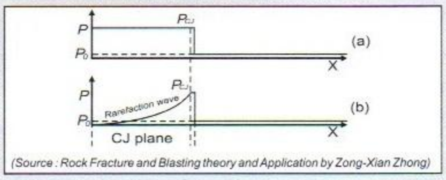
2012: Cheeta 8.0 Detonation Code: the current updated computer thermo-dynamic code that can reliably predict the performance of ideal and non-ideal explosives formulations. 2012

2015: Jones-Wilkins-Lee (JWL) Non-ideal detonation model / Equation of State (EOS) : Determination of JWL Constants for ANFO and Emulsion Explosives from Cylinder Test Data: Jose A. Sanchidrian, et al. 2015.

TRANSITION FROM IDEAL TO NON-IDEAL STATE

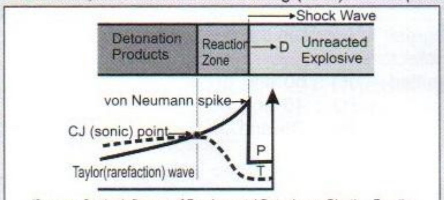
a) Ideal Detonation :

- *Chapman-Jouget (CJ) Model (1930s)*



(Source : Rock Fracture and Blasting theory and Application by Zong-Xian Zhong)

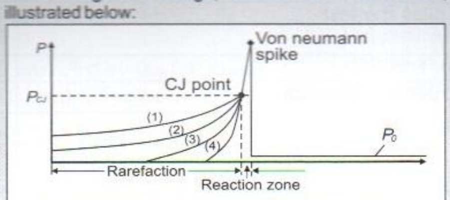
- *Zeldovic, Von Neuman and Doring (ZND) model (1940s)*



(Source : On the Influence of Fundamental Detonics on Blasting Practice by A Minchinton)

The ZND Model, makes a significant departure, by recognizing the fundamental reality of a 'finite rate of thermo-chemical reaction', and duly, incorporated a finite time 'Reaction Zone', as shown, a remarkable prescience contributing to solutions to non-ideal detonation in later years.

The ZND model envisaged the detonation process to consists of initial starting phase of an infinitely thin shock wave that compresses the explosive to a high pressure called the 'von Neumann spike' and only after the spike point reached, does the exothermic chemical reaction starts, and the flow of detonation products between the final state and the rear boundary is a time dependant rarefaction wave, influenced by size/length of explosive charge, burden and confinement, influenced by size / length of charge, burden and confinement, illustrated below:

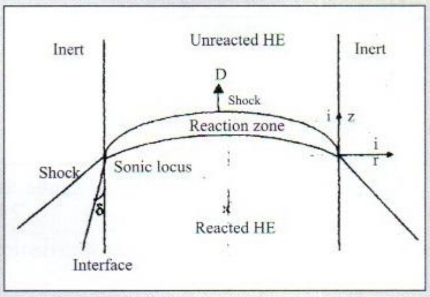


(Source : Rock Fracture and Blasting by Zong-Xian Zhong)

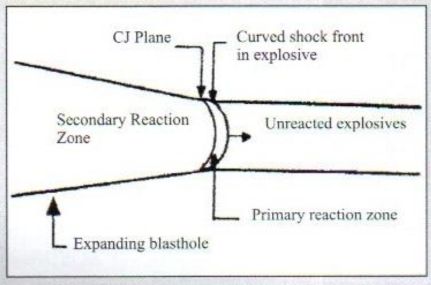
Curve 1 shows the highest confinement, and curve 4 shows the least; recharge length effect, curve 1 gives the longest charge, and curve 4 gives the shortest; and re. burden effect, curve 1 shows the maximum burden, and curve 4 shows the smallest.

b) Non-Ideal Detonation :

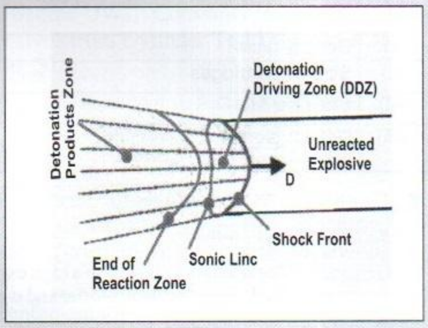
- *A schematic Representation of a two - dimensional steady-state detonation (Bdzil, 1981)*



- *Features of non-ideal detonation process (Brinkmann, 1990)*



- *Non-Ideal (two-dimension) detonation (Byers Brown, 2002)*



c) Ideal vs. Non-Ideal detonics :

Sr. No.	Properties	Ideal	Non Ideal
1.	Reaction rate	Almost instantaneous	Finite reaction rate
2.	Velocity of Detonation (D)	Dcj (maximum velocity at CJ point	<Dcj
3.	Lateral Expansion	No	Yes
4.	Shock wave front	Planar one-dimensional	Curved, multi-dimensional
5.	Energy Release	Chemical reaction is completed, and the full energy is released within the detonation driving zone (DDZ) / Reaction Zone.	Chemical reaction is not completed within DDZ / Reaction Zone, and most of the energy is released behind the Reaction Zone during the rarefaction wave phase.

Ref. : UN Model Regulations on Transport of Dangerous Goods and the Manual of Test Criteria and Methods Relating to Explosives of Class 1

Annexure - III

The "Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria" supplement the "Recommendations on the Transport of Dangerous Goods, Model Regulations" and the "Globally Harmonized System of Classification and Labeling of Chemicals (GHS)". They contain criteria, test methods and procedures to be used for the classifications of dangerous goods according to the provisions of Parts 2 and 3 of the Model Regulations, as well as of chemicals presenting physical hazards according to the GHS.

Test Methods and Criteria Relating to Explosive Class 1

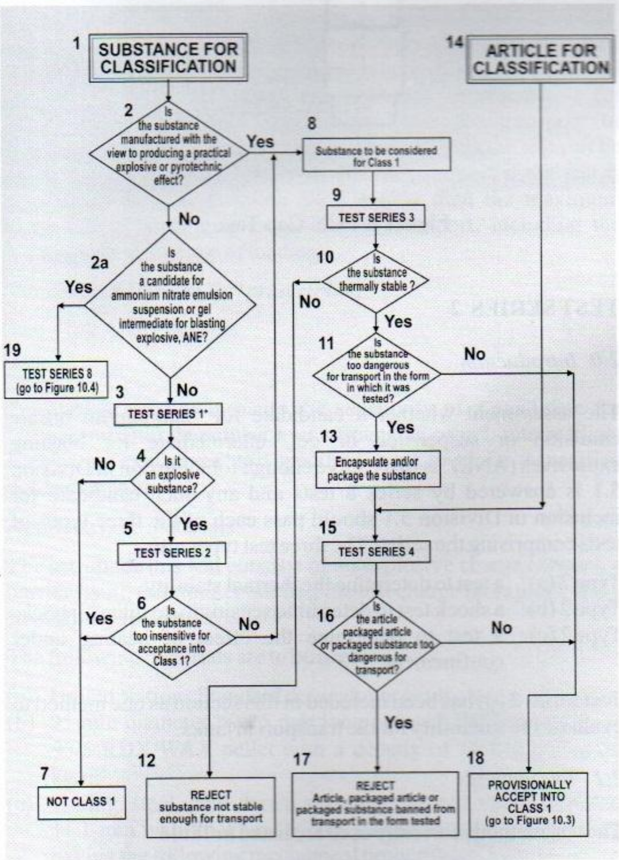


Figure 1 - Procedure for Provisional Acceptance of a Substance or Article in Class 1

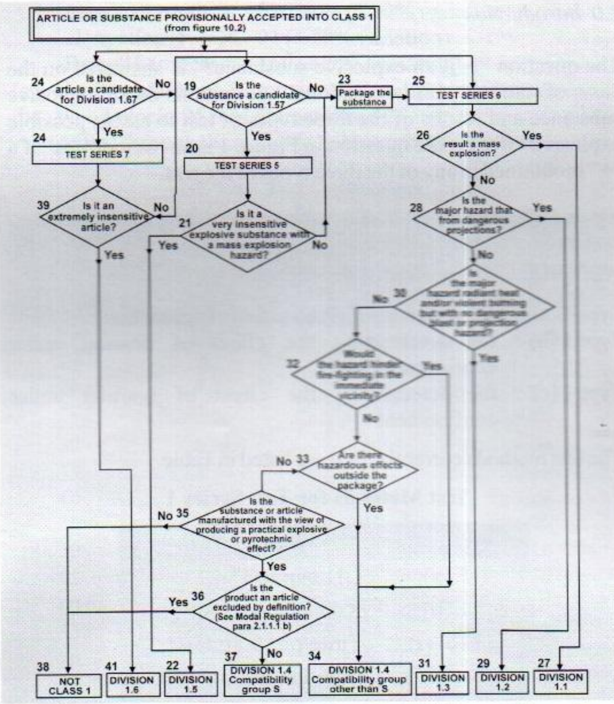


Figure - 2- Procedure for Assignment to a Division of Class 1

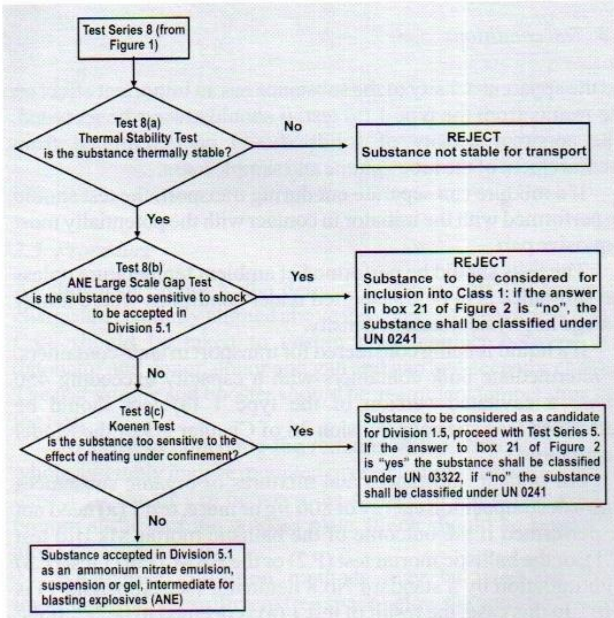


Figure 3 - Procedure for Ammonium Nitrate Emulsion, Suspension or Gel, Intermediate for Blasting Explosive

TEST SERIES 1

1.0 Introduction

The question "Is it an explosive substance?" is answered on the basis of national and international definitions of an explosive substance and results of the three types of test to assess possible explosive effects. The question in Figure 1 is answered "yes" if a "+" is obtained in any of the three types of the test.

1.2 Test methods

Test Series 1 is comprised of three types of test:

Type 1 (a) : for determining propagation of detonation;
Type 1 (b) : for determining the effect of heating under confinement; and
Type 1 (c) : for determining the effect of ignition under confinement

The test methods currently used are listed in Table

Test Methods for Test Series 1

Test code	Name of Test
1 (a)	UN gap test*
1 (b)	Koenen test*
1 (c) (i)	Time/pressure test*
1 (c) (ii)	Internal ignition test

**Recommended test*

1.3 Test conditions

As the apparent density of the substance has an important effect on the results from the type 1 (a) test, it should always be recorded. The apparent density of solids should be determined from measurement of the tube volume and sample mass.

If a mixture can separate out during transport, the test should be performed with the initiator in contact with the potentially most explosive part.

The tests should be performed at ambient temperature unless the substance is to be transported under conditions where it may change its physical state or density.

If a liquid is being considered for transport in tank-containers, or intermediate bulk containers with a capacity exceeding 450 litres, a cavitated version of the type 1 (a) test should be performed (see special provision 26 of Chapter 3.3 of the Model Regulations).

For organic substances and mixtures of organic substances with a decomposition energy of 800 J/g or more, test 1 (a) need not be performed if the outcome of the ballistic mortar Mk.IIId test (F.1), or the ballistic mortar test (F.2) or the BAM Trauz1 test (F.3) with initiation by a standard No.8 detonator (see Appendix 1) is "No". In this case, the result of test 1 (a) is deemed to be "-". If the outcome of the F.1 or F.2

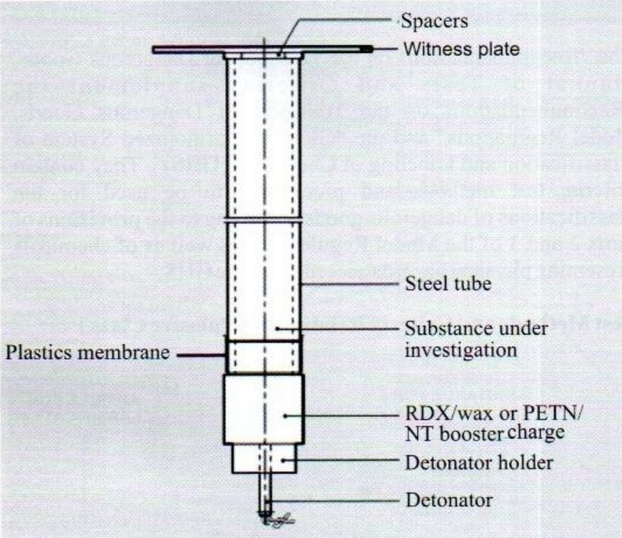


Figure 4 - UN Gap Test

TEST SERIES 2

2.0 Introduction

The assessment whether a candidate for "ammonium nitrate emulsion or suspension or gel, intermediate for blasting explosives (ANE)" is insensitive enough for inclusion in Division 5.1 is answered by series 8 tests and any such candidate for inclusion in Division 5.1 should pass each of the three types of tests comprising the series. The three test types are:

Type 2 (a): a test to determine the thermal stability;
Type 2 (b): a shock test to determine sensitivity to intense shock;
Type 2 (c): a test to determine the effect of heating under confinement;

Test series 2 (d) has been included in this section as one method to evaluate the suitability for the transport in tanks.

2.1 Test methods

The test methods currently used are listed in Table

Test Methods for Test Series 8

Test code	Name of Test
8 (a)	Thermal Stability Test for ANE [a]
8 (b)	ANE Gap Test[a]
8 (c)	Koenen test[a]
8 (d)	Vented pipe tests[b]

[a]*This test is intended for classification.*
[B]*these tests are intended for evaluating the suitability for transport in tanks.*

2.2 Test conditions

The substance should be tested as offered for transport, at the highest transport temperature.

2.3 Series 8 Type (a) test prescription

Test 8 (a): Thermal stability test or ammonium nitrate emulsions, suspension or gels.

Introduction

This test is used to measure the stability of a candidate for "ammonium nitrate emulsion, suspension or gel, intermediate for blasting explosives" when subjected to elevated thermal conditions to determine if the emulsion is too dangerous to transport.

This test is used to determine whether the emulsion, suspension or gel is stable at temperatures encountered during transport. In the way this type of test is normally carried out (see 28.4.4), the 0.5 litre Dewar vessel is only representative for packagings, IBC's and small tanks. For the transport of ammonium nitrate emulsions, suspensions or gels the test can be used to measure its stability during tank transport if the test is carried out at a temperature 20°C higher than the maximum temperature which may occur during transport, including the temperature at the time of loading.

2.4 Series 8 Type (b) Test prescription

Test 8 (b): ANE Gap Test

Introduction

This test is used to measure the sensitivity of a candidate for "ammonium nitrate emulsion or suspension or gel, intermediate for blasting explosives" to a specified shock level, i.e. a specified donor charge and gap.

Apparatus and materials

The set-up for this test consists of an explosive charge (donor), a barrier (gap), a container holding the test charge (acceptor), and a steel witness plate (target).

The following materials are to be used:

(a) United Nations Standard detonator or equivalent;
(b) 95 mm diameter by 95 mm long pressed 50/50 pentolite or 95/5 RDX/WAX pellet with a density of 1600 kg/m^3 ± 50 kg/m^3;
(c) Tubing, steel, cold drawn seamless, 95 mm outer diameter, 11.1 mm wall thickness ± 10% variations, by 280 mm long having the following mechanical properties:
 - tensile strength = 420 MPa (± 20% variation)
 - elongation () = 22 (± 20% variation)
 - Brinell hardness = 125 (± 20% variation)
(d) Sample substances, with a diameter which is just under the inner diameter of the steel tubing. The air gap between the sample and tubing wall should be as small as possible;
(e) Cast polymethyl methacrylate (PMMA) rod, of 95 mm diameter by 70 mm long. A gap length of 70 mm results in a shock pressure applied to the emulsion somewhere between 3.5 and 4 GPa, depending on the type of donor used (see Table below.
(f) Mild steel plate, 200 mm x 200 mm x 20 mm, having the following mechanical properties:
 - tensile strength = 580 MPa (± 20% variation)
 - elongation () = 21 (± 20% variation)
 - Brinell hardness = 160 (± 20% variation)
(g) Cardboard tubing, 97 mm inner diameter by 443 mm long;
(h) Wood block, 95 mm diameter and 25 mm thick, with a hole drilled through the centre to hold the detonator.

ANE Gap Test Calibration Data

PENTOLITE 50/50 DONOR		RDX/WAX/GRAPHITE DONOR	
Gap length (mm)	Barrier pressure (GPa)	Gap length (mm)	Barrier pressure (GPa)
10	10.67	10	12.53
15	9.31	15	11.55
20	8.31	20	10.63
25	7.58	25	9.76
30	6.91	30	8.94
35	6.34	35	8.18
40	5.94	40	7.46
45	5.56	45	6.79
50	5.18	50	6.16
55	4.76	55	5.58
60	4.31	60	5.04
65	4.02	65	4.54
70	3.53	70	4.08
75	3.05	75	3.66
80	2.66	80	3.27
85	2.36	85	2.91
90	2.10	90	2.59
95	1.94	95	2.31
100	1.57	100	2.04
		105	1.81
		110	1.61
		115	1.42
		120	1.27

2.5 Procedure

As shown in Figure 5, the detonator, donor, gap and acceptor charge are coaxially aligned above the centre of the witness plate. Care should be taken to ensure good contact between the detonator and donor, donor and gap and gap and acceptor charge. The test sample and booster should be at ambient temperature for the test.

To assist in collecting the remains of the witness plate, the whole assembly may be mounted over a container of water with at least a 10 cm air gap between the surface of the water and the bottom surface of the witness plate which should be supported along two edges only.

Alternative collection methods may be used but it is important to allow sufficient free space below the witness plate so as not to impede plate puncture. The test is performed three times unless a positive result is observed earlier.

2.6 Test criteria and method of assessing results

A clean hole punched through the plate indicates that a detonation was initiated in the sample. A substance which detonates in any trial at a gap length of 70 mm is not to be classified as "ammonium nitrate emulsion or suspension or gel, intermediate for blasting explosives" and the result is noted as "+".

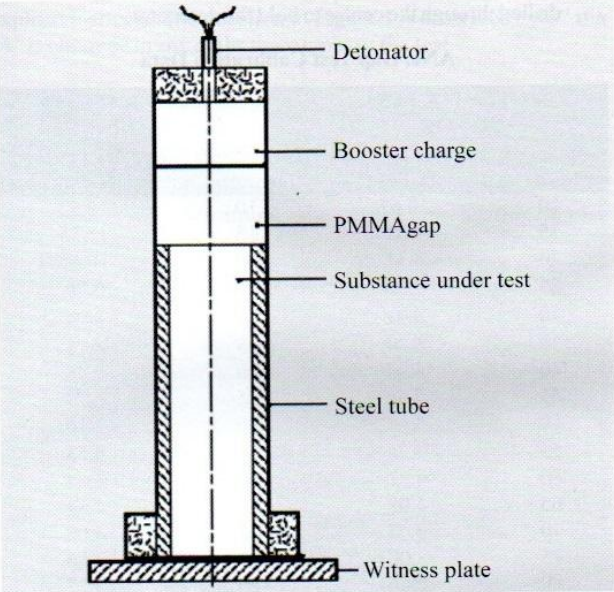


Figure 5 - ANE Gap Test

2.7 Examples of results

Substances	Density g/cm^3	Gap mm	Result	Comments
Ammonium nitrate (low density)	0.85	35	-	Tube fragmented (large fragments) Plate bent VOD 2.3-2.8 km/s
Ammonium nitrate (low density)	0.85	35	-	Tube fragmented (large fragments) Plate fractured
ANE-FA Ammonium nitrate 69%, Sodium nitrate 12%, Water 10%, Fuel/emulsifier 8%	1.4	50	-	Tube fragmented (large fragments) Plate not perforated
ANE-FA	1.44	70	-	Tube fragmented (large fragments) Plate not perforated
ANE-FB Ammonium nitrate 70%, Sodium nitrate 11%, Water 12%, Fuel/emulsifier 7%	ca 1.40	70	-	Tube fragmented (large fragments) Plate not perforated
ANE-FC (sensitized) Ammonium nitrate 75%, Water 13%, Fuel/emulsifier 10%	1.17	70	+	Tube fragmented (fine fragments) Plate perforated
ANE-FD (sensitized) Ammonium nitrate 76%, Water 17%, Fuel/emulsifier 7%	ca 1.22	70	+	Tube fragmented (fine fragments) Plate perforated

Substances	Density g/cm^3	Gap mm	Result	Comments
ANE-I Ammonium nitrate 76%, Water 17%, Fuel/emulsifier 7%	1.4	35	-	Tube fragmented into large pieces. Plate dented VOD: 3.1 km/s
ANE-2 (sensitized) Ammonium nitrate 76%, Water 17%, Fuel / emulsifier 7%	1.3	35	+	Tube fragmented into small pieces Plate perforated VOD: 6.7 km/s
ANE-2 (sensitized) Ammonium nitrate 76%, Water 17%, Fuel / emulsifier 7%	1.3	70	+	Tube fragmented into small pieces Plate perforated VOD: 6.2 km/s
ANE-GI Ammonium nitrate 74%, Sodium nitrate 1%, Water 16%, Fuel/emulsifier 9%	1.29	70	-	Tube fragmented Plate indented VOD 1 968 m/s
ANE-G2 Ammonium nitrate 74%, Sodium nitrate 3%, Water 16%, Fuel/emulsifier 7%	1.32	70	-	Tube fragmented Plate indented
ANE-G3 (sensitized by gassing) Ammonium nitrate 74%, Sodium nitrate 1%, Water 16%, Fuel/emulsifier 9	1.17	70	+	Tube fragmented Plate punctured
ANE-G4 (sensitized by microballoons) Ammonium nitrate 74%, Sodium nitrate 3%, Water 16%, Fuel/emulsifier 7%	1.23	70	+	Tube fragmented Plate punctured
ANE-G5 Ammonium nitrate 70%, Calcium nitrate 8%, Water 16%, Fuel/emulsifier 7%	1.41	70	-	Tube fragmented Plate indented VOD 2 061 m/s
ANE-JI Ammonium nitrate 80%, Water 13%, Fuel/emulsifier 7%	1.39	70	-	Tube fragmented Plate indented
ANE-J2 Ammonium nitrate 76%, Water 17%, Fuel/emulsifier 7%	1.42	70	-	Tube fragmented Plate indented
ANE-J4 Ammonium nitrate 71%, Sodium nitrate 11%, Water 12%, Fuel/emulsifier 6%	1.40	70	-	Tube fragmented Plate indented
ANE-J5 (sensitized by microballoons) Ammonium nitrate 71%, Sodium nitrate 5%, Water 18%, Fuel/emulsifier 6	1.20	70	+	Tube fragmented Plate perforated VOD 5.7 km/s
ANE-J6 (sensitized by microballoons) Ammonium nitrate 80%, Water 13%, Fuel / emulsifier 7%	1.26	70	+	Tube fragmented Plate perforated VOD 6.3 km/s

MANUFACTURING OF WORLD CLASS TECHNICAL AMMONIUM NITRATE (TAN) IN INDIA : A PERSPECTIVE

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1.0 Introduction

Deepak Fertilisers & Petrochemicals Corporation Limited (DFPCL)is the only manufacturer of Technical Ammonium Nitrate (TAN) - a key ingredient to the mining and explosives industry, in India. DFPCL has a total installed manufacturing capacity of 4,69,000 MTPA from its plants at Taloja in Maharashtra and Srikakulam in Andhra Pradesh. Its world-class range of TAN products caters to the mining, infrastructure and pharmaceutical sectors.

DFPCL is the only company to have adopted the four eminent Technical Ammonium Nitrate manufacturing know-how and technologies in the world, viz. Stamicarbon (Netherlands), Grande Paroisse (France), Norsk Hydro (Sweden) and Uhde (Germany), guaranteeing consistent supply of better quality, thermally stabilised and free flowing, (both Low and High Density) Ammonium Nitrate. This paper revolves around the World Class Practices at Plant / Personnel being adopted by DFPCL.

2.0 Systematically Designed & Managed Process

The Ammonium Nitrate and Nitric acid complex of DFPCL is located at Taloja, Navi Mumbai. Taloja Industrial area is governed by Maharashtra Industrial Development Corporation and holds the common facilities like Common Effluent Treatment plant, Solid Hazardous Waste Handling etc.

During the last three decades, DFPCL has absorbed world class process technologies for operations of all it plants at Taloja and East Coast of India. Majority of them include Ammonium Nitrate and Nitric acid manufacturing facilities.

Plant & facilities	Capacity (TPD)	Process Licensor
Weak Nitric Acid Plant	2100	3 plants of Weatherly make 1350 MTPD
Ammonium Nitrate Prilled AN and AN Melt	1420	2 plants of UD, Germany 750 MTPD Plant1 - Stamicarbon 400 TPD Plant2- UD Technology 600 TPD Plant3- GPN Technology 300 TPD Plant4- Norsk Hydro prc 120 TPD

DFPCL is in Ammonium Nitrate and Nitric Acid operation for the last 24 years. The latest facility of TAN (Technical Ammonium Nitrate) has been commissioned in 2010 and has been operating effectively with the support of professionally qualified personnel.

The manufacturing unit comprises 900 MTPD ammonium nitrate production and handling facility out of which Low Density prill of 600 MTPD and High Density prill of 300 MTPD can cater to both domestic and international market.The nitric acid requirement is met from the Weak Nitric Acid production unit of 750 MTPD, based on Weatherly design.

The complex is also built in with supportive Utility facilities such as High Pressure & Medium Pressure Boiler, DM plant, Gas Turbines to generate captive power, Waste Heat recovered Steam Generation unit, Cooling Tower & Effluent Treatment Unit.

Ammonia requirement is fulfilled through in-house production facility at Taloja as well as through import, for which the company has its own storage and handling facility at Jawaharlal Nehru Port Trust area.The operation control is highly automated and is monitored by the competent personnel through DCS operating logic.

Processes are well documented in reference to the guidelines available from Process Licensor as well as OEM guidelines/Operating and Maintenance manual. Their application are quite standardised through systematic training plan of the operating executives.

2.1 Facility, Experienced Team & Product

With world class facility, experienced team and controlled process, DFPCL has developed Ammonium Nitrate brands of various grades for optimum performance, tailor-made to the customer needs the specialized products are :

- **OPTIMEX** Coated Ammonium Nitrate for HANFO / ANFO blasting and doping of bulk explosives.
- **OPTIFORM** Ammonium Nitrate in uncoated form, preferred by makers of Emulsions &Slurry Explosives.
- **OPTISPANA** chemically pure grade of Ammonium Nitrate, for the pharmaceutical / nitrous oxide industries.

The portions (1) & (2) can be shifted under previous sections. They are not related to products and are related to planning and design, and process.

3.0 Complying National and International Standards

In the process of TAN manufacturing, DFPCL promotes the use of norms and standards, for Integrated System Management based on ISO 9001, ISO 14001 & BS - 18001 standards. DFPCL also monitors tracking of products through SAP- ERP system for:

1. In process quality monitoring and assurance
2. Specified quality parameters

The company has a high end Quality Control Laboratory equipped with Karl Fischer moisture analyser, Thermo Fischer Spectrophotometer, Licensor recommended Friability analyser, and Crushing Strength evaluator; where all the analytical processes conform to ASTM, BIS or Licensors specific standard.

3.1 pH Analyzer:

pH analysis is carried out for in-process samples as well as finished products. This is one of the process safety parameters which facilitates the operational control and is important from the aspect of process efficiency.

For PH measurement by PH Meter which is accurate and provision of calibration while checking PH UHDE UAN 01-1409 A.11.11.01 **:** *Our specification 4.8 min.*

3.2 Karl Fisher Moisture Analyzer :

This internationally recommended instrument is used to evaluate the moisture content in the ammonium nitrate prill with accuracy. The moisture content is important to establish the product retaining its free flowing characteristics, as well as its primary link with other characteristics such as bulk density, oil absorption and coating effectiveness.

Moisture analysis is carried out by Karl fisher method as recommended by licenser Stami-carbon analytical method DSM 805-B2 & UHDE UNA 01-1409 A.11.04.01, for moisture analysis the company uses Mettler make KF Instrument which is used internationally **:** *Our specification 0.15% max.*

3.3 Friability (after thermal cycling) Analyzer :

This process licensor recommended instrument is used to assess the thermal stability of the finished product, before and after its exposure to controlled thermal cycling. This ultimately determines the wear resistance and thermal properties of the product.

Friability after thermal cycling of prills also known as the thermal stability test means the resistance of prills to abrasion after cycling between 15 and 45° C four times. The method tries to stimulate the temperature ranges experienced by prill during handling and storage. The prill is kept for 4 hours at 15° C then heated to 54° C then cooled back to 15° C. Granules go through transition point two times, one time from phase IV to phase III and one time from phases III to IV. This cycle is repeated four times and the prill then rotated in friability apparatus with 50 steel balls. The weight of abraded fines passing through 1 mm screen is determined

- 15° C 4 hrs.
- Temperature ramp 15° C at 0.25° C per minute (total 2 hrs)
- 45° C. for 4 hrs.
- Temperature ramp 45° C to 15° C at 0.25 deg C per minute (total 2 hrs.)
- Repeat this temperature program four times.
- Find friability

Instrument used Low temperature incubator specially made for this purpose **:** *Our specification < 20%*

3.4 Oil Absorption :

This process licensor recommended method indicates the porosity of the prills and helps in establishing in-process control so that the desired level of oil absorption is achieved in the finished prills. Oil absorption characteristic is essential for oxygen balance in the ANFO manufacturing process.

Diesel fuel oil is used along with ammonium nitrate to make explosive, for the determination of the fuel oil absorption of LDAN the sample is soaked in fuel and then excess oil is wiped off and the amount of oil retained is determined by the increase in weight of the sample test method as recommended for Stami-carbon analytical test method DSM-AGRO-1071-E and UHDE UAN 01- 1409 A.11.09.04.

Some other manufacturer's diesel oil absorption by vacuum method gives 1-2% higher values as compared to the above test method; our specification is 8% min.

3.5 Crushing Strength Monitor :

This process licensor recommended method is used to assess the static/ mechanical strength of the final product, which is an indicator of the product strength and its characteristics to overcome the pressure effect during storage/transit.

Crushing strength by recommended for Stami-carbon analytical test method DSM-AGRO-1031E and UHDE UAN 01- 1409 A.11.22.01 **:** *Our specification 0.4 kg /prill min.*

3.6 Wear Resistance Test :

By Stami-carbon analytical test method N88 2483 is called wear resistance by Udhe UAN 01- 1409 A.11.23.02 it called as friability meaning is same the resistance of prill to abrasion : *our specification - wear resistance is above 90% (before friability < 5%).*

All the test procedures are well documented. All the test results are recorded in SAP system which are available on - line for the users. Final products are analyzed to ensure conformation to product specifications. Only products meeting the specifications are certified for dispatch. To take care of Customer Complaints if any, the company has a well laid down a re-dressal system, where the complaints are investigated and corrective actions are taken for compliance.

4.0 Sustainability of Excellence

4.1 Operational Excellence

- Integrated Management System audits (internal and external)
- Fire & Safety Audits (internal and external)
- Compliance Audit (internal and external for regulatory and legal fulfilments)
- Training is facilitated as part of the staff skill development programme.
- Well documented and approved Onsite and Offsite Emergency plan is laid down to Implement and measure the effectiveness of deployed EHS Culture.
- Implementing the learnings of safety practices & best operational control system of AN-plants all over the world by attending ANNA-Conference, through SAFEX-Publication, by following the best practices of EFMA-guidelines on AN-Manufacturing, storage & handling.

4.2 TAN security

The security during the manufacturing as well as transportation process, prevention and protection of unintended use has been implemented, monitored and complied through the applicable National Regulation "AN Rule 2012". The rule enforces specific restrictions on plot plan, boundary barrications, working floor height, deployment of police verified personnel, CCTV monitoring, allotment of unit identification number to each pack of product, tracking through bar coding and GPS monitoring as well as updated MIS maintenance and timely submission to Govt Authorities.

Through its stringent EHS practices, standard operating system and procedure, and strive for sustaining operational excellence, the company has obtain ISO 9001, 14001 & BS-18001 certificates. The EHS statistics are well maintained through daily monitoring, periodical inspection & audits, employee involvement as well as promotional & motivational activities.

To sustain the environment friendly status, the effluent generated in the Ammonium Nitrate manufacturing process is consumed by the absorber of weak nitric acid plant or recycled to AN evaporator for minimising the effluent generation.

4.3 Effluent Treatment Plant

Most of the effluent generated is consumed in the absorber of weak nitric acid plant or recycled to AN evaporator for minimising the effluent generation.

Left out effluent from different units is taken into Collection Tank, aerated and stripped after pH correction to remove free NH3. Further in the de-nitrification system, Nitrate is removed by biological treatment through especially cultured anoxic bacteria where NO_3 is converted to N_2.

4.4 Hazardous Waste Disposal

The hazardous waste generated (used oil, waste residue containing oil, discarded containers, used oil filter of non-metallic type and spent catalyst) in the premises is disposed by the MPCB/CPCB authorised agent. By complying national and international norms and standards, the company is committed to take care of the interest of all stakeholders.

5.0 Safe Storage & Handling Practices

DFPCL offers the packing size in 3 to 4 variants such as 25 kg, 50 kg, 1 MT and 1.2 MT - depending on the customer requirement as well as logistic need. Moreover, the company has invested in auto bagging facility for better up-time as well as bar coding facility to ensure each bag being facilitated with a unique identification no. for complying the safe distribution with the domestic as well as international market.

The ability to load 1500 MTPD is carried out through direct truck loader, break bulk loading through EOT, container loading through forklift using Cascade make push & pull attachment.

A Safety Management System (SMS) covering Policy, Framework, Training & Practices, Risk assessment criteria, MSDS Management, Emergency Response, Evacuation Guidelines, Security system & personnel Management, Fire Fighting considerations, Housekeeping methodology and Movements of Inventories catering to the health and safety of the community, employees, property and the environment is in place at storage facilities in compliant with local regulations and company policy. The system is also applicable to all employees at the facilities.

Since the AN carries the potential to form an explosive mixture on addition of certain ingredients, it AN Rule 2012 came into force in India. Manufacturing, possession for sale, bagging, transportation as well as export falls under the purview of AN Rule 2012.

UN Certification which is primarily confined to export of dangerous goods is also applicable to TAN. Therefore, due care is taken that packaging to ensures materials are made with adequate strength to withstand substantial variations in temperature, pressure, humidity and vibration during the transportation process. The inner liner of each bag is of 100 micron thickness considering negligible water permeability through it. These are heat sealed to completely isolate from ambient moisture. Due testing and certification compliances from Indian Institute of Packaging are timely carried out and well documented. After satisfactory performance of the sample packaging, a Certificate is issued by the Indian Institute of Packaging to the manufacturer of packaging material for manufacturing.

The packaging certified for utilisation of transporting Dangerous Goods by air/sea are cross checked by the shippers before being actually used for the purpose. The certified packaging shall have UN marking as indicated in the Certificates and rightly legible (printed or embossed only on the package), as only the certified packaging are loaded on the ship.

CSIR-CIMFR CONTRIBUTIONS FOR BLASTING & PRODUCTIVIY IMPROVEMENT IN MINES AND CIVIL INFRASTRUCTURAL PROJECTS

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A) Blast Optimisation

- Site specific blast design
- Measurement of input & output parameters

  i. Specific drilling
  ii. Specific explosive consumption

- Optimum fragmentation based mine characteristic curve

  i. Fragmentation measurements by Wipfrag/ Fragalyst
  ii. Shovel performance
  iii. Dumper performance
  iv. Crusher performance
  v. Determination of optimum fragment size

- Quantification of productivity improvement in terms of time and cost savings

B) Controlled Blasting

- Presplitting
- Smooth blasting
- Cushion blasting
- Bottom hole initiation system
- Electronic delay detonation
- In-hole delay cut method
- Bottom decking method

C) Controlled Blasting at Kalpakkam Nuclear Power Project:

i. The use of bottom hole initiation systems like shock tubes in conjunction with Noiseless Trunk Line Delays (NTLD) to control the vibration, noise/air blast and flyrock to the allowable levels.
ii. Use of sufficient delay sequence and presplitting to reduce vibration intensity and back break
iii. Use of blasting mats to control the flyrock and noise/airblast

D) Special Blasting Techniques Improved and Applied by CSIR-CIMFR

i. Urban Blasting for metro rail construction projects
ii. Underwater blasting for sea/river bed deepening and widening

  a. Specialised seismic explosive/seismic detonators high density explosive
  b. Couplable Plastic Tube (CPT) explosive are used for charging of underwater holes
  c. Strength of explosive was 90% and Velocity of Detonation was 5000m/s.
  d. Nonel shock tube initiation was used with 25m delay to each hole.
  e. The blastholes used to be stemmed with coarser sand.
  f. Delay arrangements: 17 ms hole to hole delay and 42 ms row to row.
  g. The charge diameter was 65 mm and the total hole depth was 4-5m and in rock it was varying from 1.75-2 m.
  h. Hole-to-hole delay initiation was carried out to get better fragmentation and to reduce maximum charge per delay for reducing intensity of vibrations.

iii. Demolition Blasting for removal of civil structures (abandoned, old, illegal etc).
iv. Break through rock-plug blasting for lake tapping at Modaksagar water supply tunnel project.

  a. Proper Geological and geotechnical characterization of rock plug and parent.
  c. Length of Intake Tunnel.
  d. Muck Pit design.
  e. Plug Thickness.
  f. Rock characterization.
  g. Controlled blast design.
  h. Execution of blasting.

v. Longhole Raise driving fast and swift shaft excavation.

E) Future Plans of CSIR-CIMFR

The following major R&D initiatives have been undertaken by CSIR-CIMFR under 12th Five year Plan describes the futuristic roadmap towards the sustainable development mining and fuel sector:

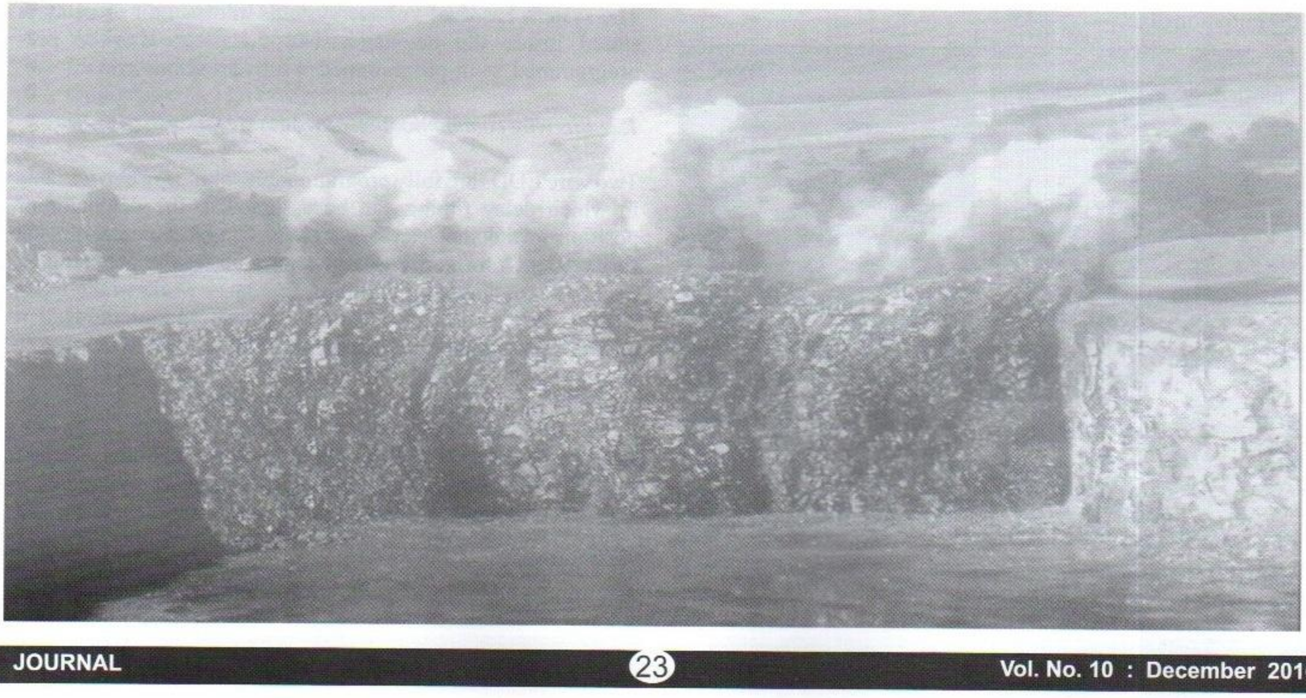
a) Coal Extraction Technology: Development of suitable design methodology for extraction of coal at greater depths (>300 m) and optimal extraction of locked-up coal from underground mines using artificial pillars for Indian geomining conditions.

b) Underground Coal Gasification Technology: UCG allows us to extract previously unminable, low quality and hard to reach coal. The UCG process gasifies coal underground thus generating a gas that is captured on the surface. The gas can be used for synthesis of liquid fuels at costs competitive with the current oil supply. It can also be used for environmentally friendly power production.

c) Coal Preparation Technology: CSIR-CIMFR has initiated pilot plant investigations on the beneficiation of non coking coals and coking coals and development of process flow sheet. The Pilot Plant for washing both coarse and fine coals are equipped with online sensors and has the flexibility of investigating different sub processes. Attempts are also being made to develop zero waste technology by value addition to washery middlings and rejects

d) Electricity Generating Technology: These includes high-efficiency combustion technologies such as sub-critical, supercritical and ultra-supercritical pulverised fuel combustion technology, fluidized bed combustion technology, pressurized fluidized bed gasification, circulating fluidized bed gasification and integrated gasification combined cycle technology, etc. Coal Combustion and Gasification Based Technologies includes Oxy-fuel combustion, Co-combustion, Co-gasification, Circulating Fludised Bed Gasification (CFBG), Chemical Looping, Moving Bed Gasification, Coal liquefaction, Fischer Tropsch (FT) synthesis, Bio-gasification of low rank coal, etc.

e) Mine Automation: Mine automation using intelligent machinery is the need of the hour. Robot technology for underground coal mines is a work package of a mega project proposed under 12th FYP by CSIR. The objective of this work package is to deal with Environmental monitoring and sample collection in unapproachable and hazardous areas, monitoring and 3D mapping of unapproachable and goaf areas, detection of trapped miners and supply of life support in inundated mines and disaster rescue vehicle for trapped miners. Besides these, CSIR-CIMFR has also initiated a project on "Development of tele robotics and remote operation technology for underground coal mines" along with CSIR-CMERI, Durgapur.



ELECTRONIC DETONATOR : A TOOL FOR ENVIRONMENT FRIENDLY BLASTING

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ABSTRACT

Since the invention of Nitroglycerin Explosives in 1831 by Alfred Nobel, the mining industry was in need of initiating devices which could help in increasing blast size and in improving safety during charging and blasting operations, as well as explosive performance. The development from plain detonators & safety fuse system to shock-tube initiation system significantly contributed to commercial blasting. However each system has some limitations in terms of accuracy of delay, safety requirements as well as flexibility complexity in blast hook-ups. The development and successful trials of Electronic Delay Detonators (EDDs) have helped blasting engineers in solving modern mining requirement of large blast with minimum vibration, better control on fragmentation, blasting multilayer rock together, controlling throw & back break etc. EDDs have been introduced in the Indian market in the last 7-8 years. The Indian mining industry is gearing up to embrace the technological benefits that the Electronic detonators provide.

The paper makes an attempt to highlight the benefits associated with use of electronic detonators and future growth prospects of the same in Indian Mining & Construction industry.

Keywords- Electronic detonator, blasting, ground vibration.

1.0 Introduction :

Electronic Detonator Technology - In an electronic detonator (EDD), delay is achieved electronically. An integrated circuit chip (Figure 1) and a capacitor internal to each detonator control the initiation time.

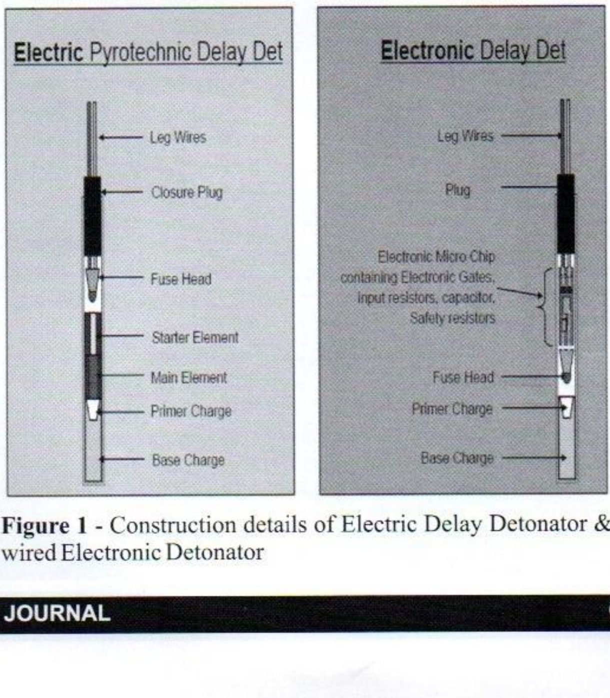

Figure 1 - Construction details of Electric Delay Detonator & wired Electronic Detonator

EDD technology which has evolved over time can be categorised as below :

1.1 Daisy Chain Communication (4 wire system) :

The system has dual voltage system. Information of delay is stored inside the detonator. The detonators can be pre-programmed, semi-programmed or fully programmed.

1.2 Bus wire communication (2 wire system) :

Two wire EDDs are fully programmable. There are two variants in which delay timing can be assigned to the detonator or position in the shot can be assigned to the detonator. In the former case information can be stored inside the detonator or inside the equipment controlling the delay while in the latter case it is stored inside the control equipment. Most of the system adopts dual voltage system for better safety.

1.3 Wireless EDD :

Wireless EDDs are also available in some countries. These EDDs do not need any bus /harness wire for connecting holes. The EDDs along with boosters are lowered inside the holes and EDDs are programmed wirelessly (Figure 2).

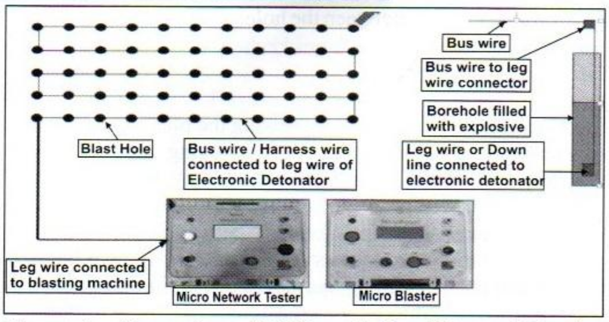

Figure 2 - Connection of EDDs with Bus Wire and Blasting Machine

2.0 Advantages of Electronic Detonator :

An EDD has a number of advantages, e.g. higher precision, improved blasting results due to a wide range of delays, reduction of airblast/ground vibration, and safe use in extraneous electric environments, and the possibility of limiting the amount of charge per delay. It has some disadvantages too, e.g. higher cost per detonator.

EDDs have been introduced in Indian mines almost eight years ago, mainly for controlling environmental issues viz vibration and air blast. With tighter norms of vibration limits as posed by statutory bodies, EDDs are helping mining companies to carry out blasting activity in a more environmental friendly way.

Benefits by use of EDDs are summarized as below:

- Environmental Control
- Better Fragmentation
- Better control over Muck pile shape
- Wall & Back-break control
- Increase in blast size
- Opportunity to increase pattern
- Blasting multilayer rock formation etc

2.1 Environmental Control :

Due to accuracy of the timing of EDD, the explosive energy is released at the exact time it was set to; this ensures that there are no unplanned spikes in energy (and therefore vibrations).

By choosing incremental delay time that creates "destructive interference" (Figure 3) at frequencies that are favoured by local geology, the vibration that excites structural elements could be reduced. In this method, accurate delay times are crucial for effective vibration control. Electronic detonators have less than 1 ms scatter. By recording a single hole signature and computer analysis determines the application of delay timing between holes, between rows and between decks which would produce the most suitable delay interval to control ground vibration and structural response. This technique has a new potential in this new technique of controlling blast vibration.

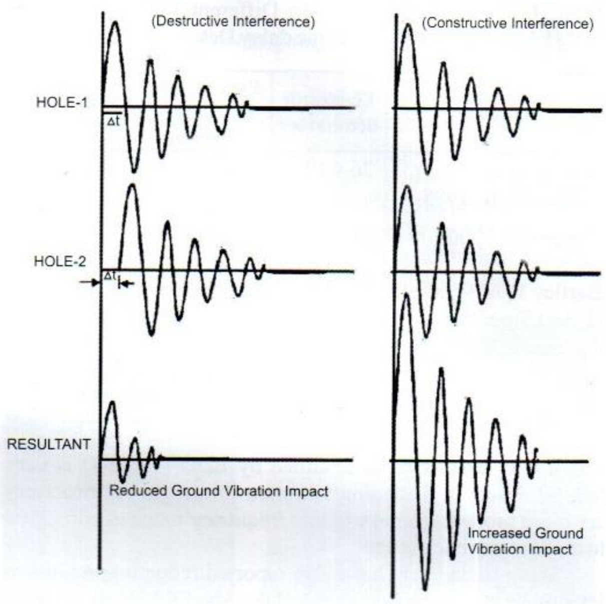

Figure 3 - An Example of Constructive and Destructive Interference of Wave.

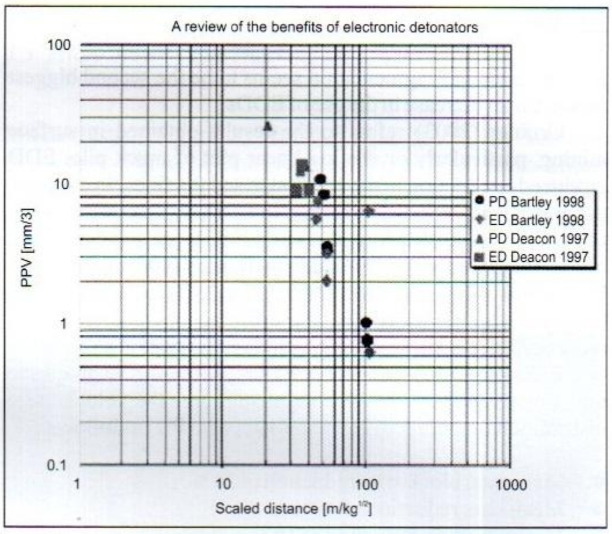

Figure 4 - Comparisons of Peak Particle Velocities induced by Electronic and Pyrotechnic delay Detonators

The study conducted by Decon C & Duniam P and Bartley Da & Trousselle R has shown reduction in PPV by use of EDD in comparison with Pyrotechnic delays (PD). The data compared in the above studies (Marilena et al) are pasted below.

Few studies have evaluated the increase in frequency by use of EDD. Summary of some these studies are tabulated below.

Table 1 - Comparison Between Different Frequency values using Electronic and Pyrotechnic delay Detonators.

Authors	Electronic detonators	Pyrotechnic delay detonators	Reduction in frequencies
Bartley D A, Trousselle R, 1998	26-64 Hz	20-47 Hz	30-36%
Carter R A , 2002	26-39 Hz	8-20 Hz	>95%
Bartley D A, Winfield B, McClure, R, Trousselle R, 2000	13-63 Hz	19-55 Hz	-31-15%
McFerren W., Moodley, P, 2004	30-71 Hz	26-57 Hz	15-25%

The higher frequency so obtained by EDD (Table 1) is very helpful aspect in managing vibration limits. As the structures are more prone to damage in low frequency range as compared to higher frequency range

Some researchers have also reported reduction in airblast levels also in comparison to PD. Baka Abu (2002) has reported reduction of air blast by 15% from 127 dB to 108dB. McFerren et al (2004) has observed reduction of air blast by 3%.

2,2 Better Fragmentation :

Improvement in Fragmentation seems to be the second biggest reason for an increase in the use of EDDs.

Grobler (2003) refers to the results obtained in surface mining, particularly on the log linear plot of muck pile; EDD produced a reduction in the upper size and the fines. In contrast, the grain size distributions related to EDD, evaluated by König et al. (1994) and Havermann et al. (1995), are systematically higher compared to PD. The study by Bartley (2001) of the post-blast muck pile excavation indicated a 25% reduction in dig time using *EDD*. Moreover, the crushing operations show a reduction of electric power consumption (kWh/t) of about 6 -10 % if EDDs are employed. When EDDs are employed, thanks to the improvement of the fragmentation, the block size distribution is upgraded (in comparison with PD) as follows:

- Maximum block size: reduction of 24 %.
- Mean size: reduction of 25 %.
- Minimum size: reduction of 10 %.

Piyush Rai has reported reduction of mean fragment size from 0.55-0.59 m (with PD) to 0.43-0.45 m by use of electronic detonator in hard rock formation.

2.3 Better Control over Muckpile Shape :

Muck pile requirements for dragline, shovels and bucket wheel loaders are different. Using EDDs, it is possible to speed up and slow down certain parts of the shot in order to change the muckpile profile. It is possible to change the height of the pile by varying the timing between the holes.

2.4 Increase in Blast Size :

EDDs can be very helpful in increasing the blast size by taking advantage of the precise timing and being able to reduce vibration and control vibration and frequency. With the help of vibration prediction model to support increase in blast size and firing sequence, EDD bring productivity benefits.

Idling of mining machinery during the time of blast as well as wear and tear of mining equipment due to shifting away the blast face can be reduced by increasing the size of blast without increasing the vibration limits. Some of the Indian mines has reported increase in blast size by 40-50% in critical areas.

2.5 Wall and Back Break Control :

Accurate delay timing and control over firing sequence helps in reducing back break. This helps in subsequent blasts design and supports fly rocks and oversize boulders. Use of EDD in tunnel operation reduces vibration and also helps in achieving better roof control and reduction in cycle time by reducing descaling operations.

2.6 Other Benefits :

The goal for drill and blast is to use the energy from the explosive product to do the most useful work on the rock. In most mines, the explosive product costs more than all other drill and accessories costs combined. EDD when used to their potential will achieve more on the rock using the same energy. Depending on the mining situation, this can deliver increased productivity or assist to reduce costs by blasting the rock better so it digs faster and the mine produces more for the same cost.

Also it is possible with EDD to blast multiple coal seams or seams having steep gradient along with intermittent burden. In metal mines, ore & waste can be blasted together, with very low dilution.

3.0 EDD Indian Scenario :

EDDs in India are provided by three manufacturers & are available in two varieties i.e. Factory Programmable EDD & On-field Programmable EDD. The factory programmable EDD have fixed delay timings as programmed during the manufacturing process. On-field EDD can be programmed at site as per the blasting requirements of the site.

Economic Explosives Ltd (EEL), which is part of Solar group, is a leading supplier of EDDs in India. EDDs are developed and manufactured by adhering to the core principle of inherent safety. The EDD system consists of following elements

- Programmable Electronic Detonator - Microdet-1
- Micro Logger - For assigning delay timing to Microdet-1
- Bus wire - For connecting all the holes in the shot

- Micro Tester - For checking the circuit once the holes are connected.
- Micro Blaster - Device for firing the holes charged with Microdet-1.

3.1 Microdet-1 :

Microdet -1 EDD (Figure 5) can be programmed at site. It contains microprocessor chip with a digital timing circuit. Important design features of the product are listed below :

- Can provide delays up to 8000 ms at an interval of 1 ms.
- Each detonator has a unique detonator ID number
- Chip & capacitor has the capacity to safely store, release energy and allow firing sequence.
- It has also got all safety features to prevent firing due to stray current, Electromagnetic waves etc
- Lead wire consists of twin copper/ copper coated steel wire with PVC coating which connects detonator to connector.
- The connector is a hinged plastic device & connects the individual detonator to the main bus line.
- Lead wire is coiled on to a plastic spool which also can house the detonator in the center shaft space.

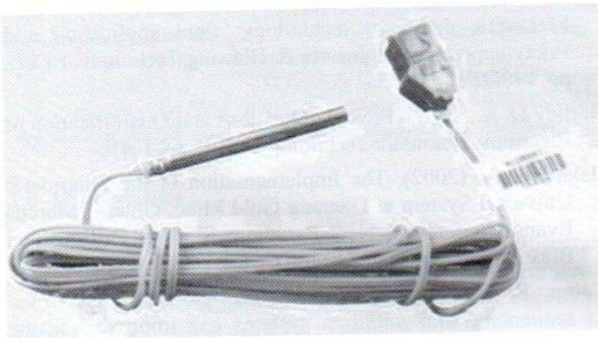

Figure 5 - Microdet -1 Electronic delay Detonator

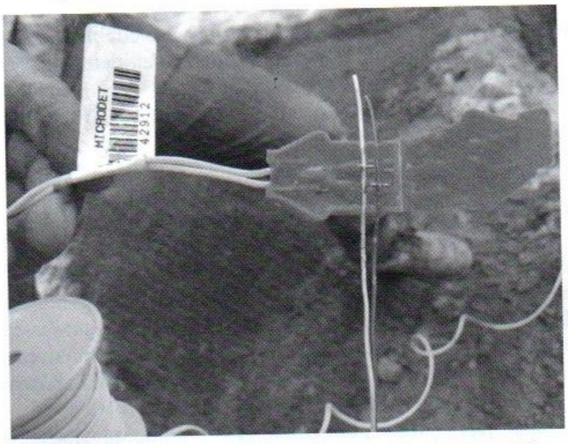

Figure 6 - Connector Connecting Bus Wire & Leg Wire of Microdet - 1

3.2 Micro Logger - For assigning delay timing to Microdet-1 :

The Micro logger (Figure 7) is used to set the delay time. It has the required capability to store information like hole number, detonator ID, delay timings. While logging one end of the logging cable is attached to logger and the other end to Microdet-1 through connector. All the logging data from Micro logger will be transferred to Micro tester for testing the circuit. Logging data also transferred to Micro Blaster before firing the shot.

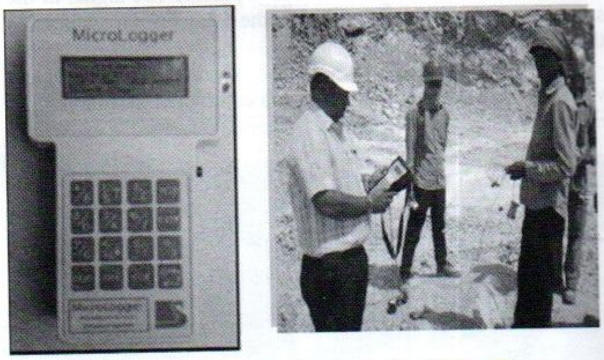

Figure 7 - Micro Logger for Assigning Delay Timing.

3.3 Micro Tester - For checking the circuit once the holes are connected :

Micro Tester (Figure 8) has the capacity to test 500 nos detonators. The data from logger is transferred from Micro Logger to Micro Tester through a transfer cable. Micro-network tester communicates with all detonator units & shows connection connectivity to each of them. The delay timing of any Microdet1 units can be edited at this stage. It also checks total resistance and also display "Short circuit" if any.

Figure 8 - Micro Tester for Checking the Circuit

3.4 Micro Blaster-- Device for firing the holes charged with Microdet-1 :

It can detonate max 500 Microdet units. After checking the circuit through Micro tester and before firing, the data from Logger is transferred to Blaster. When turned on and connected, it again checks the integrity and continuity of the circuit. Once the Blaster ARM key is turned on, all the detonators will be armed within one minute and will fire at the pre-assigned delay timing. The firing at this stage can be aborted by pressing "ABORT" button. All the detonators receive fire signal at the same time but will fire according to the delay timing assigned to them.

Field test of connectivity of and detonators (Figure 9) and view of the blast result (Figure 10) conducted at a large coal mine. The blast resulted in lower ground vibration.

Figure 9 and 10 - Field checking of connectivity and blast result with Microdet-1 in a large coal mine

4.0 Future Scenario :

With increasing need of coal production and growth of mines in near habitat areas & growing environmental concerns, EDDs would help mining companies to address the above challenges. With increasing availability of measurement tools for fragmentation, wall control, vibration & blast modelling tools will also lead to greater usage of EDDs in India.

EDDs are also likely to find applications in construction activities like tunnelling in the cities & control blasting operation close to sensitive structures. Development of smart cities and rapid construction of roads, increasing demand of aggregates would propel the demand for EDDs for controlled blasting.

With emphasis of GOI to increase the coal production to 1.5 billion tonnes and mining approaching populated area, controlling vibration and air-blast will be the major concern area for blasting which EDDs can prove an effective tool.

The consumption of EDDs is likely to grow in India with demand coming from limestone, construction and coal mines situated in vibration sensitive areas. EDDs are also likely to be used in dragline blasts & other niche application.

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Visfotak EXPLOSIVES SAFETY & TECHNOLOGY SOCIETY

SCIENTIFIC / TECHNICAL PAPERS

ROCK EXCAVATION BY CONTROLLED BLASTING AT SENSITIVE URBAN AREAS FOR BANGALORE METRO RAIL CONSTRUCTION PROJECT

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ABSTRACT

The construction of Bangalore Metropolitan Rail project is likely to generate environmental effects like ground vibrations, air overpressure and flyrock during rock excavation by blasting. Station box excavation was carried out for the South-North corridor at City Market and Chickpet stations. The work is being carried out by M/s Coastal-TTS JV, under the technical consultancy of CSIR-Central Institute of Mining & Fuel Research (CIMFR). The station box dimensions were about 20 m wide, 272 m long and 20 m high.The rock to be excavated was hard granite with compressive strength of 100 to 120 MPa. The distances from critical structures to the centre line of rock excavation varied from 10 to 50 m. The critical structures included temples, hospitals and heritage structures. Controlled blasting operations were carried out keeping the adverse impacts like flyrock, ground vibration and air overpressure within the stipulated limits. Pre-splitting, muffled blasting and 'bottom hole decking technique' were used to minimize the effects of blasting during the rock excavation. The bottom air decking resulted in 25-30% improvement of fragmentation and better uniformity index in granite rock formations, in spite of 20% reduction in specific charge. The measure of vibration intensity i.e. peak particle velocity was reduced by 35% in comparison to the conventional charging without decking in the trial blast studies. The blast results proved that the measures adopted for rock excavation at sensitive locations were not only safe but also productive. This helped in completion of excavation targets well in time.

1.0 Introduction :

Urban infrastructural development has become very important aspect in view of the faster economic growth and migration of people to urban destinations for employment and improving quality of life. This is resulting in great deal of problems to the urban transportation system, which in turn is demanding for Metro Rail construction and underground space creation in the cities. In view of the excessive carrying capacity of the traditional public transport, metro rail transportation is the best alternative to solve the traffic problems as well as for providing eco-friendly green transportation. Construction of metro rail projects as part of urban mass transport system is becoming essential part of every large city development in India. Metro rail projects can be constructed as underground system or elevated system depending on the geological and geotechnical properties of rock mass formation. Construction of infrastructural projects like metro rail in cities poses many problems such as dust, noise, vibrations and airblast. Therefore, it is always a challenge to construct any metro rail project smoothly. CIMFR conducted the study of site-specific controlled blast design for rock excavations.

As part of execution of controlled blasting 'bottom hole decking technique' was applied for improving fragmentation, reducing specific charge, ground vibrations and avoiding toe formations in bench blasting of granite rock at all the stations. The paper deals with field investigations with bottom hole air decking and discusses the results obtained in minimizing the blasting side effects in Bangalore Metro Rail Project.

2.0 Field Experiments on Controlled Blasting :

Bangalore is the country's fastest-growing metropolitan area and the Metro Rail construction project is being developed by the Bangalore Metropolitan Rail Corporation Ltd (BMRCL). The Bangalore metro rail project consists of both elevated and underground components. The tunnels are being made by tunnel boring machines while the underground stations were planned to be excavated by drilling and blasting method, which is likely to generate environmental effects like ground vibrations, air overpressure and flyrock. Excavation was carried out for the South-North corridor and East-West corridor. The rock excavation for the South-North corridor at City Market Station and Chickpet station was carried out by M/s Coastal-TTS JV. Venkatesh et al (2013) gives a detailed description on their experiences on controlled blasting studies for East-West corridor of Bangalore Metro Rail project. CSIR-CIMFR provided technical guidelines for blasting design for controlling ground vibrations, air overpressure and flyrock during rock excavation at the two underground stations of the project. The distances from critical structures to centre line of rock excavation of these station areas varied from 10 to 100 m. The sensitive and critical structures include temples, hospitals and heritage structures as shown in Figures 1-2 respectively. The following general controlled blasting techniques were used to minimise blast induced side effects during the rock excavation.

i) Restricted charge per delay
ii) Bottom hole initiation
iii) Pre-splitting
iv) Use of small diameter blast holes
v) Use of decked charges
vi) Installation of hard barricades
vii) Optimum specific charge & burden
viii) Use of proper muffling system
ix) Proper stemming column and stemming material
x) Adequate delay period and
xi) Avoiding delay scattering

Figure 1 - Sensitive and Critical Structures (hospital and heritage building) at City Market Metro Station

Figure 2 - Sensitive and Critical Structures (Temple and building) at Chikpet Metro Station

2.1 Geological Descriptions of Blast Site :

The rock encountered in the blasting area is mostly of crystalline to metamorphic origin. The formation of rock is Peninsular Gneiss which contains older Gneissic complex. The granite is the major rock formed along the south shaft area. Gneiss of granite to granodiorite, intrusion of quartz, feldspar and biotite layers were also seen towards the northern region. There were also quartz monzonites formed on the northern region. Subsurface profile at the site generally consists of fill overlying residual soils underlain by completely weathered bed rock and then bed rock. The encountered layers are given below. A first layer of about 0-1.5m consists of fill up soil mostly of yellowish brown silty sand is encountered. A second layer of residual soil 1.5-6m mostly of silty sand is encountered and below that a layer of silty sand to gravel 6-10m and in some portion clayey silt were also encountered.A third layer of completely weathered to highly weathered rock strata is encountered at an average depth of 10-14m.A fourth layer of moderately weathered rock at an average depth of 14-17m is encountered. A fifth layer of completely hard rock strata at an average depth of 17m and above were encountered. The foliation of rock strata is towards north east and the rock stratum is dipping at30.5^{0}N. The strike of the bed is N52^{0}W.There are no major faults in the area and the joints were irregular yet few horizontal joint sets were encountered in some portion. The layer of 14-17m moderately weathered rock has the core recovery of 40%-70% and has the RQD value of 40%-50%. The layer of hard rock has 80% core recovery and has 70% RQD. The RMR value of the rock strata is 41-60 (fair) and the Q-value i.e., Quality of the rock is FAIR. Ground water was observed at a depth of 7m to 8m below ground surface.

2.2 Rock excavation for Station Construction :

Station boxes of approximate width of 50m and length 400m are required to be excavated by drilling and blasting technique. There are two different methods for construction of underground metro stations, namely top down method and bottom up method. Bottom up method is the general method of soil/rock excavation adopted for construction of stations as it is flexible and open method of excavation, which is more productive but less safe, many a times. Bottom up method is the most simple excavation approach in urban conditions for both soil and rock excavation. Hydraulic excavators are deployed for removal of top soil. When the strength of rock is above 25 MPa, it is difficult to excavate the rock by non-blasting techniques. In such projects rock blasting becomes the most preferred method of hard rock excavation. But the rock excavation by blasting is associated with adverse effects like ground vibrations, air overpressure, noise, flyrock and dust. The side effects of blasting could be controlled by application of some innovative controlled blasting techniques, which are explained in the following sections.

2.3 Application of Controlled Blasting Techniques :

The main objective of controlled blasting techniques is the control of fly rock, ground vibration and or air overpressure within the permissible limits. The other purpose of controlled blasting is to minimise fracturing and loosening of the rock mass beyond the predetermined excavation line/profile. The objective is normally achieved by minimising and judicious use of explosives in the blast holes. Several controlled blasting techniques such as line drilling, presplitting, smooth blasting and cushion blasting are used to achieve these objectives.
Out of all the side effects of blasting, control of ground vibrations would become most essential aspects as the nearby structures are more vulnerable and sensitive to the ground vibrations. The principal factors that affect vibrations levels at a given point of interest are the maximum charge per delay, the distance from the blast, the delay period used and the blast geometry. The permissible peak particle velocity (mm/s) at the foundation level of all the sensitive structures was based on the threshold limits prescribed by Directorate General of Mine Safety (Anon, 1997). Various controlled blasting techniques applied at the Bangalore Metro Rail Project are described in the following sections.

2.4 Line Drilling :

Line drilling is one of the techniques used for over break control. In line drilling, a single row of closely spaced small diameter holes is drilled along the neat excavation line. This provides a plane of weakness to which the primary blast can break and to some extent reflects the shock waves created by the blast, reducing the shattering and stressing in the finished wall. Line drilling is best suited to homogenous formations where bedding planes, joints, and seams are at a minimum. The only place where it is applicable is in areas where even the light explosive loads associated with other controlled blasting techniques may cause damage beyond the excavation limit or where line drilling is used between loaded holes to promote shearing and guide the presplit line. Therefore, line drilling was implemented adjacent to the sensitive structures like Hospital at City Market station and Temple at Chikpet station. Initial line drilling was carried out with the ROC drills of 45mm diameter with a spacing of 0.1m for a depth of 5m. Below 5m depth, the Jack hammer holes of 32mm and with a spacing of 75mm for a depth of 2.4m. It was observed that line drilling could not control the vibrations completely. Therefore, it was decided to go for presplitting to control the vibrations and damage.

2.5 Presplit Blast Design at the Periphery of Excavation :

Controlled blasting techniques are used in construction projects to minimize the damage and deterioration of surrounding rock mass or structures. Presplitting is a technique used to produce high quality final pit walls and to reduce the blast induced ground vibrations. Damage from back-break can be minimized, thereby insuring the final pit walls stand at the designed angle. Thus costly excess waste removal is avoided. Safety in the pit is enhanced. Control blasting is an essential component of procedures to maintain the stability of final pit walls prone to failure. Strip mines using blast casting also frequently employ pre-splitting of the active highwalls. Subsequent blasts can be designed for maximum effect behind the pre-split highwalls. Presplitting involves a single row of holes drilled along the excavation line. Presplitting the rock forms a discontinuous one which minimises or eliminates overbreak from the subsequent primary blast and produces a smooth, finished rock wall. Presplitting is also used to reduce ground vibration in some critical cases. The pre-splitting was practiced at the final line of excavation/periphery of the station box. It was preferred to go with small diameter holes for pre-splitting as the pre-split blasting itself is potential to generate excessive vibration levels. The site specific pre-split blast design parameters for the prevailing rock are given in Table 1 and Figure 3. The presplit blasting technique in this project was adopted to reduce the blast induced ground vibrations and high wall damage. Test blasts were initially conducted at safer distances to arrive at final pre-split design parameters.

Table 1 - Blast Design Parameters for Pre-splitting

Parameter	Value/description
Diameter of holes	32mm
Angle of holes	90^0
Spacing	0.5m
Bench height	1.5 m
Depth	2 m
Charge per hole	0.125 kg
Initiation system	Bottom hole
Stemming column	0.5m
Hole-hole delay	17ms

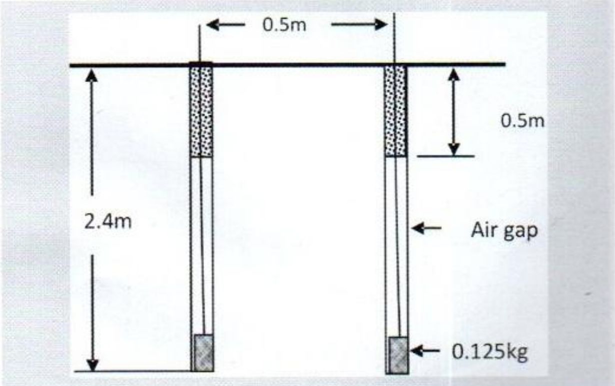

Figure 3 - Pre-split Blast Design Parameters with Jack Hammer Drill Holes

Pre-splitting yielded very good results in terms of controlling overbreak, damage and ground vibrations.The pre-splitting test blast and post-blast fracture plane are shown in Figure 4 and 5 respectively. The vibration reduction due to pre-splitting is shown in Figure 6. There is a reduction of 40 to 45% in the vibration level at 50m distance from the blast site. In view of the very good results in pre-splitting, it was considered to implement this technique all through the periphery of the station box excavation of City Market station.

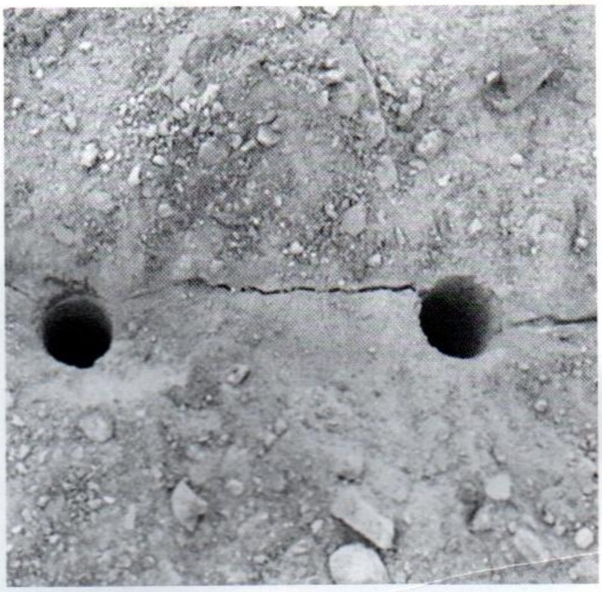

Figure 4 - Pre-split test blast results in creation of crack between holes

Figure 5 - Pre-split test Blast results in Creation of Fracture Plane

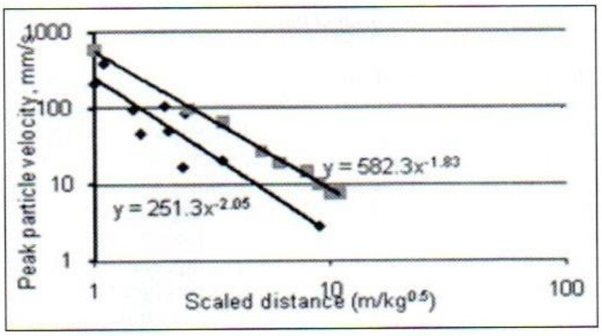

Figure 6 - Plots of Peak Particle Velocity versus Scaled Distance for before (upper) and after Pre-splitting (lower)

2.6 Fly Rock Control Techniques :

The factors which influence the fly rock distance include:

1) Height of stemming column and type/quality of stemming material.
2) Irregular shape of free face
3) Excessive burden or blasting without free face
4) Muffling of the blast area and the muffling material type
5) Scattering and overlapping of delay timings of the delay detonators/relays.
6) Presence of water in blast holes.

The first four parameters can be controlled by proper blast design whereas the last two parameters are not easily controllable. Fly rock can be controlled by proper blast design and by muffling/covering. It is known that unless blast design is proper, muffling will not be effective. Proper blast design and accurate implementation of the blast are the two areas of fundamental concern for controlling the fly rock. The third important parameter is understanding the local geology and adjusting the explosive charge with regard to the geological features. The reliable and effective method of controlling fly rock fragments from the mouth of the blast holes (vertical flyrock on the rear side) is the height of stemming column. It has been observed that the fly rock, particularly towards the rear side, was effectively controlled by maintaining the height of stemming column in all holes greater than the burden. The height of stemming column should be 1.2 to 1.5 times the effective burden in all holes. A good stemming material should retain borehole pressure till the burden rock starts to move. Dry angular material under the effect of the impulsive gas pressure tends to form a compaction arch which locks into the wall of a blast hole, thus increases its resistance to ejection. In general, drill cutting is better stemming material as compared to sand and should be preferred except in case of watery holes (Ramulu, et al. 2005). In watery holes, only sand free of clayey materials should be used as stemming material. Muffling or covering of holes including entire area to be blasted is one of the most common method to contain the distance of travel of flying fragments particularly when blasting is done within the danger zone (DGMS Circular, 2003).

A three layered muffling system as shown in Figure 7 was used to control flyrock for all the blasts. That include:

a) Sand bags covering all the blast holes and connecting lead tubes
b) Chain linked wire-mesh with 2.5 cm mesh size, on the sand bags
c) Rubber mats of 1.2 ton weight covering the entire blast area

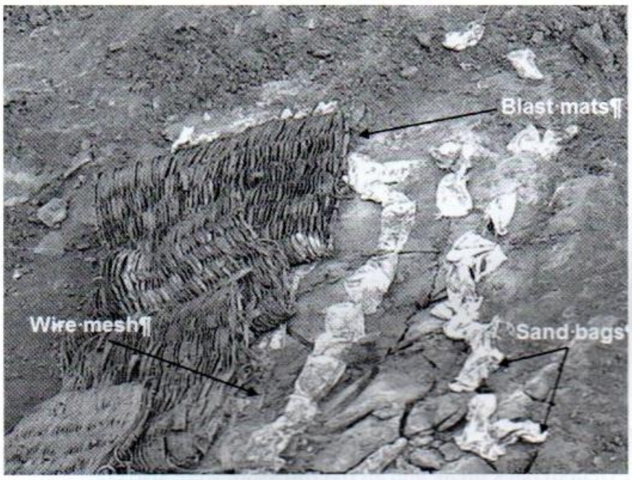

Figure 7 - Three Layered Muffling System used to Control Flyrock

Muffling or covering of holes including entire area to be blasted is one of the most common methods to contain flying fragments particularly when blasting is done within the danger zone. For initial rounds of blasts already available guidelines by previous researchers (Jimeno et al, 1995) were used and it was refined further for zero tolerance to flyrock. No blasting should be carried out without proper muffling. To restrict the flying fragments from the blast, the blast area shall be muffled comprising 25 mm x 25 mm, 14 SWG link mesh, old rubber tires of trucks and rubber blasting mats of minimum specified size and weight. The blasting block shall be covered fully and in addition, 3m on all the four sides of the charged block.

3.0. Controlled Blasting using Bottom Hole Air Decking :

'Bottom hole decking technique' was applied for improving fragmentation, reducing specific charge, ground vibrations and avoiding toe formations in bench blasting of granite rock at all the stations. The bottom hole air-decking was developed to avoid the advantages of general middle deck air decking and to avoid its complex charging procedure. The bottom hole decking consists of air decking at the bottom of the hole in dry holes by means of a wooden spacer or a closed PVC pipe, covered at the upper end as shown in Figure 8.If blast holes are wet, water decking is created at the bottom by means of a spacer with a weight attached to it. The diameter of the spacer should be preferably one third of the blasthole diameter for easy lowering while preventing the charge from going down the bottom while loading. The reported values of air-deck length was taken as basis for optimum bottom deck length which was about 10% of the hole depth (Mead et al, 1993). The hole contains explosive and stemming column as in conventional loading but with a spacer at the bottom. The principle of bottom hole air decking in achieving optimum explosive energy interaction on rock mass is given below:

- Reduced shock energy around the blast hole due to cushioning effect of air decking, which otherwise would result in crushing
- Explosive energy-rock interaction is more at the bottom due to relative relief zone existing at that zone.
- Effective toe breakage is due to striking and reflection of shock waves at the bottom face of hole

The procedure and sequence of blast hole loading and initiation for the bottom hole decking are given below:

- Inserting the spacer into the hole bottom by dropping from surface or lowering down.
- Loading the primer explosive cartridge attached by Nonel shock tube/Detonating cord and charging the column charge conventionally
- Stemming of the hole by proper stemming material, preferably by drill cuttings or coarser sand.

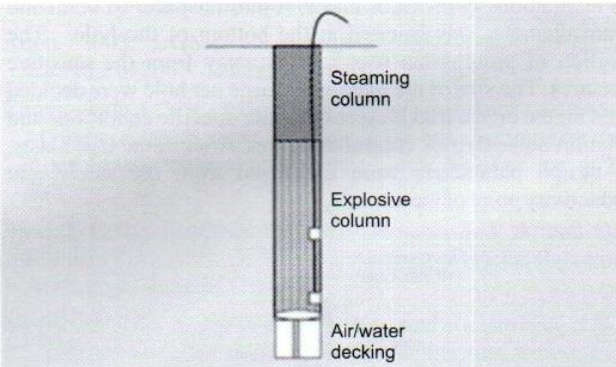

Figure 8 - Components of Bottom Hole Decking inside a Blast Hole

The advantages of the bottom air decking technique in comparison to the conventional middle air decking are given below:

i) Applicable to the jointed rock formation which is not effective with middle air decking.
ii) In wet holes, generally, slush is deposited at the bottom due

to falling of drill cuttings and hole side collapse; this slush mixes with primer in conventional charging resulting in explosive deterioration and lower velocity of detonation, which is reflected in breakage and fragmentation. This thing is efficiently avoided by bottom air decking which separates the primer from slush.

iii) The highly confined toe is free of explosive charge but exposed to high concentration shock energy, resulting in good toe breakage and low vibration, low air overpressure intensity.

iv) The reduced overall peak shock reduces the back break and flyrock.

The bottom air decking resulted in 25-30% improvement of fragmentation and better uniformity index in granite rock formations, in spite of 20% reduction in specific charge. The peak particle velocity was reduced by 35% in comparison to the conventional charging without decking in the trial blast studies.

4.0 Design of Production Blasts :

After achieving the free face to the bench using jack hammer holes by box cut method, progressive blasting was carried out by vertical benching. For production blasts the Jack hammer holes of 32mm diameter was deployed to comply the vibration limits and flyrock control measures. The blast size i.e. number of holes was limited by the anticipated blast induced vibrations rather than the production targets of project.

The blast hole charge pattern for production blasts is given in Figure 9 and blast design parameters are given in Table 2. The depth of hole is about 1.5 - 1.75m depending on the rock profiles and undulations in previous blasts. A plastic spacer of 0.3m and 25mm diameter was inserted at the bottom of the hole. The direction of progression was kept as away from the sensitive structures. The size of the blast and charge per hole were decided based on the on the trial blast results, site-specific conditions and vibration/noise flyrock control measures. After initial trial blasts, the design parameters were optimized from the safety and productivity point of view.

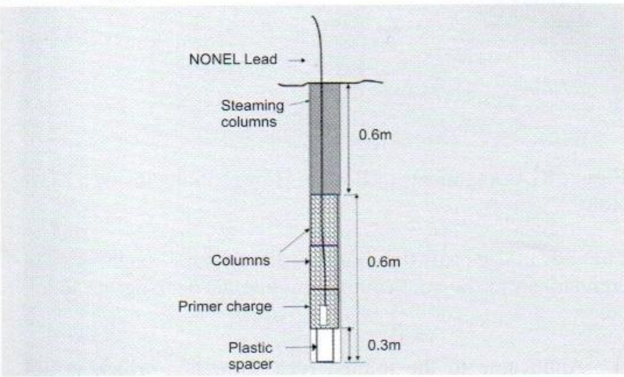

Figure 9 - Blast Hole Charge Pattern for Production Holes with Jack-Hammer

Table 2 - Blast Design Parameters for Production Blasting

Parameter	Value/description
Diameter of holes	32mm
Angle of holes	90^0
Burden	1.0m
Spacing	1.25m
Depth	1.5m
Charge per hole	0.375 kg
Specific charge	0.2-03 kg/m^3
Initiation pattern	Bottom initiation
Initiation system	Shock tube initiation with 200ms DTH and 17, 25, 42 ms with TLD, 4m long twin detonator system
Stemming column	0.6-0.75m
No of holes per delay	1
Delay between hole-hole	17/25ms
Delay between row-row	42ms

4.1 Blast Results with Regular Production Blasts

The blast performance analysis was done based on the degree of fragmentation, vibration intensity and flyrock projectile. The extent of back break and air overpressure were also considered as secondary blast performance assessment parameters. The fragmentation analysis was done by using a software tool called 'WipFrag' for finding out mean fragment size. All the blast performance indicating parameters are summarized in Table 3. The vibration intensity never exceeded 4mm/s at the nearest ordinary structures and was maintained below 1.75 mm/s near historical structures and hospitals. The blast fragmentation and extent of back-break are shown in Figure 10. Although the mean fragment size is not optimum for the excavators used in the site, it was considered as good blast from point of view of safety.

The uniformity index measured was 1.78 with the help of fragmentation analysis software, WipFrag. The uniformity index typically has values between 0.6 and 2.2 (Cunningham 1983). A value of 0.6 means that the muck pile is non-uniform (dust and boulders) while a value of 2.2 means a uniform muck pile with majority of fragments close to the mean size. The importance of the uniformity index is size distribution curves having the same characteristic size but different values of uniformity index. Therefore, the observed uniformity index is towards better side.

Table 3 - Blast Performance Indicating Parameters

Sl No.	Blast performance indicator	Value
1	Fragmentation (Mean fragment size)	0.32m
2	Vibration Intensity (PPV) at 50m	1.85 mm/s
3	Flyrock projectile at 5m	Nil
4	Air overpressure at 50m	118 dB
5	Back break	0-0.25m

You cannot achieve everything when blasting is controlled to minimize ground vibration, air overpressure and flyrock. One cannot expect the most suitable size of fragment at the same time. Priorities are to be set, blasts are designed to achieve goals acordingly.

Figure 10 - Post Blast Results of Blast Fragmentation and no back-Break

5.0 Conclusion

The construction activity for metro rail projects involving blasting is a challenge in urban environment. Almost all generally followed controlled blasting techniques were used to minimise blast induced side effects during the rock excavation at station box excavations of the metro rail project, City Market and Chikpet stations. CSIR-CIMFR designed and successfully implemented controlled blasting techniques to restrict all the environmental effects. Line drilling and pre-splitting were carried out keeping the adverse impacts like back break, flyrock, ground vibration and air overpressure within the stipulated limits. Based on the site-specific ground vibration studies, condition of the structures and the prevailing norms, a permissible limit of below 5 mm/s was decided for ordinary structures and 2mm/s for historical structures and hospitals. The suggested muffling with heavy rubber blasting mats restricted the flyrock within 10 m. The blasthole diameter was restricted to 32 mm and the specific charge was between 0.25 and 0.3 kg/m^3. Bench height was also restricted to 1.5 to 2m and production higher than the targeted production of 300-400 m^3 per day was achieved frequently. The vibration intensity never exceeded to 4mm/s at the nearest ordinary structures and was below 1.75 mm/s near historical structures and hospitals. CSIR-CIMFR developed 'bottom hole decking technique', which is user friendly and simple, was applied for improving fragmentation, reducing specific charge, ground vibrations and avoiding toe formations in bench blasting of granite rock at two stations. The bottom air decking resulted in 25-30% improvement of fragmentation and better uniformity index in spite of 20% reduction in specific charge. The peak particle velocity was reduced by 35% in comparison to the conventional charging without decking. The blast results proved that the measures adopted for rock excavation at sensitive locations were not only safe but also productive. This helped in completion of excavation targets well in time.

6.0 Acknowledgments

The authors are thankful to Managing Director, BMRCL and Chief Engineer, UG, BMRCL for their cooperation and support in implementation of controlled blasting. Thanks are due to the Project Manager, Coastal-TTS, for awarding the project to CSIR-CIMFR. Authors are also thankful to Mr. Nigel Butterfield, Project Manager, UG, Mr.Y.Tezuka, CSE, UG. Thanks are also due to their colleagues Dr. A.K. Raina, Dr. P.B. Choudhury, Dr. B. Prabhakar, Sri B.K. Jha and Dr. A.K. Soni for their cooperation during field work.

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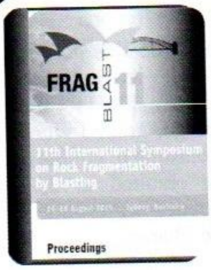
TECHNOLOGY ABSTRACTS



Selected Abstracts from the Proceedings of the 11th International Symposium on Rock Fragmentation by Blasting on 24-26 August 2015, Sydney, Australia.

A Simple Technique for using High Energy in Blasting

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Abstract

In non-ferrous metal mining operations, it is generally necessary to crush and grind the ore to a very fine particle size to-effectively liberate the contained mineral from the host rock. Fragmentation by blasting is the first stage of this commination process.

Numerous studies and independent modelling of the Mine to Mill process have demonstrated the potential for significant downstream productivity improvements from improved blast fragmentation. However, safety and environmental constraints associated with the blasting process usually limit the extent to which blast energy or powder factor can be increased. An effective blasting solution has been identified that enables the safe utilisation of powder factors several times higher than those used conventionally to provide significant improvements in fragmentation. The solution uses a static 'blanket' of broken rock overlying the blast, to contain this increased blast energy and control rock movement. To produce this broken layer of rock, the subdrill in each blast is significantly increased to preblast (or precondition) the entire stemming region of subsequent blasts on the next mining bench.

The solution has been evaluated at a large open cut poly-metallic mine in Mexico. Results from the application of this technique have shown significant improvement in run-of-mine fragmentation, with subsequent downstream productivity improvement indicated.

A New Approach for Blasting

An effective blasting .solution that achieves the safe utilisation of powder factors several times higher than those used conventionally has been developed. This approach will be referred to as the preconditioning technique. The preconditioning technique was developed in consideration of the two primary influencers of fragmentation the amount and distribution of explosive energy.

This approach makes use of large diameter blastholes, drilled on a reduced burden and spacing and charged with a single continuous deck of high bulk-strength explosives to achieve the required high ,explosives energy levels,

Previous work (Brent *et al.* 2012) has examined the use of powder factors in so-called 'ultra-high intensity blasting' (UHIB) that were several times higher than those used conventionally. The UHIB method uses a static 'blanket' of broken rock overlying the high-energy blast to contain the increased blast energy below. Modelling studies and full-scale field trials have shown that this blanket of broken rock efiective1y contains the high blast energy below and reduces the risk of flyrock and a airblast. In the UHIB method. the static 'blanket' was provided by firing an earlier layer of rock within the same blast event In contrast, the preconditioning technique produces this 'blanket' of rock by significantly increasing the subdrill in each blast to preblast (or precondition) the entire stemming region of subsequent blasts on the next mining bench. The 'blanket' in the preconditioning method is provided by the broken rock from the subdrill region of the earlier blast event on the bench above.

EXPLOSIVES SAFETY & TECHNOLOGY SOCIETY
TECHNOLOGY ABSTRACTS

Measurement and Assessment of Bulk Explosive Products

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ABSTRACT

There are various methods currently in use to determine detonation performance of bulk explosive products including velocity of detonation (VOD), high speed photographic analysis, fragmentation analysis and unconfined detonation of samples. For assessment prior to detonation the current practice is limited to a measurement of cup density. This paper presents additional techniques that have been developed to provide measurement and assessment of bulk explosive products. Techniques applicable prior to detonation include a mobile laboratory to allow on-site chemical and physical analysis of sensitised products and 'in-hole density' measurement to monitor the in-hole density during sleep time. Assessment of detonation performance is achieved using detonation pressure sensors. These sensors allow measurement of detonation pressure, average VOD, propagation time and magnitude of the pressure induced in the explosive column by detonation of adjacent blasthol

Introduction

Explosive rock breakage is the most economical and efficient way to break large volumes of rock. In general, an explosive has three characteristics:

1. it is a chemical compound initiated by heat, shock, impact and/or friction
2. it decomposes rapidly upon initiation
3. upon detonation a rapid release of heat and high pressure gas occurs to overcome the confining forces of the surrounding rock (Bhandari, 1997).

The most commonly used explosive product in the mining industry is ammonium nitrate fuel oil (ANFO). The mix of ammonium nitrate (AN) to fuel, if stoichiometrically correct, will result in a detonation given Equation 1:

$$3NH_4NO_3 + Ch_2 \rightarrow 3N_2 + CO_2 + 7H_2D \qquad (1)$$

Explosive manufactures design their product to be fuel rich, and therefore oxygen negative, resulting in an idealised reaction as shown in Equation 2. It can be seen that less nitrogen is emitted in this scenario:

$$2NH_4NO_3 + CH_2 \rightarrow 2N_2 + CO_2 + 5H_2O \qquad (2)$$

Further to this, if the reaction does not go to completion, it will become oxygen positive, which in turn produces nitrogen oxide (NO). NO readily oxidises to nitrogen dioxide (NO_2), which forms the visible orange cloud associated with post blast fume generation. Equations 3 and 4 detail these idealised reactions respectively:

$$5NH_4NO_3 + CH_2 \rightarrow 4N_2 + 2NO + CO_2 + 7H_2O \qquad (3)$$

$$2NO + 0_2 \rightarrow 2NO_2 \qquad (4)$$

Poor detonation performance, from a practical perspective, can be due to one or a combination of factors such as explosive product characteristics; confinement effects; ground conditions; inappropriate blast design parameters; explosive product selection; on-bench practices and potential contamination of explosive product in the blasthole. This paper presents methods to assess these factors through measurement of explosive quality, in-hole density and detonation pressure measurement. Specifically, a variety of physical and chemical analytical techniques are used to assess explosive characteristic's, in-hole density measurements are used to access the effectiveness of on-bench practices (i.e is the product density being affected by loading practices) and pressure measurements are use assess confinement, ground conditions, blast design and explosive product selection.

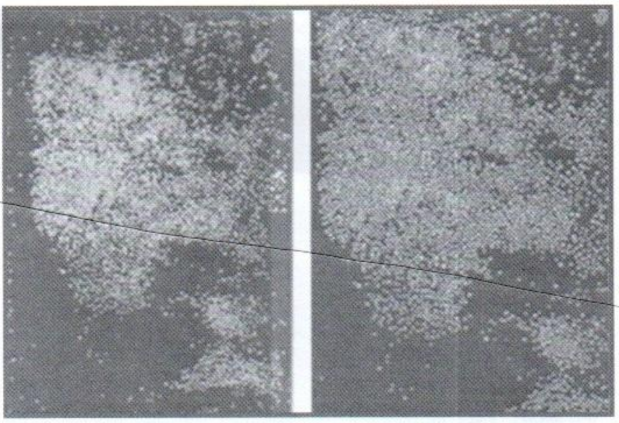

Figure 2 - Screen showing prill analysis and size distribution

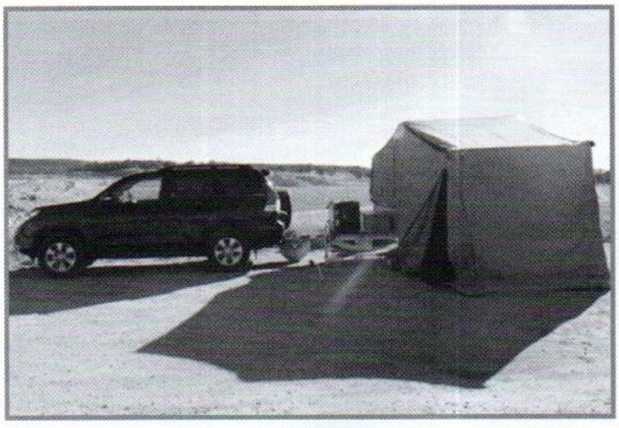

Figure 3 - Mobile laboratory operating adjacent to a mine site

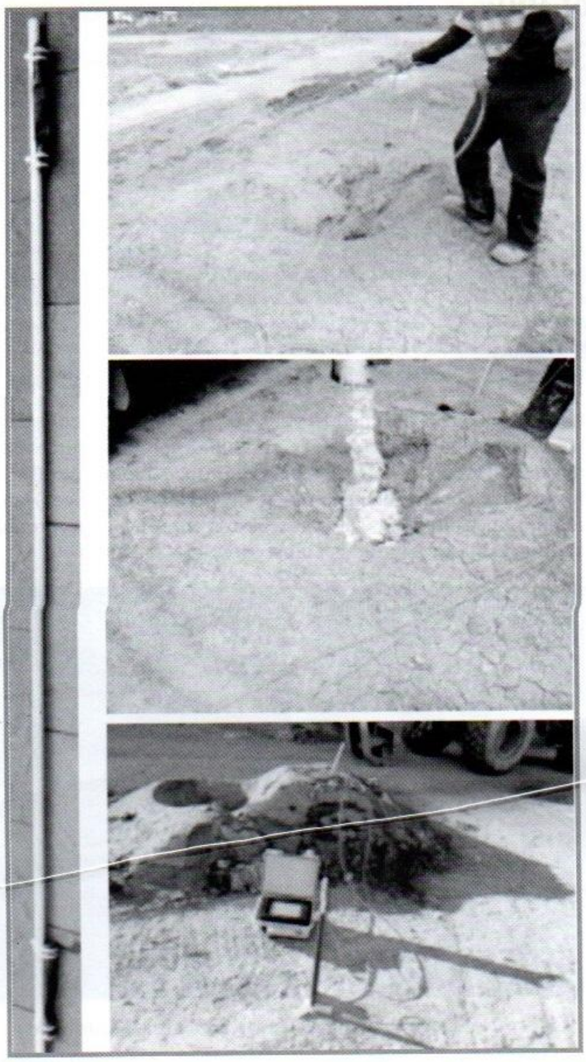

Figure 4 - The sensor (left), lowering the 'in hole' density sensor into a blasting, loading and measurement at any time up until detonation

Table 4 - Measurements and the calculated ideal detonation pressure for chalk quarry measurements

Detonation pressure (GPa)	Detonation Temperature (^{0}C)	Velocity of detonation (m/s)	Relative cup density (kg/m^2)	Ideal calculated detonation pressure (GPa)
1.9	3308	3539	800	2.5
1.4	2200	3525	800	2.5
1.7		3727	800	2.8
1.7	3208	4209	800	3.5
1.3	2408	4219	800	3.6
0.9	3300	3441	800	2.4
1.3	3100	3720	800	2.8

Table 5 - Measurements and the calculated ideal detonation pressure for hard quarry measurements

Detonation pressure (GPa)	Detonation temperature (^{0}C)	Velocity of detonation (m/s)	Relative cup density (kg/m^2)	Ideal calculated detonation pressure (GPa)
5.4	2900	5500	1200	6.1
6.9	2900	5500	1200	6.1
4.9	3500	5497	1200	6.1
4.9	3300	5500	1200	6.1
5.4	2900	5500	1200	6.1
6.9	2900	5500	1200	6.1
4.9	3500	5500	1200	6.1
4.9	3300	5500	1200	6.1

Figure 6 - Loading transducer into a blasthole

Figure 7 - Charging Blasthole

Table 6 - Comparison of chalk and hard rock blasts

Value	Chalk	Hard Rock
Detonation pressure (GPa)	1.6±0.5	5.5±0.8
Ideal detonation pressure (GPa)	2.9	9.1
Velocity of detonation (m/s)	3800±320	5500
Density *(g/m)*	800	1200
Temperature (^{0}C)	2900±500	3150±300

High-Speed Video - An Essential Blasting Tool

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ABSTRACT

The practice of recording blasts for quality control purposes has been conducted for several decades, However, at the low frame rates of a standard video camera, essential data is frequently missed as it occurs when the shutter is closed between frames.
The use of high-speed video for the research, development and monitoring of the performance of blasting procedures is a well proven but under utilised practice.

The recent development of low cost, easy to use high-speed digital cameras and user friendly software can deliver a capability into mine management as a day-to-day production tool that can greatly improve blasting performance and reduce costs ..

Digital high-speed video and image analysis software can accurately quantify each blast. Analysis of the images can facilitate the identification of causes, of variance from design, geology changes, errors in blast practice and areas of poor performance. The use of high-speed video greatly enhances the audit and review processes so that future blast design can be quickly and appropriately modified to deliver improved blasting performance and reduced costs,

The three videos demonstrate the differences between standard video and high-speed video and the detail that can be obtained from them. These videos of open cut blasts can be used to identify blast performance variances. Capturing images at 1000 frames per second allows the analysis on at millisecond timescale where detonator timings, fragmentation, venting, fume generation and flyrock can be accurately identified.

Analysis of Blast Videos

Figure 1 - Shock wave pulses from detonating holes

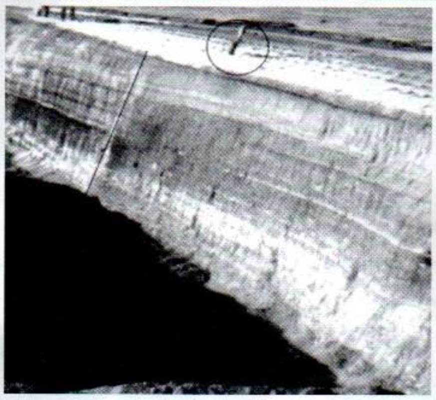

Figure 2 - Rifling 200 ms after shock pulse hit the face

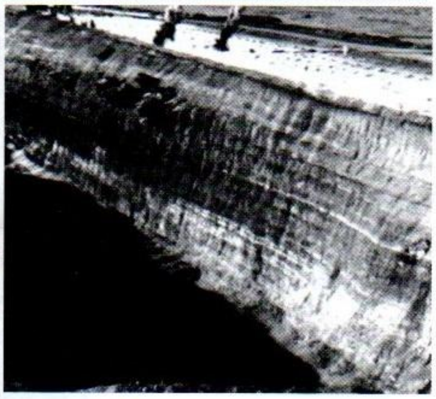

Figure 3 - Face bursts of gases escaping

Figure 4 - Four signal tubes burning, frame 120

Figure 5 - Three signal tubes burning, frame 121

Figure 6 - High resolution image

Measurement of Blast-induced Pressure in Bench Blasting and Deciphering Explosive Performance through Rock Mass Response Analysis - A Methodology

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ABSTRACT

Rock mass response in blasting is an important element to determine the performance of a blast along with its other outcomes. The near-field monitoring for rock mass response analysis is vital for determining the behaviour of a blast; however, due to costly and cumbersome methods involved in such measurements the subject has received scant attention so far and the publications on this account are perfunctory in nature. This paper presents a non-destructive method to monitor the blast-induced pressure in the rock mass at a distance from a blasthole. The methodology of monitoring and a few examples of actual field monitoring are detailed in this paper. The responses of the rock in the near-field of a blasthole under dynamic loading have been documented to predict fragmentation and throw. The proposed method has also been used in limited cases earlier by the author to predict flyrock using a semi-empirical method and trajectory equation. The pros and cons of the method are discussed while throwing light on the actual response and the prediction of fragmentation and throw of blasted rock.

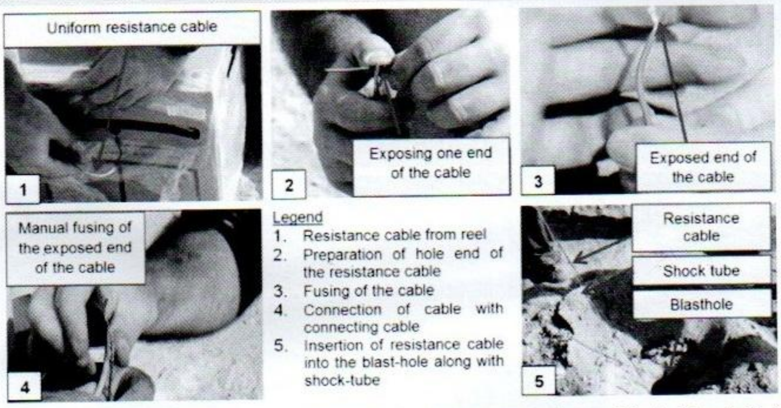

Figure 2- Preparation and insertion of velocity of detonation cable in blasthole(s)

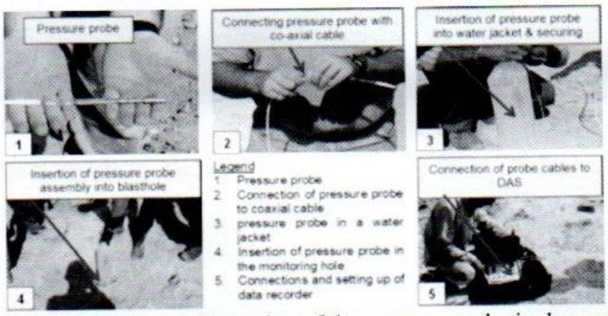

Figure 3- Preparation and insertion of the pressure probe in dummy hole

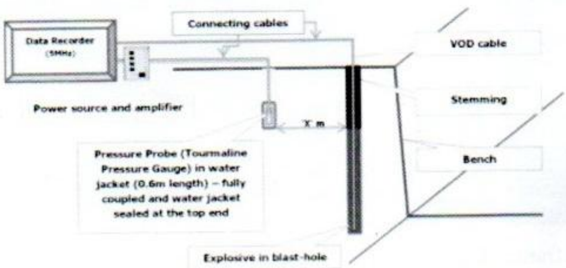

Figure 4 - Method for monitoring of velocity of detonation and pressure at a distance

Detonation and Breakage Performance of a Hydrogen Peroxide-based Explosive Formulation

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ABSTRACT

A novel explosive formulation that substitutes the use of ammonium nitrate (AN) with hydrogen peroxide (HP) as the main oxidising agent has been developed and tested as part of an Australian Coal Industry Research Program (ACARP) project. The main objective was to provide a step-change solution that has the potential to completely eliminate NOx fumes in blasting. The development of this HP / fuel-based explosive started with a comprehensive detonation characterisation program, consisting of unconfined velocity of detonation (VOD) measurements of samples at different diameters, densities and void sensitization techniques. VOD results showed that the HP/fuel-based explosive mixtures behaved similarly to non-ideal commercial explosives; in that way mixtures could be tailored to achieve specific detonation performance targets. The next stage of testing in this development involved preliminary confined tests to evaluate the rock breakage potential of the HP / fuel-based explosive mixtures. Fully instrumented single-hole tests were conducted in a limestone quarry. Results from these preliminary trials confirmed the rock breakage performance of HP / fuel-based explosive mixtures. The confined VOD measured in one of the tests was 5100 m/s in a 102 mm diameter blasthole at a density of 0.96 g/ml. The corresponding borehole pressure measurement of this HP charge was 2.61 GPa with a detonation temperature of 2921°C. Based on near-field accelerations, both HP and ANFO charges displayed similar attenuation characteristics in the test conditions. Post-blast observations indicated that the breakage performance of the HP mixtures clearly reflected the in-hole detonation performance measurements obtained, confirming the ability of these explosive mixtures to both fragment and effectively displace the rock mass under evaluation. Further research work continues with the future commissioning of a prototype mixing and delivery unit, the successful completion and analysis of data from multiple-hole trials, and further characterisation work associated with product stability, reliability and performance under different geotechnical conditions.

Higher Energy Bulk Explosives Matching Products to Rock Types Using an Energy Map Concept

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ABSTRACT

Bulk explosives provide the energy to move a rock mass and reduce it to an optimal size (fragmentation). The intensity of energy needed depends on several factors including a customer's geology and end objectives. An energy mapping tool has been developed to help customers to determine their bulk explosive needs based on these objectives.

At one end of the energy map dealing with high-energy products, a new range of bulk explosives products for surface mining have been developed. With these products, it is possible to provide blast designs with up to nearly triple the relative bulk strength (RBS) of ANFO, and address primary focus areas for mining operations, including the reduction of drill and blast costs, improvements in production rates, better face advance through improved broken stock management, better drill productivity, improved milling efficiency and lower energy costs in surface mines.

In this paper, field trial results from the first level of new high-energy products are presented. These products have an RBS 2.25 times that of ANFO. Industry variations of a smaller diameter (89 mm) pumped product for civil quarrying applications, and for large diameter (311mm) hard rock metalliferous mines are presented. For both cases the run-of-mine fragmentation levels obtained with the new bulk explosives are contrasted with the fragmentation profile generated with the currently accepted product range applied in similar geological conditions. The new products show increased fragmentation across the measured size distribution, with reduction in P_{50} values of 20 and 37 per cent over the currently used product for the 311 mm and 89 mm diameter blastholes respectively,

Advanced Technology for Setting out of Blastholes and Measurement while Drilling

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ABSTRACT

The goal of this project has been to digitise and use drill parameter data from rotary drilling (measurement while drilling; MWD) for a more effective planning of the blasting process in surface mines. A more accurate and reliable digital drilling and automatic hardness identification technology was developed, which includes both a hardware and software system. In the aspect of hardware, we designed a positioning, navigation and hardness perception terminal system which consists of a global positioning system original equipment manufacturer board, programmable logic controller and sensors of measuring major parameters, and a wireless data transmission system which combines digital blasting platform and wireless transmission facilities. In the aspect of software we developed the navigation software of locating blastholes using LabVIEW and C++, and the blasthole design software using AutoCAD ActiveX (C#) technologies. This new technology is applied at Jiangxi Dexing Copper Mine, and initially realising the digitisation of drilling and hardness identification in blasting zone.

A Holistic Approach to Managing Blast Outcomes

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ABSTRACT

Rio Tinto's Hunter Yalley Operations is a large open pit coalmine situated in the heart of the Hunter Valley in Australia, The Riverview West Pit has faced increasing production challenges in recent times due to decreasing dragline strike lengths and increasing environmental constraints on vibration, overpressure and fume generation. Conventional mining techniques would involve five to six production blasts per strip to recover multiple coal. seams, Each blast event carries the risk of exceeding the strict environmental requirements. By working collaboratively with Orica it was realised that the blasting method known as Stratablast™, in conjunction with advanced computer modelling techniques, could provide productivity gains whilst simultaneously providing more control over the environmental effects and the impact on nearby infrastructure.

As a result of this change, the number of blasts, per strip was reduced to one, with the implication that a great deal of care and forethought was needed to manage the increased challenge posed by multiple constraints in the proposed mining area. This innovative approach of combining throw and stand-up blasts allowed the extraction of all major coal seams in a single pass blast event. The blasts, were initially designed with a large factor of safety to stay within environmental limits as they were over 1.1 km in strike length with more than 800 holes and with a total charge weight of about 1000 t of bulk explosives. Furthermore, there were conflicting priorities around the desired blast outcomes. So far, 11 such blasts have been designed and successfully filled. After each blast, innovative design changes have been iteratively implemented to provide further control over environmental impacts, whilst continuing to improve productivity. As a result of these changes, blasts have progressively increased in complexity with the inclusion of features such as, damage zones, mid-spliting, time gaps and different directions of firing. The consequence of this complexity is that the blast duration can be as long as 28 seconds to accommodate all components of the blast.

This project has increased the productivity of the Riverview West Pit through blast design improvements and allowed the environmental impacts to be managed with far more control and predictability than would have been possible under a conventional blasting regime. There still remains room for further optimisation of mine productivity and this is being addressed through a process of continuous improvement.

Physical and Technical Evaluation of Possibility Using Low-density Explosives in Smooth Blasting

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ABSTRACT

It was demonstrated that the stable propagation of the explosive process is possible in low-density emulsion explosives (EEs) obtained through mixing of emulsion with a significant amount of expanded polystyrene (or other similar) granules. Such a process takes place in the form of a detonation-like wave of emulsion drops in explosive gas streams flowing out of the high-pressure area of the reaction zone.

Chemical reaction in such EEs takes place in the form of surface combustion of emulsion particles interacting with the gas stream. A method was developed for determining parameters of decomposition of low-density EEs, and it was demonstrated that a gradual pressure increase takes place in products during the explosion of such EEs.

The performed analytical research allowed low-density EEs (obtained through mixing of emulsion with a significant amount of expanded polystyrene) to be recommended for smooth blasting.

Industrial-experimental blasts at quarries of Ural and Siberia, with extreme positioning of sides and using low-density EEs, have confirmed the viability of the recommendations given.

The obtained results are useful in the advancement of smooth blasting technology using low-density EEs.

RECENT PATENTS OF INTEREST (2016)

United States Patent Application
THOMSON; Stuart Patrick ; et al.

20160146588
May 26, 2016

Method of Underground Rock Blasting

Abstract

A method of blasting rock at an underground blast site in which boreholes (11a, b, c) are drilled in a rock mass 10 from a drive defining face 12, each borehole is loaded with at least one charge of explosive material (13a-c, 14a-c, 15a-c), at least one detonator is placed in operative association with each charge, and a sequence of at least two initiation events is conducted to blast the rock mass, in each of which only some of the charges are initiated, by sending firing signals to only the detonators associated with said charges and in which each initiation event is a discrete user-controlled initiation event. In one of the at least two initiation events a stranded portion of the rock mass such as a pillar is created that has already been drilled and charged, and the stranded portion of the rock mass is blasted in a subsequent one or more of the at least two initiation events without personnel accessing said stranded portion. First explosive charges (13a, b, c and 15a, b, c) may be blasted in the one initiation event, leaving a pillar of stranded ore with the preloaded borehole 11b extending through it. The detonators may be wireless.

Summary of the Invention

[0013] It is an object of the present invention to provide methods for improved blasting of rock at an underground location.

[0023] The method of the invention requires accurate initiation of the detonators, and in embodiments the detonators may be electric or electronic detonators. In a particular embodiment, the detonators are electronic. Such electronic detonators may be wired or wireless. However, there is a risk that wiring connecting, for example, a blasting mechanism to the detonators that are initiated in a subsequent one of the at least two initiation events may be damaged by the earlier initiation, and for this reason wireless detonators are likely to be selected.

Inventors : **Thomson; Stuart Patrick**; *(Singapore, SG)* ; **Freeman; Sean Michael**; *(Leederville, AU)*
Assignee : **Orica Explosives Technology Pty Ltd.** Melbourne Victoria AU

United States Patent Application
ZANK; Johann; et al.

20160145165
May 26, 2016

A Method of Producing an Explosive Emulsion Composition

Abstract

A method of producing an explosive composition comprising a liquid energetic material and sensitizing voids, the sensitizing voids being present in the liquid energetic material with a non-random distribution, which method comprises: providing a flow of liquid energetic material; and delivering sensitizing voids into the flow of liquid energetic material in a series of pulses to provide regions in the liquid energetic material in which sensitizing voids are sufficiently concentrated to render those regions detonable and regions in the liquid energetic material in which the sensitizing voids are not so concentrated.

Summary of the Inventions

[0012] In an embodiment, the present invention provides a method of producing an explosive composition comprising a liquid energetic material and sensitizing voids, the sensitizing voids being present in the liquid energetic material with a non-random distribution, which method comprises:

Providing a flow of liquid energetic material; and delivering sensitizing voids into the flow of liquid energetic material in a series of pulses to provide regions in the liquid energetic material in which sensitizing voids are sufficiently concentrated to render those regions detonable. It will be appreciated that there will also be other regions in the liquid energetic material in which the sensitizing voids are less concentrated or absent, rendering different detonation properties in these

Inventors : **ZANK; Johann**; *(Valentine, AU)* ; **RAYSON; Mark Stuart**; *(Tuggerawong, AU)* ; **SUJANSKY; Vladimir**; *(East Burwood, AU)* ; **WALTER; James**; *(Cottesloe, AU)* ; **KIRBY; Ian John**; *(Ayr, GB)* ; **COOPER; John**; *(Ayr, GB)*
Assignee :

United States Patent Application **20160146587**
ZANK; Johann; et al. **May 26, 2016**

Explosive Composition Manufacturing and Delivery Platform, and Blasting Method

Abstract

A mobile manufacturing and delivery platform that is adapted to provide in a blasthole an explosive composition comprising a liquid energetic material and sensitizing voids, the sensitizing voids being present in the liquid energetic material with a non-random distribution. The platform comprises a storage tank for the liquid energetic material; at least two delivery lines for conveying respective streams of the liquid energetic material from the storage tank; a void delivery system for producing sensitizing voids in at least one of the streams of liquid energetic material; a mixer for mixing the streams of liquid energetic material to produce the explosive composition; and a blasthole loading hose. The mixer may be provided at the end of the loading hose. A blasting method employs the platform to manufacture and deliver the explosive composition into a blasthole, which composition is subsequently detonated.

Summary of the Invention

[0109] In accordance with a first embodiment of the invention there is provided an explosive composition comprising a liquid energetic material and sensitizing voids, wherein the sensitizing voids are present in the liquid energetic material with a non-random distribution, and wherein the liquid energetic material comprises (a) regions in which the sensitizing voids are sufficiently concentrated to render those regions detonable and (b) regions in which the sensitizing voids are not so concentrated, wherein the explosive composition does not contain ammonium nitrate prill.

[0110] The explosive composition of the present invention is defined with reference to its internal structure. The liquid energetic material comprising (a) regions in which the sensitizing voids are sufficiently concentrated to render those regions detonable and (b) regions in which the sensitizing voids are not so concentrated, rendering different detonation characteristics. Thus, a charge made up (entirely) of liquid energetic material in which the sensitizing voids are sufficiently concentrated to render the liquid energetic material detonable will have different detonation characteristics when compared with a charge made up (entirely) of liquid energetic material in which the sensitizing voids are not so concentrated. The (regions of) liquid energetic material having lower concentration of sensitizing voids (i.e. those regions "in which the sensitizing voids are not so concentrated" may be per se detonable but with reduced detonation sensitivity when compared with (those regions of) liquid energetic material including higher concentration of sensitizing voids. Alternatively, (the regions of) liquid energetic material having lower concentration of sensitizing voids may be per se non-detonable.

[0111] Herein differences in detonation sensitivity relate to the intrinsic sensitivity of the individual regions, and also concentration of the sensitizing voids present within the regions, of liquid energetic material. It is generally accepted that the sensitivity of an energetic material to shock wave initiation is governed by the presence of the sensitizing voids. Shock-induced void collapse due to application of a shock wave is a typical mechanism for hot spot formation and subsequent detonation initiation in energetic materials. The generation of the shock induced hotspots, or regions of localized energy release, are crucial processes in shock initiation of energetic materials. The effectiveness of the shock initiation further depends on the amplitude and duration of the shock wave.

Inventors : **ZANK; Johann**; *(Valentine, AU)* ; **RAYSON; Mark Stuart**; *(Tuggerawong, AU)* ; **SUJANSKY; Vladimir**; *(East Burwood, AU)* ; **WALTER; James**; *(Cottesloe, AU)* ; **KIRBY; Ian John**; *(Ayr, GB)* ; **COOPER; John**; *(Ayr, GB)*

Assignee : .

United States Patent Application **20160153752**
N V; Srinivaso Rao ; et al. **June 2, 2016**

Detonator

Abstract

In the present invention; a new detonator was developed which can be used with safety fuse, electrical fuse head or non-electric shock tube. It can be instantaneous or with delay. These detonators are made without any lead salts and sensitive primary ***explosives****. These detonators are safe to handle. These detonators function exactly like conventional detonators. The application of these detonators is also same as that of conventional detonators. The safety in handling is very high when compared to conventional detonators*

Inventors : **Lorenzo; James M.**; *(Mars, PA)* ; **Pyles; Robert A.**; *(Bethel Park, PA)*

Assignee : .

United States Patent Application **20160265883**
Lorenzo; James M. ; et al. **September 15, 2016**

Energy Absorber for High Performance Blast Barrier System

Abstract

The present invention provides an energy absorber for a blast barrier system comprising a substantially tubular member extending longitudinally along an axis from a first end portion to a second end portion, each of the first end portion and the second end portion having a substantially similar geometric, profile, wherein the energy absorber collapses under a predetermined load when compressed by a residual blast force. The energy absorber of the present invention may help minimize damage to people and structures by further dissipating force from a blast in a blast barrier system.

Inventors : **Lorenzo; James M.**; *(Mars, PA)* ; **Pyles; Robert A.**; *(Bethel Park, PA)*

Assignee : .

SPECIAL REPORT

IME

institute of makers of explosives

The safety and security institute of the commercial explosives industry since 1913

ISSUE BRIEFS (2016)

We are presenting below a selected set of 'Issue Briefs' that were prepared by IME during 2016, to assist the Legislators and the Regulators in formulating policies and standards with regard to Safety and Security of commerce and use of explosive products in the USA. We are grateful to Ms Debra S. Satkowiak, President, IME, for permitting us as 'Liason Member', to publish the ' Issue Briefs -2016' for the benefit of the explosives industry in India. We also appreciate that Ms Satkowiak, very kindly consented to formally preface the briefs.

Editor

Preface

For more than 100 years, the Institute of Makers of Explosives (IME) has pursued the commercial explosives industry's desire to promote the safety and security of explosives products. The membership of IME includes manufacturers, distributors, and transporters of commercial explosives, and the firms that support them. Since IME's inception in 1913, the member companies of the Institute have worked cooperatively on a wide variety of endeavors including, the development of safety standards and industry best practices, ensuring the security of commercial explosives from their initial manufacture through their end use, and working with the U.S. Congress and Federal and State agencies to see that laws and regulations affecting the industry are reasonable and effective.

In furtherance of these goals, IME publishes a series of Safety Library Publications (SLPs), instructional videos, and guidance documents. IME also prepares "Issue Briefs," to assist in explaining the Institute's views on current legislative and regulatory issues to Congress, regulators, and the public. Issue Briefs succinctly describe IME's positions on topics important to the industry in order to inform and educate lawmakers and other interested persons, and to invite further inquiry.

A number of IME's Issue Briefs are reproduced below, and describe issues that IME is currently engaged in on the legislative and regulatory front. As with all IME publications, the Issue Briefs are also available electronically, free of charge, on the Institute's website at www.ime.org. IME welcomes this opportunity to share these materials with the Visfotak community - Ms Debra S. Satkowiak, President, IME

1.0 Environment

1.1 Fumes from Blasting

Issue : Should the Department of Interior's Office of Surface Mining Reclamation and Enforcement (OSMRE) promulgate a standard prohibiting visible emissions from blasting operations?

Background: In April 2014, WildEarth Guardians (WEG) petitioned OSMRE to consider a rule to prohibit the production of visible nitrogen oxide (NO_2) during blasting operations for coal mining activities. IME believes that such a standard would be unattainable on a reliable and consistent basis.

Discussion: The detonation of explosives involves a chemical reaction that unavoidably results in the production of certain gases. While steps can be taken to help reduce the production of gases, they cannot be eliminated altogether. During blasting operations, ideal conditions are rarely, if ever, encountered. The contamination of the explosives products with ground or surface water and drill cuttings, reactivity of the explosives with the rock or other materials being blasted, instability within boreholes, and subsurface geological formations will impact emissions. All of these frequently encountered and largely uncontrollable elements affect the explosive quality and chemical kinetics of the product.

While attempts can be made to minimize emissions, the environmental variables discussed above cannot be eliminated or influenced in a manner that would allow the categorical "prevention" of visible emissions in all cases. There is no way to prospectively determine, from a technical or scientific perspective, whether all conditions affecting blasting will be optimum from shot to shot.

In addition, we do not agree that varying opacity of visible emissions generated by blasting can be equated to the concentration of NO_2 in the "cloud." Because of the inherent difficulties involved in obtaining direct measurements of particular gases in post-blast emission clouds, opacity monitoring has been used as a fall back measure to alert workers and the public of the presence of some amount of NO_2. Opacity is not, however, an accurate means of determining actual concentrations of the chemical. Color perception is highly subjective and is influenced by numerous other factors including the intensity of the sunlight, the perspective/location from which a visible emission is viewed, the presence of other particulates in the ambient air, and the background against which an emission is viewed. It cannot be used as a measure of regulatory compliance.

Existing regulations administered by OSMRE, EPA, and MSHA also safeguard mine employees and surrounding communities. These regulations, in tandem with the voluntary efforts of mine operators in implementing extensive administrative controls operate in unison to successfully ensure the safety of workers and the public.

Recommendations: IME recommends that mine operators continue to work with blasters within the confines of current regulations, augmented by administrative controls, to minimize emissions. No additional regulatory action is necessary at this time.

1.2 Risk Management Program and Ammonium Nitrate Prill (AN)

Issue: In order to ensure public and environmental safety, is it necessary to expand the Environmental Protection Agency's (EPA) Risk Management Program (RMP) to cover AN?

Background: The White House issued Executive Order 13650, *Improving Chemical Facility Safety and Security* (EO). Section 6(c) of the EO, among other things, instructs EPA to determine if RMP can and should be expanded to cover AN.

AN is an indispensable ingredient in blasting agents used in mining, construction, and other essential industries. Currently, upwards of 75 percent of the billions of pounds of AN consumed annually is manufactured for the explosives industry. AN-based blasting agents have become the most widely used explosive materials in the world since their introduction in the 1950s. There is no viable alternative.

The "technical" grade of AN used in the explosives industry has the same chemical composition as the "fertilizer" grade of AN used in the agricultural sector, only the density of the prill is different. AN, in either form, is not self-reactive and does not pose a threat of an accidental release of energy or fumes unless subjected to substantial and sustained heat (e.g., fire) or shock from high explosives. Since 1971, manufacture and storage of AN has been regulated under OSHA rules found at 29 CFR 1910.109(i) that specifically address the specific properties of this material. There has been no known accidental detonation of AN where a facility has been compliant with this OSHA standard. In addition, AN is subject to a number of other ATF, EPA, DHS, OSHA and DOT safety and security regulations.

EPA's RMP is part of the federal government's response to the catastrophic accident in Bhopal India. The intent of RMP is to prevent accidental releases to the air and mitigate the consequences of releases that do occur by focusing prevention measures on extremely hazardous substances that pose the greatest risk to the public and the environment.

Discussion: The insensitivity of AN renders the material highly unlikely to mass-detonate during manufacturing, storage, and transportation. DOT acknowledges AN's insensitivity, classifying it as a Division 5.1 oxidizer and listing it as a "Table 2" not "Table 1" material. Likewise, OSHA has never regulated AN manufacturing under PSM program, which also stems from the Bhopal incident. The imposition of requirements as complex as those under the RMP to the storage of a stable, insensitive substance would be superfluous and would be unlikely to incrementally increase the margin of public safety. AN does not pose the type of threat that RMP is intended to address, and it is adequately and safely controlled under other federal programs.

Recommendations: IME recommends that any proposal to expand RMP to cover AN be rejected. Existing federal regulations applicable to this material is sufficient to ensure its safe handling and management. The addition of yet another layer of regulation would do nothing to safeguard the public or the environment.

2.0 Safety

2.1 Process Safety Management and Ammonium Nitrate Prill (AN)

Issue: In order to ensure workplace safety, is it necessary to expand the Occupational Safety and Health Administration's (OSHA) Process Safety Management (PSM) program to cover AN?

Background: The White House issued Executive Order 13650, Improving Chemical Facility Safety and Security (EO). Section 6(c) of the EO, among other things, instructs OSHA to determine if PSM can and should be expanded to cover AN. AN is an indispensable ingredient in blasting agents used in mining, construction, and other essential industries. Currently, upwards of 75 percent of the billions of pounds of AN consumed annually is manufactured for the explosives industry. AN-based blasting agents have become the most widely used explosive materials in the world since their introduction in the 1950s. There is no viable alternative.

The "technical" grade of AN used in the explosives industry has the same chemical composition as the "fertilizer" grade of AN used in the agricultural sector, only the density of the prill is different. AN, in either form, is not self- reactive and does not pose a threat of an accidental release of energy or fumes unless subjected to substantial and sustained heat (e.g., fire) or shock from high explosives. Since 1971, storage and handling of AN has been regulated under OSHA rules that specifically address the properties of the material. These rules at 29 CFR 1910.109(i) are based on NFPA safety standards. There has been no known accidental detonation of AN where a facility has been compliant with this OSHA standard. In addition, AN is subject to a number of other ATF, EPA, DHS, and DOT safety and security regulations.

OSHA's PSM standard implements section 304 of the Clean Air Act Amendments (CAAA). The CAAA was enacted in response to the catastrophic accident in Bhopal, India. Section 304 required OSHA to promulgate a chemical process safety standard to prevent accidental releases of highly hazardous chemicals that could pose a threat to employees. The PSM standard requires employers to complete 14 hazard assessment actions related to chemical processes.

Discussion: AN does not pose the type of threat that the extensive PSM requirements are intended to address. OSHA excluded blasting agents, which, while very insensitive, are a class of explosives, from PSM concluding that "blasting agents do not pose the potential catastrophic consequences to employees required of chemicals subject to [PSM]." Similarly, AN, the principal ingredient in blasting agents, also is excluded. If properly managed under existing OSHA's 29 CFR 1910.109(i) standards, AN is stable, its behavior is known, understood, and predictable, and does not present a hazard to workers or the public. Meanwhile, the NFPA's AN standards have been updated. Since this is a "voluntary consensus standard", it has special standing under the National Technology Transfer and Advancement Act. This Act states that Federal agencies "shall use technical standards that are developed or adopted by voluntary consensus standards bodies, using such technical standards as a means to carry out policy objectives or activities."

Recommendations: IME recommends that any proposal to expand PSM to cover AN be rejected. Given the decades-long safety record of the OSHA standard, imposing a complex regulatory program like PSM would only add cost and significantly burden impacted small businesses. Any new safety standards for the storage and handling of AN should be based on the revised NFPA code or other applicable best-practice standards.

3.0 Security

3.1 Drone (Unmanned aircraft Systems/UAS) Safety & Security

Issue: What safety and security concerns about the operation of drones justify federal control and regulation?

Background: The use of drones and advances in UAS technology are on the rise. Currently, drones are beneficially used by a wide range of industries. The explosives industries rely on drones to assess the safety of re-entering post-blast sites at mines and quarries. Critical infrastructure, including explosives manufacturing sites, benefit from the use of drones inspect process pipe for leaks, examine flare stacks for maintenance issues, and even assess tanks when it would be too dangerous for a person to enter. Drone technology that would safely allow flight beyond the line of sight of operators and use at night are examples of technological advances that would greatly benefit industry.

There have been numerous incidents of drones conducting unauthorized flights over critical infrastructure. Some fly-overs may be by unknowing hobbyists. However, drones can be used for surveillance or mapping of a critical infrastructure site. Drone video footage of our nation's critical infrastructure has been posted to websites such as YouTube without consent of the owner/operators of the facility. As such, bad actors could use this information for nefarious purposes, including to attack critical infrastructure. There are also real and present safety concerns with unauthorized drones flying over or making contact with a critical infrastructure facility. A drone that loses control and crashes, or if it is armed, could cause significant damage and injury.

Discussion: In response to these concerns and needs, state legislatures across the country have been actively moving UAS legislation forward. In 2015, 45 state legislatures considered over 160 bills related to drones. While not all of these bills passed their respective state legislatures, it is important to recognize that drone issues are gaining increased attention at the state level. For example, five states Arkansas, Florida, Louisiana, Nevada and Texas passed legislation that addresses unauthorized drone fly-overs. While we welcome this attention, a streamlined, national policy approach on the use of drones is needed. A patchwork of differing state laws and regulations will ultimately make compliance more difficult for both UAS manufacturers and users. The pending Federal Aviation Administration's Notice of Proposed Rulemaking (NPRM) would provide safety rules for small UAS (under 55 pounds) conducting non-recreational operations, but the NPRM fails to address the unauthorized use of drones near or over critical infrastructure facilities.

Recommendation: We support the safe use of drones and we do not want to limit this new innovative technology. However, there should be limits to prevent unauthorized drone operations over critical infrastructure because of the potential safety and security risks they can clearly pose to facility operations, workers, and surrounding communities. We strongly urge Congress to address the unauthorized use of drones this year as part of its efforts to reauthorize the Federal Aviation Administration.

3.2 Security Marking of Explosives

Issue: Should there be a global standard for formatting security markings on explosive products?

Background: The United States was the first country to require the security markings on explosive products. The markings are essential to identify the last legal possessor of the product. Subsequently, other nations have developed standards for marking.

Discussion: Unfortunately, the format for the markings has not followed a consistent pattern. Not only does this present an artificial barrier to trade, but it hampers the ability of law enforcement to interpret and act on the information provided by the markings that are from different countries. This haphazard approach does nothing to aid or encourage countries that currently have no marking requirements to adopt and implement them. These factors undermine the effectiveness of these markings.

To address this situation, IME has developed a globally harmonized format for explosives security markings that is based on the marking format required by European Commission Directive 2009/43/EC. The IME is sponsoring a proposal[1] before the United Nations Sub- Committee of Experts on the Transport of Dangerous Goods (UNSCETDG) to include this marking standard in Chapter 1.4 of the United Nations Recommendations on the Transport of Dangerous Goods, Model Regulations.[2]

Recommendations: IME recommends:

- Global support for the IME proposal described above during the 2015-16 biennium of the UNSCETDG.
- That nations with explosives security marking requirements in effect adopt the proposed globally harmonized format as the preferred format, or as an acceptable alternative format, for explosives security markings required in their countries.
- That nations which are in the process of developing requirements for explosives security markings utilize the proposed globally harmonized format as the preferred format, or as an acceptable alternative format, for explosives security markings to be required in their countries.
- That nations which have not implemented explosives security marking requirements consider doing so and that they adopt the proposed globally harmonized format as the required format for explosives security markings required in their countries.

4.0 TECHNICAL

4.1 Ammonium Nitrate Detonability Question

Issue : Is ammonium nitrate (AN) prill a Class 1 explosive or not?

Background: Since the tragic 2013 incident at West, TX involving AN, some assert that AN has a TNT detonability equivalence of 0.72, a metric approaching the globally-accepted value of "ANFO" (ammonium nitrate fuel oil), a Division 1.5 explosive.[1] Others assert that the technical grade of AN (TGAN) used in the explosives industry is inherently "explosive" while the fertilizer grade (FGAN) used in the agricultural industry is not.

Discussion: AN is a stable, noncombustible chemical compound. The chemical structure of TGAN and FGAN is the same, NH_4NO_3. The only difference is the density of the finished prill. TGAN is less dense than FGAN.

AN is not an explosive. It has been classified as an oxidizer by the U.S. Department of Transportation. (DOT) and by the National Fire Protection Association (NFPA) based on prescribed tests.

While AN prill is not an explosive, it can detonate under extreme conditions such as shock from an explosion or intense and sustained heat because it contains an ammonium molecule (NH3) which acts as an inefficient fuel meaning that there is not enough fuel to consume all the oxygen supplied by the No3 molecule. In a fire, AN can melt 3 at 337 F° and decompose at 410 F°. This physical change increases the likelihood of a thermal explosion. Likewise, AN that is exposed to a shockwave from an explosion may be heated from the extreme compression to the point of decomposition and may detonate if the pressures are high enough and sustained long enough. When melted, there is no difference between FGAN and TGAN.

Determining a TNT equivalence based on this inefficiency has produced a range of results. The highest theoretical value in this range, based on the Thermodynamic Code "TDS", predicts a 0.42, not a 0.72, TNT equivalence. This means that the maximum amount of energy that could be expected from a detonation of AN would be no more than 42% of same amount of TNT.[4] Other subject matter expert sources have predicted ratings as low as 0.25 TNT equivalence.[5] The explosive inefficiency of AN also accounts for the fact that not all product will contribute to the detonation.

Recommendations: Additional studies and testing may validate or lead to reducing the TNT equivalence for AN. Until testing shows otherwise, AN prill, if managed properly, is an inert material which will not detonate. In the meantime, emergency responders should be trained not to attempt to fight that have engaged AN and to evacuate at-risk populations.

4.2 Taggants in Explosives

Issue: Should taggants be mandated in commercial explosives?

Discussion: Taggants can refer to two types of marking before technologies. Detection taggants are used to detect explosives before detonation. Identification taggants are intended to be used to trace explosive materials to their source before and after detonation.

The Antiterrorism and Effective Death Penalty Act of 1996 (ATEDPA) requires detection agents for plastic bonded explosives (PBX). These agents enhance the detection of PBX which has historically been used by terrorists around the world. It is possible to add these detection agents to PBX without compromising their intended performance. IME supports the marking of PBX with detection agents. However, identification taggants present a different story.

From time to time, efforts are made to require identification taggants in explosives. The ATEDPA mandated a study of the feasibility of placing identification taggants in industrial explosives. The Bureau of Alcohol, Tobacco, Firearms, and Explosives (ATF) was tasked with this responsibility and The National Academy of Sciences (NAS) was contracted to conduct a third-party examination.

IME has worked closely with both the ATF and NAS to ensure that industry data was available to complete the study. The NAS report, completed and issued in March 1998, concluded:

"At today's level of threat, it is not appropriate to require commercial explosives to contain identification taggants. All of the taggant technologies currently available raise concerns about long-range environmental consequences, effectiveness in law enforcement, safety issues, and costs."

The ATF issued an Interim report in March 1998 and also concluded:

"At this stage of the Study it is clear that ... there are remaining complexities surrounding the issue. Any effort which is to have a measurable impact on the prevention and investigation of bombing incidents must be an integrated one, involving the effective regulation of explosives and explosive materials, the effective enforcement of those regulations, and the effective application of cutting edge technologies."

IME's position is consistent with these findings:

Less than 1 percent of the bombings in the United States involve commercially manufactured high explosives.

- Placing identification taggants in commercially manufactured high explosives is only minimally beneficial to law enforcement and in many cases may complicate the investigation and prosecution of a bombing.
- Countries which have faced real terrorism problems, such as Israel, Ireland, Germany, Japan, and Great
- Britain, have not adopted a taggant program and do not intend to do so.
- The substantial costs associated with placing taggants in commercially manufactured high explosives are not justified by the minimal benefits.

Recommendation: Any mandate for the addition of identification taggants must be based on sound science and a cost-benefit analysis. It is not in the best interest of the industry, public, the environment, or law enforcement to mandate identification taggants in commercial explosives at this time.

SPECIAL REPORT

SAFEX INTERNATIONAL

Safex International

'Safex Incidents Notices' : March, 2015 to March, 2016

Summary

Activity				No. of Incidents
* Manufacturing :	Fixed Plant			
	HE		3	
	Explosive Accessories		9	
			12	12
Mobile Manufacturing Unit (MMU)			-	-
* Handling :	Within Plant Area		-	
	Outside Plant Area		1	
			1	1
* Storage :			-	-
* Transportation	Vans		-	
	MMU		-	
			-	-
* Waste / unused explosives disposal, etc.			2	2
			TOTAL	15

Almost all the incidents were due to human errors either arising from lack of due diligence during supervision / lack of awareness.

- Editor

1

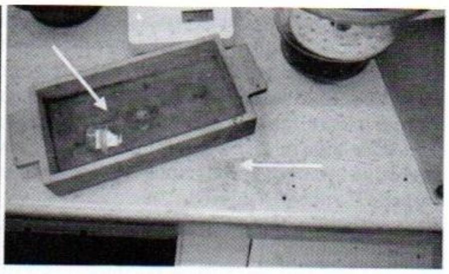
1) **INCIDENT TITLE : 11 June 2014:Czech Republic Lead Azide Explosion**

2) **INCIDENT OUTLINE**

a) **What material was involved :** 1.6 g of Lead Azide (LA)

b) **What happened**: 1.6 g of LA were initiated when a female operator was moving the second closed glass weighing container from the scale back to the tray on the table. The explosion did not propagate to the first weighing container in the wooden tray. It toppled over and LA was spilt over the tray.

Likely position of the operator at the time of the incident



Tray and location of ignition

The actual operation is to weigh the container with LA, put it in a heating cabinet for a predetermined time and weigh it back to determine the water content.

c) **Why did it happen theory** : Numerous tests were done to check friction, potential changes of surfaces on smoothness and electrostatic behaviour without obvious findings. The workplace arrangement is designed for a right hander to operate. The operator conducting the measurement is left-handed and may have dropped or tipped over the glass container with her wrist/wrist band to supply sufficient energy for the LA to initiate.

d) **What was the impact** : The operator suffered shock and left hand and forearm lacerations from glass splinters that had to be treated at the hospital. Minor material damage.

3) **COMMENT**

a) **Value of incident** : The design of manual workplaces handling sensitive explosives has to look at all details. Change management has to be applied when personnel and working characteristics change. This being an 'old' operation, all lab procedures and arrangements (e.g. looking for potential transmission effects) were reviewed in detail and several improvements were made.

b) **Observations :**

2

1) **INCIDENT TITLE :** 3 Sep 2014: Fire in the outside filter unit of a loading line building

2) **INCIDENT OUTLINE**

a) **What material was involved :** An estimated total of 5 kg of delay powder (in filtering unit)

b) **What happened**: At the loading line, adhesive residues of delay powder are pressed out from trays in at a station designed for this purpose. As this procedure leads to occasional (technology related) ignition, the exhaust from this device is mixed with a fire suppressant additive in the ducting towards the filter unit. However, on the day of the incident, hot or burning particles were transmitted into the filtering unit on the outside of the building causing a fire inside the unit. The building was evacuated and the fire extinguished by the local fire brigade. The filtering unit had been installed 6 months before the incident.

c) **Why did it happen theory** : It appeared that the mixing ratio of fire suppressant/delay powder was not sufficient to prevent burning particles to be transmitted into the filter unit. Though certified by the supplier of the filter material, it had not been resistant to the effects caused by ignited delay powder.

d) **What was the impact** : There were no injuries. The filtering unit was destroyed. Material in process (400 detonator shells and open explosives/delay powder) had to be disposed due to contamination with smoke from the air ventilation system (backflow of fumes from the filtering unit into the building).

3) **COMMENT**

a) **Value of incident** : All scenarios for a potential transmission of an ignition should be risk assessed. Large scale (1:1) tests should be conducted to verify supplier information/certification

b) **Observations :**

3

1) **INCIDENT TITLE :** 29 October 2014: Indonesia Unplanned Detonation of a blast hole

2) **INCIDENT OUTLINE**

a) **What material was involved :** 80 Kg of emulsion based bulk explosive product at the blast hole which has been stemmed and tied in.

b) **What happened**: One blast hole detonated prematurely approximately 47 minutes after charging. The hole was 4meters deep, and had been loaded with 80kgs bulk product (70% emulsion/30% Ammonium Nitrate (AN) dry addition) into a plastic liner due to ground cavities. It was located at the free face in the northern part of the shot. There were 373 holes at the shot.
Detonation resulted in rock breakage and black smoke release, the hole initiated in full order. Diameter of crater was approximately 2 meters, fly rock distributed to radius approximately 20 meters. The nearest person was 70 meters from the hole that detonated. No one was injured.

c) **Why did it happen theory** : The event is believed to have been caused by hot and/or reactive ground coming into contact with the explosive. It is not known whether the detonator, booster, or bulk explosive was the first to react.
The pattern was drilled 4 days before the incident. It is possible that the drilling process led to the exposure of oxidisable sulphur and organic matter to air, allowing the ground heating process to begin. Liner was used in the blast hole due to ground cavities. The blast hole was at the free face, hence there may have been some incoming air, which may have assisted any oxidation reaction to proceed.
The hole showed signs of having an elevated temperature prior to loading. A temperature measurement was undertaken prior to deeming the hole to be safe to load, however, the actual temperature may not have been determined accurately due to incorrect measurement process, including using a measurement device inappropriate for the task. Subsequent laboratory testing revealed that the ground around the location of the blast was highly reactive with AN. Reactivity testing resulted in 6 out of 13 samples reacting with AN at 550C, some within a one hour time frame.

d) **What was the impact** : No one was injured.
The hole initiated in full order. Diameter of crater was approximately 2 meters, fly rock distributed to radius 20 meters

3) **COMMENT**

a) **Value of incident** : The Incident emphasises the importance of the implementation of controls set out in the AEISG Code of Practice Elevated Temperature and Reactive Ground.

b) **Observations : -**

4

1) **INCIDENT TITLE :** 8 December 2014-Australia:Propellant Colloid Extrusion

2) **INCIDENT OUTLINE**

a) **What material was involved :** Single base propellant colloid

b) **What happened**: During the blocking press operation propellant colloid from blocking press #6 was extruded out of the top of the press forcing the lid on the press to open. Colloid was extruded out, past the lid.

c) **Why did it happen theory** :Under investigation

d) **What was the impact** : There was no injury reported or ignition of propellant colloid as a result of this incident. There was some damage to the blocking press. This damage was largely limited to score marks that were found in the lid of the press.

3) **COMMENT**

a) **Value of incident** : This incident highlights that incidents can still occur in mature processes.

b) **Observations :**

5

1) **INCIDENT TITLE :** 6 March 2015- Australia Ignition During Propellant Colloid Pressing
2) **INCIDENT OUTLINE**
   a) **What material was involved :** Single base propellant colloid
   b) **What happened**: During a routine propellant colloid pressing operation, an operator heard a noise described as a loud pop that was followed by a rush of air and a cloud of smoke. All personnel present exited the building and the manual fire suppression water deluge was activated.
   c) **Why did it happen theory** : Under investigation
   d) **What was the impact** : There was no reported injury as a result of this incident, and no plant damage reported.
3) **COMMENT**
   a) **Value of incident** : This incident highlights that incidents can still occur in mature processes.
   b) **Observations :**

6

1) **INCIDENT TITLE :** 26 March 2015- Burning Ground Explosion Durango, Mexico
2) **INCIDENT OUTLINE**
   a) **What material was involved :** Contaminated (emulsion) film; 2 bags with shock tubes (cut off from detonators); to support the fire: wooden pallets, cardboard, 7 decontaminated hoses from suspended watergels production, Diesel fuel; unexploded detonators from a previous burning disposal
   b) **What happened**: On a previous burning cycle, old detonators had been burned in a fire (those had actually been intended to be disposed of by blasting) in the burning ground area.Shrapnel and unexploded detonators were scattered around. Without properly cleaning the area, contaminated film with residues of sensitized emulsion and fire supporting material had been stacked for the next burning cycle. Several minutes after the burning team (2 operators) had left the burning area (by car), an explosion occurred.
   c) **Why did it happen theory** : The exact reason for the explosion is yet unknown. It is assumed that remaining detonators located within the waste material pile exploded and initiated a subsequent explosion of sensitized emulsion in the film material (estimated net explosives amount 30 50 kg). The amount of material burned (pile size) suggests that explosive material had also been under confinement.
   d) **What was the impact** : The burning platform (reinforced concrete, located in a remote area) had been severely damaged. There were no injuries.
3) **COMMENT**
   a) **Value of incident** : Regarding the disposal of old detonators, existing procedures had been violated. Detonators must not be burned in the open. The burning process of material contaminated with sensitized emulsion had not been properly risk assessed (this was a new process after a new emulsion plant had been commissioned) and existing operating procedures for burning had not been adapted to this new process. In accordance, operators had not been trained and supervised appropriately. The burning ground is located in a remote area and secured. Personnel had moved to a safe distance according to the existing procedure (reducing consequences).
   b) **Observations :**

7

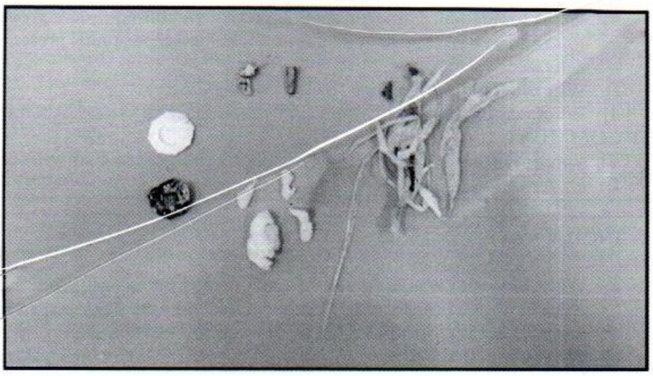
1) **INCIDENT TITLE : 1 April 2015 Portugal : Detonating Cord Destruction Detonation**
2) **INCIDENT OUTLINE**
   a) **What material was involved :** Detonating cord.
   b) **What happened**: The incident occurred while destroying detonating cord by burning in the quarry. The cord was burning for approximately 15 min. when the fire gave way to a detonation and, although nobody was injured the shock wave caused some minor damage in the vicinity.
   c) **Why did it happen theory** : The possible causes are still under investigation. More information will be reported when the investigation process is completed.
   d) **What was the impact** : Nobody was injured but the shock wave caused some minor damage in the vicinity.
3) **COMMENT**
   a) **Value of incident** : The importance and purpose of procedures to be followed to be understood by all employees working in the explosives environment.
   b) **Observations :**

8

1) **INCIDENT TITLE :** 01 July 2015: South Africa Emulsion pump explosion
2) **INCIDENT OUTLINE**
   a) **What material was involved :** UG100 a cap sensitive underground AN-only bulk emulsion matrix. Emulsion matrix is an oxidizing agent classified under the United Nations system (UN3375) as a dangerous good of Class 5.1, packing group 3.
   b) **What happened**: A progressive cavity emulsion transfer hopper pump, used to pump emulsion explosives into the silo started automatically after the emulsion plant was shut down for the evening. The pump ran dry which resulted in the explosion.
   c) **Why did it happen theory** : The incident is presently under investigation and the exact cause is therefore unknown. Emulsion explosives containing ammonium nitrate which is subjected to stimuli capable of causing an explosion can explode when exposed to extreme heat or fire, a combination of heat and pressure, contamination with fuels, organic matter and other chemicals or a combination of any of these.
   d) **What was the impact** : No people were injured in the explosion. Damage to infrastructure at the emulsion plant
3) **COMMENT**
   a) **Value of incident** : The true value of this incident can only be assessed once the investigation is complete and report issued.
   b) **Observations :**

9

1) **INCIDENT TITLE :** 14 July 2015 : Foreign bodies in emulsion PC pump in stationary manufacturing
2) **INCIDENT OUTLINE**
   a) **What material was involved :** Foreign bodies in emulsion PC pump
   b) **What happened**: The operator on duty reported a strange sound in a PC (progressive cavity) emulsion pump in line #1 of the packaged emulsion plant. The operation was stopped and the pump was dismantled. Pieces of cartridge film, aluminium clip parts, PE lumps (from cartridge film sealing) and pieces of plastic were identified (see photo below). Pump rotor, stator and joints did not suffer any significant damage.



   C) **Why did it happen theory** : The PC pump has a hopper with a mesh. Manually recycled emulsion is added to the hopper by pushing it through the mesh. There is a separate port to add recycling material by use of a diaphragm pump. This pump is also equipped with a hopper and a removable mesh (which was removed at shift start-up to pump start-up emulsion that will not be cartridged directly into the hopper of the diaphragm pump). Not following the operating procedure, operators on the previous shift removed the mesh to add recycling material (from out of spec and damaged cartridges) into the hopper of the diaphragm pump. The collecting tray contained other waste (PE lumps, plastic and aluminium clip pieces) that the cartridging operator did not separate from the cartridges/material to be recycled as it is required. Carelessly the contaminated material was then re-entered into the process. A mesh at the end of the pipe above the hopper of the dosing PC pump feeding the cartridging machine prevented the foreign bodies to move further.
   d) **What was the impact** : No damage. Loss of production.
3) **COMMENT**
   a) **Value of incident** : In spite of preventive measures in place, all scenarios should be thought through. Also, operational discipline and proper supervision are an absolute key to ensure safe operations. The night shift operator acted correctly to stop the operation and inform his supervisor about the strange sound.
   b) **Observations :**

10

1) **INCIDENT TITLE :** 22 November 2015: South Africa Shock – Tube Extrusion Line HMX/Al detonation
2) **INCIDENT OUTLINE**
   a) **What material was involved :** Approximately 250g HMX / Aluminium powder.
   b) **What happened**: An initial flash was observed, via the video footage, from the bottom of the 1st extruder head and the detonation of HMX/Al in the funnel takes place ~14 seconds later. No injuries occurred, but serious damage to the powder feed system was caused.
   c) **Why did it happen theory** : The most likely root cause of the initial flash was accumulated HMX/Al powder within the extrusion head, which ignited most likely due to the exposure of the powder to high temperatures for an extended time in the head. The ingress of powder into the head is possible from the bottom of the extruder, as well as from the top. Confinement of the HMX/Al in the funnel caused the ignition to build up to a detonation. The confinement was from the top by the charging valve, and from the bottom by the dosing roller, and this prevented sufficient venting of ignited powder.
   d) **What was the impact** : No people were injured in the explosion. Damage to the extrusion line, particularly the powder dosing system.
3) **COMMENT**
   a) **Value of incident** : The confinement of HMX/Al powder played a major role in the extent of the damage.
   b) **Observations :** None

11

1) **INCIDENT TITLE :** 26 January 2016:USA ,Flare Manufacture- Composition Ignition
2) **INCIDENT OUTLINE**
   a) **What material was involved :** Magnesium/ Teflon /Viton composition.
   b) **What happened**:Freshly mixed composition was falling off a vibrating bed dryer into a hopper when an ignition occurred.
   c) **Why did it happen theory** : Initial investigations suggest that composition has built up between vibrating and stationary equipment leading to a pinch.
   d) **What was the impact** : No one was injured. The building and equipment was badly damaged.
3) **COMMENT**
   a) **Value of incident** : -
   b) **Observations : -**

12

1) **INCIDENT TITLE :** 28 February 2016: Russia-HMX/Aluminium Powder Incident
2) **INCIDENT OUTLINE**
   a) **What material was involved :** A small quantity of HMX/Aluminium Powder composition for use in shock tube .
   b) **What happened**: The incident occurred at the shock tube manufacturing facility in the HMX/Aluminium powder feeding part of the shock tube line. The powder initiated (probably deflagrated) which caused a loud clap sound and high temperature .The operator stopped the line (dosing stopped automatically) when he heard the sound. He smelt smoke and subsequently found traces of burning in the flexible pipe.
   c) **Why did it happen theory** : The deflagration was probably caused by static electricity accumulating in the flexible cotton dusted pipe and accumulation of powder in the vibrating groove.
   d) **What was the impact** : There were no injuries to personnel or serious equipment damage. The flexible pipe was damaged and could not be used further.
3) **COMMENT**
   a) **Value of incident : -**
   b) **Observations : -**

13

1) **INCIDENT TITLE :** 07 October 2015: Brazil Emulsion pump deflagration
2) **INCIDENT OUTLINE**
   a) **What material was involved :** Bulk emulsion matrix, classified as oxidizing agent under the United Nations system (UN3375) as a dangerous good of Class 5.1. Quantity of explosives : 10 KG
   b) **What happened**: After finishing the batch of matrix at the end of the shift, the operator turned the pump off and left the production area in the evening. He assumed that pump had stopped but for some unknown reason it did not happen and the pump continued to run. After 50 minutes of dry running a deflagration occurred.
   There were no injuries and minimum damage when the deflagration occurred into the pipeline between the progressive cavity emulsion pump and the storage tank.
   c) **Why did it happen theory** : The exact cause is not known as yet. The investigation is under way and will analyse the possible contributory factors related to people, plant and procedures.
   d) **What was the impact** : There was limited damage to equipment: 2 meters of 2" steel pipe was destroyed. A nearby window was broken as well as part of the insulation of the storage tank. No environmental issues were encountered.
3) **COMMENT**
   a) **Value of incident** : This is the second pump incident this year and is a wakeup call for the whole industry to review pump safety matters in all areas where critical pumps are used
   b) **Observations :**

14

1) **INCIDENT TITLE :** 10 November 2015: Spain-Ignition of Propellant
2) **INCIDENT OUTLINE**
   a) **What material was involved :** Nitrocellulose.
   b) **What happened**: An initiation event took place during a manual cleaning operation at the bottom of an open nitrocellulose homogenizing tank that was being prepared for start-up.
   This initiation was quick and short, and the reasons for the initiation is still unknown.
   The internal Emergency Response Plans were activated and the zone isolated.
   c) **Why did it happen theory** : The reasons for the initiation are still unknown. An internal investigation team sponsored by the MAXAM Corporation and Expal Business Unit has been set up and the investigation is ongoing. The company is also collaborating with the local authorities to find the causes of the accident and prevent reoccurrence.
   d) **What was the impact** : Two workers that were doing tasks at the bottom of the tank suffered severe burns as a result of the thermal radiation.
   The workers were primarily treated by the local medical department and then transferred immediately to a nearby hospital, at the burn unit ICU in Murcia. The tank suffered no significant damage.
3) **COMMENT**
   a) **Value of incident** : The confinement of HMX/Al powder played a major role in the extent of the damage.
   b) **Observations :** None

15

1) **INCIDENT TITLE :** 01 March 2016 : Australia, Pyrotechnic Composition Fire
2) **INCIDENT OUTLINE**
   a) **What material was involved :** A quantity of Magnesium ,Teflon and Viton in acetone.
   b) **What happened**:It is believed that a small fire in a mixer transmitted through extraction to a wet scrubber which deflagrated.
   c) **Why did it happen theory** :The incident is presently under investigation and the exact cause is therefore unknown.
   d) **What was the impact** : No injuries to personnel, Minor damage to the interior of the building .The scrubber was destroyed.
3) **COMMENT**
   a) **Value of incident : -**
   b) **Observations : -**

सी.एस.आई.आर - केन्द्रीय खनन एवं ईंधन अनुसंधान संस्थान

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History :

The idea of "Visfotak" as a Scientific Society took birth in 1998, on the eve of the National Seminar on Explosives Safety and Technology *(Visfotak - 98),* when for the first time the three major constituents of the industry, viz. the Government Regulatory Bodies, the Manufacturers, and the Users respectively, were formally brought together on one platform to deliberate on common Concerns and Issues. Arising from the deliberations, a proposal to establish a Scientific Society exclusively dealing with the Safety & Technological aspects of the Explosives industry was unanimously endorsed.

Consequently, the Explosives Safety & Technology Society (Visfotak) was registered vide Certificate No. 410 / 99 (Nagpur) dated June 17th, 1999.

Objectives :

(a) To promote and develop modern concepts relating to safety and technology in manufacture, handling, and usage of explosives.
(b) To assist the Government of India through its appointed departments and officials in recommending, formulating policies pertaining to explosives manufacture, handling and usage.
(c) To hold seminars, workshops, conferences to promote interaction between the three constituents, viz. the Government regulatory bodies, the manufacturers of explosives and the users of Explosives, in the interest of the growth and health of the explosives industry.
(d) to collaborate with academic and research institutions in promoting the objectives mentioned above.
(e) To promote and strengthen affiliation with other world bodies / societies dealing with explosives safety and technology for exchange of information.
(f) To institute awards, fellowships and scholarships for the excellence in the field of explosives.

Governance :

The activities of the Society are overseen by a Governing Council, comprising of eminent professionals and technocrats, including nominees from the two major Regulatory Bodies ,viz, the Office of the Chief Controllers of Explosives, and the Directorate General of Mines Safety, respectively.

Institutional Association :

- **'Institute Associate Member' of Safex International . e.f 30 May, 2008**
(Safex International is a global organization founded by the manufacturers of explosives and pyrotechnics , currently having 110 members in as many as 46 countries. For more vdetails on Safex , visit www.safex-international.org)
- **'Liaison Member ' of the Institute of Makers of Explosives (IME) , e.f. Oct 29 , 2014**
(IME is the safety and security institute of the commercial explosives industry in USA since 1923. For more details on IME , visit www.ime.org)

Membership of the Society :

The membership application form is enclosed. The application form can also be accessed and down loaded from the society's web-site .

Student Chapter:

This is an initiative launched by the society to promote the mission of the society amongst the students and academics who are , directly or indirectly associated with the science and technology of explosives. The application form for membership of the student chapter is enclosed ; it can also be accessed and downloaded from the society's web-site .

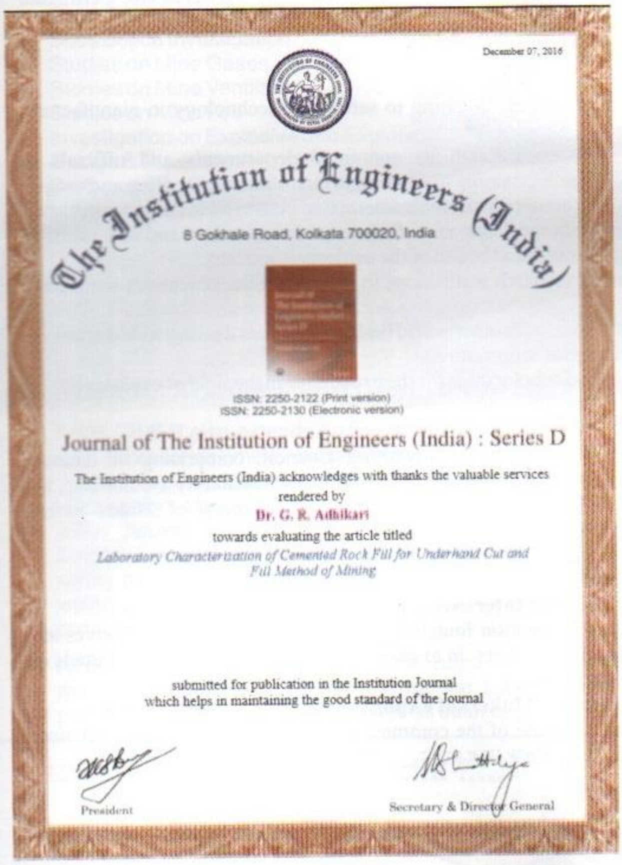
Visfotak being a Scientific Society, shall totally refrain from partisan activities of any manner or kind and shall not entertain tasks which are biased with commercial interest of its individual members.

SPECIAL REPORT

Editorial News :

The Institution of Engineers (India)

The Council of the Institution of Engineers, India recently awarded a "Certificate of Appreciation" to Dr. G.R. Adhikari, Member, Editorial Board, for valuable services rendered to the Institution.



December 07, 2016

The Institution of Engineers (India)

8 Gokhale Road, Kolkata 700020, India

ISSN: 2250-2122 (Print version)
ISSN: 2250-2130 (Electronic version)

Journal of The Institution of Engineers (India) : Series D

The Institution of Engineers (India) acknowledges with thanks the valuable services rendered by

Dr. G. R. Adhikari

towards evaluating the article titled

Laboratory Characterization of Cemented Rock Fill for Underhand Cut and Fill Method of Mining

submitted for publication in the Institution Journal which helps in maintaining the good standard of the Journal

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Visfotak EXPLOSIVES SAFETY & TECHNOLOGY SOCIETY

REGISTERED UNDER SOCIETIES REGISTRATION ACT MAHARASHTRA NO. 410 / 99 NAGPUR (INDIA)

MEMBERSHIP APPLICATION FORM

(Registered members will be given a Certificate and they would be entitled to participate in all the events conducted by the Society, and receive the publications of the Society free of cost).

Category of Membership : (Please tick ✓) MEMBERSHIP FEE FOR FIVE YEARS ONLY

CORPORATE MEMBER ☐	INSTITUTIONAL MEMBER ☐	INDIVIDUAL MEMBER ☐
Entrance Fee Rs. 2,000/- (US $ 200)	Entrance Fee Rs. 2,000/- (US $ 200)	Entrance Fee Rs. 1,000/- (US $ 100)
Membership Fee Rs. 3,000/- (US $ 300)	Membership Fee Rs. 3,000/- (US $ 300)	Membership Fee Rs. 1,000/- (US $ 100)

Name of Corporate Body / Institution ______________________________

Represented by (Head - Other) * ______________________________

* NAME IN FULL ______________________________

(First Name) (Middle Name) (Surname)

Date of Birth ______________ Designation / Current Status ______________

Mailing Address ______________________________

City __________ Pin Code __________ Country __________ E-mail __________

Telephone (Office) __________ (Home) __________ (Mobile) __________ (Fax) __________

Qualifications Educational ______________ Professional ______________

Year of passing ______________ Institute / University ______________

Nature of Industry (Explosives, Mining, Hydel Power, Cement, Highways, Irrigation, Academic / Research / Technical Services, Defence, Statutory Bodies, Other) (Please specify) ______________

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Membership of Professional Bodies, Awards, Recognitions ______________

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Professional Experience ______________________________

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Areas of Specialization ______________________________

Mode of Payment : Payments towards Membership fee may please be made by Cheque in favour of 'Visfotak' drawn on any Bank. Add Rs. 30/- for Outstation Cheques or send a Demand Draft payable on any bank in NAGPUR.

DD / Cheque No. ______________ Date ______________ For Rs. / US $ ______________

Drawn on ______________ Bank ______________

Please forward the above application along with Cheque / Demand Draft to the following address :

The Secretary General, Visfotak - Explosives Safety & Technology Society
Maimoon Chambers, Gandhibagh, Nagpur - 440 032 (India)

Tel. : 2768631 / 32 ▪ Fax : 0712 - 2768034 ▪ E-mail : visfotak@yahoo.com

Place : ______________ Date : ______________ Signature ______________

*** Please enclose a detailed BIO-DATA and a recent passport size PHOTOGRAPH.**
For Corporate and Institutional Members enclose Bio-data of the Head or Representative

Please send your detailed address, telephones / mobile numbers, fax and e-mail ID

admas

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Visfotak EXPLOSIVES SAFETY & TECHNOLOGY SOCIETY

REGISTERED UNDER SOCIETIES REGISTRATION ACT MAHARASHTRA NO. 410 / 99 NAGPUR (INDIA)

MEMBERSHIP APPLICATION FORM FOR STUDENT

(Registered members will be given a Certificate and they would be entitled to participate in all the events conducted by the Society, and receive the publications of the Society free of cost).

Membership Fee : (Please tick ✓) MEMBERSHIP FEE FOR FIVE YEARS ONLY

ENTRANCE FEE ☐ Rs. 50/-   MEMBERSHIP FEE FOR FIVE YEARS ☐ Rs. 200/-

Name of Corporate Body / Institution* ______________________

Represented by (Head - Other) ______________________

*NAME IN FULL ______________________

(First Name) (Middle Name) (Surname)

Date of Birth ______________________

Name of Institution ______________________

City __________ Pin Code __________ Country __________ E-mail __________

Telephone (Office) __________ (Home) __________ (Mobile) __________ (Fax) __________

Educational Qualification ______________________

Academic Course being persued : ______________________

Membership of Professional Bodies, Awards, Recognitions ______________________

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Membership of Professional Bodies, Awards, Recognitions ______________________

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Areas of Interest ______________________

Mode of Payment : Payments towards Membership fee may please be made by Cheque in favour of 'Visfotak' drawn on any Bank. Add Rs. 30/- for Outstation Cheques or send a Demand Draft payable on any bank in NAGPUR.

DD / Cheque No. __________ Date __________ For Rs. / US $ __________

Drawn on __________ Bank __________

Please forward the above application along with Cheque / Demand Draft to the following address :

Dr. N.R. Thote, Assistant Professor
(Hony. Secretary, Student Chapter
Explosives Safety & Technology Society (Visfotak)
Department of Mining Engineering
Visveswaraya National Institute of Technology, Nagpur - 440 011

Place : __________ Date : __________ Signature __________

***Please enclose a detailed BIO-DATA and a recent passport size PHOTOGRAPH.**

Please send your detailed address, telephones / mobile numbers, fax and e-mail ID

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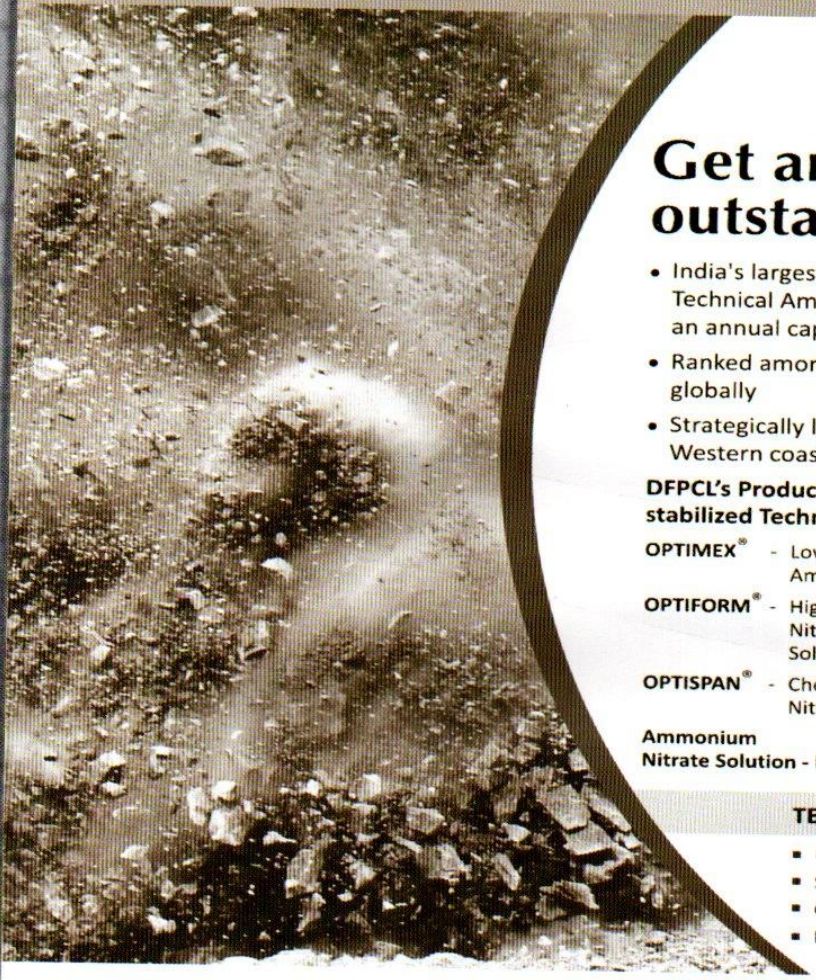

Design and Produced : Cyber Space, 25/3, Ganesh Colony, Opp. Ganesh Mandir, Pratap Nagar, Nagpur - 22
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